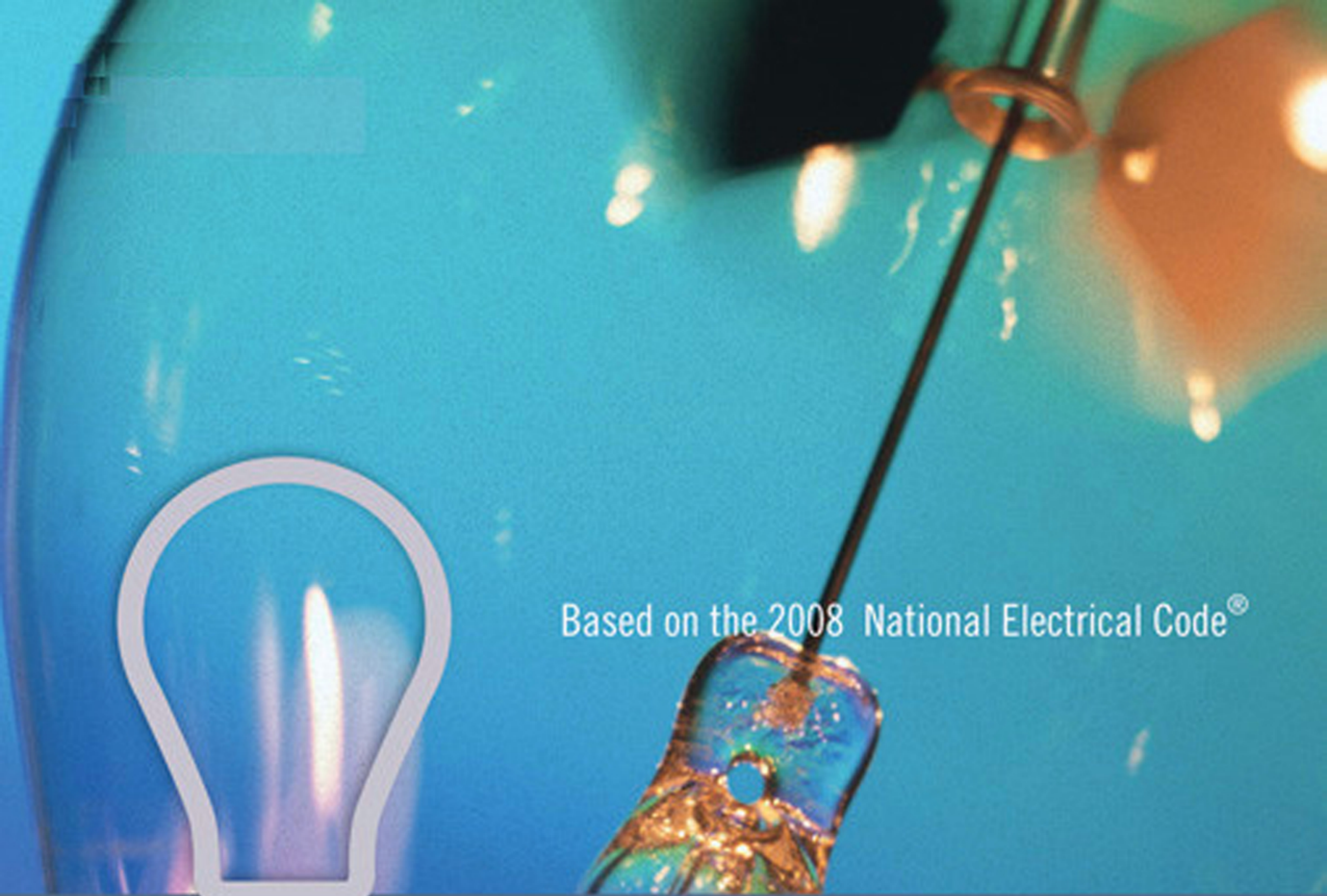

Based on the 2008 National Electrical Code®

INTERPRETING THE NATIONAL ELECTRICAL CODE®

8th Edition

Truman C. Surbrook • Jonathan R. Althouse

Based on the 2008
NATIONAL ELECTRICAL CODE®

INTERPRETING THE *NATIONAL ELECTRICAL CODE®*

Eighth Edition

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Library of Congress Cataloging-in-Publication Data

Surbrook, Truman C.
Interpreting the National Electrical Code / Truman C. Surbrook, Jonathan R. Althouse.—8th ed.
p. cm.
Includes index.
"Based on the 2005 National Electrical Code."
ISBN 1-4283-2373-2 (alk. paper)
1. Electric engineering—Insurance requirements—United States. 2. National Fire Protection Association. National Electrical Code (2005) I. National Fire Protection Association. National Electrical Code (2005) II. Althouse, Jonathan R. III. Title.

TK260.S87 2008 2007051783
621.319'24021873—dc22

ISBN-13: 978-1-4283-2373-5
ISBN-10: 1-4283-2373-2

Delmar Cengage Learning
5 Maxwell Drive
Clifton Park, NY 12065-2919
USA

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Printed in the United States of America
1 2 3 4 5 6 7 11 10 09 08 07

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PREFACE

INTERPRETING THE NATIONAL ELECTRICAL CODE® is a text and workbook designed as a self-contained study course for learning to read and interpret the meaning of the Code, and to find information about how to do wiring installations. This text is intended for use by personnel with some experience in electrical wiring and use of the *National Electrical Code*®. The text is organized into 15 units covering the entire Code. The individual units cover a particular subject and show how to find information about that subject in the entire Code.

PREREQUISITES

Electrical wiring experience and a basic familiarity with the *NEC*® are desirable for the student to maximize learning from this text and the course in which it is used. Basic arithmetic, written communication, and reading skills are required for the course. Students with an interest in electrical wiring and the Code will, after completion of this text and course, be able to find information from the Code needed to do residential, commercial, farm, and industrial wiring and to be successful with electrical examinations.

EACH ARTICLE DISCUSSED

A brief description of the type of information found in every article of the Code is included in the text. Code article discussions are included in the unit of the text where the article contains important information for the subject of that unit. The Contents provides a list of Code articles included in each unit to provide a quick reference for the student to find information in this text.

CODE CHANGES DISCUSSED

This text contains a discussion of the *NEC*® changes of significance since the last edition of the Code. The articles that pertain to the subject of the unit as listed in the Contents are contained in each unit. This discussion of changes is intended to explain the meaning and application of the change. Every article of the Code is included in this discussion of Code changes.

USEFUL WIRING INFORMATION INCLUDED

Each unit of this text contains useful information for understanding the meaning behind Code requirements, or information on the subject of the unit useful for applications in the field that is not included in the Code. This text can, therefore, be used as a handy reference for making wiring installations.

SAMPLE CALCULATIONS

Many types of calculations are needed for making electrical installations. This text includes a discussion of the Code requirements, and then provides sample calculations as would be typically encountered in everyday wiring. Methods have been developed in this text that help the electrician better understand the Code requirements for making electrical calculations.

ILLUSTRATIONS

The illustrations in this text provide numerous references to Code sections to help the reader find important information in the Code. The purpose of the illustrations is to help the reader gain an understanding of a typical application of a particular Code section. It is not possible for an illustration to provide all information contained in a particular Code section. It is important that the reader study the particular Code section referenced to gain a complete understanding of the meaning of the Code section.

PRACTICAL CODE QUESTIONS AND PROBLEMS

Learning to find information in the *NEC*® requires looking up answers to practical everyday wiring installation questions. Each unit of this text contains two sets of 15 practical questions or problems pertaining to the subject of the unit. The Beginning Worksheet contains questions that are at the Journey electrician or first license level and are especially useful for persons studying to take the first level electrician examination. The Advanced Worksheet contains questions that are at the Master or advanced electrician level and are especially useful for persons studying to take a Master or advanced electrician examination. The questions are multiple choice, and the answers to the questions are found in the Code articles listed for that particular unit. Space is provided to write the Code sections where the answer was found. When calculations are required to obtain an answer, space may not be adequate to write the solution in the text. The instructor will give the answer and work the calculation during the class session. An answer sheet to hand in for grading is provided at the end of the text for the student to circle the answer and write the Code reference.

METRICS (SI) AND THE *NEC*®

The electrical trade in the United States continues to be based on the inch-pound system of measurements, while most of the remainder of the world uses SI metric (Systeme International d'Unites) dimensions. The 2008 edition of the Code will continue to provide dimensions in SI metric followed with the inch-pound equivalent in parentheses. This text will provide dimensions in inch-pound units followed with the SI metric equivalent in parentheses. Electrical materials and equipment used in the United States continue to be provided with inch-pound dimensions, although some plans and specifications may have dimensions given as SI metric. In this case, it will be necessary to make a conversion. *Annex A-2* in this text gives common conversions from SI metric to inch-pound units and from inch-pound units to SI metric.

In general, the SI metric dimensions in the Code have been rounded to an even number. For example, 12 in. is actually 305 mm. The Code rounds 12 in. to an even 300 mm. This rounding of units can result in a significant difference in measurements and in some calculations. *Annex A-1* at the end of this text gives common lengths used in the Code and the SI metric conversions. When these distances are rounded as in the Code, *Annex A-1* gives the difference. The Code in *90.9(D)* permits either inch-pound or SI metric measurement to be used for electrical installations, even though they may be slightly different.

Wire sizes continue to be given in the Code as AWG (American Wire Gage) and kcmil (thousands of circular mils). Standard SI metric wire sizes are in sq. millimeters and are different than standard AWG sizes. Conversions to sq. millimeters are given in the Code for standard AWG and kcmil sizes. These are considered soft conversions since the basis for sizing the wires is AWG and kcmil. A hard conversion is a switch to standard metric sizes in sq. millimeters.

Trade sizes of conduit and tubing continue to be used in the Code. Conduit threads continue to be specified as National Pipe Threads (NPT). Some equipment may be provided with metric pipe threads, in which case adapters to NPT are provided. Because conduits and tubing of different types have different dimensions, standard trade sizes are used, which have approximately the same internal diameter. Actual dimensions of the different types of conduit and tubing are given in *Table 4* of the Code. These standard trade sizes for the purpose of SI metric conversion have been given a number called a metric designator. This metric designator is the approximate inside diameter in millimeters. Metric designators for standard conduit and tubing trade sizes are given in *Table 300.1(C)* and in *Annex A-3* of this text.

INTERNATIONAL RESIDENTIAL CODE®

The *International Residential Code*® (*IRC*®) applies to the construction of one- and two-family dwellings. It is a standard developed by the International Code Council, Inc., and revised every 3 years. The first edition carried the date 2000, the second edition carried the date 2003, and the third edition carried the date 2006. The next edition will have the date 2009. The *IRC*®, adopted by a number of jurisdictions in the United States, is the standard for construction of one- and two-family dwellings. The *IRC*® contains standards for building, mechanical, plumbing, and electrical installations. The electrical section of the 2006 *IRC*® is based on the 2005 edition of the *National Electrical Code*® (*NEC*®). The *IRC*® covers only 120/240-volt, single-phase, 3-wire services rated up to and including 400 amperes. Other sizes and types of service to a one- or two-family dwelling are permitted as covered in the *NEC*®. The *IRC*® has a numbering system different from the *NEC*®, and much of the text is written and organized differently in the two Codes. There are a few differences in the requirements of the *IRC*® as compared with the *NEC*®, but most rules in these two Codes are essentially equivalent.

It is important for persons learning the electrical trade to determine whether the *International Residential Code*® applies in a particular jurisdiction. If the *IRC*® applies, it is recommended that persons studying this text practice looking up answers in the *IRC*® as well as in the *NEC*®. The *INSTRUCTOR'S GUIDE* for this text also provides Code references from the *IRC*® where applicable. In a few cases the answers are different, and those differences are explained. Electrical requirements are covered in *Chapter 33* through *Chapter 42* of the *IRC*®. The section numbering system for the *IRC*® is different than for the *NEC*®. This text does not discuss the *IRC*® or give references from the *IRC*®. It will be left up to the instructor to explain how to find answers to questions based on the *IRC*®.

E-RESOURCE

The e-Resource includes PowerPoint slides, a testbank, and an *INSTRUCTOR'S GUIDE*. The *INSTRUCTOR'S GUIDE* gives a detailed lesson plan for each of the 15 sessions. It is also possible to offer the course in segments of less than 15 sessions, and suggestions for a shorter format are provided. The *INSTRUCTOR'S GUIDE* contains all answers to the student homework questions and problems, as well as complete calculations. Code references are also given for each homework question or problem. Some questions or problems have multiple Code references. All possible Code references are provided with a background discussion to help the instructor explain the reasoning behind the answer and Code reference.

TO THE STUDENT

This is a text and workbook that can be used for self-study, but it was developed primarily for use with 3 to 4 hours of instruction for each unit. The greatest benefit will be derived from the text and course if the student will make a concerted effort to work all problems and answer all questions. The only way to learn to find information in the *NEC*® and to interpret the information is to use the Code to find answers to daily wiring questions. The class discussion of the answers to questions will be of greatest meaning when the student has made an effort to find the answer and Code reference.

The instructor will briefly review the main points of the Code material that will be used to answer the homework questions. These pointers may save time lost searching for answers in the Code. The instructor will review the changes in the Code of greatest significance since the last edition. This will help to avoid confusion with the previous Code.

The student should quickly read the Code discussion portion of the text that describes the type of information found in each article. This will help to make question look-up more efficient. Then the student should read carefully the portion of the text that discusses Code material and gives sample calculations. Most problems will be similar to these sample calculations. The student should work the homework problems. It will take 2 to 4 hours to answer the questions and work the homework problems. It usually works best to spend some time on several occasions rather than trying to work the homework all at one time.

Before returning to class, write the answer and the Code reference on the answer sheet to hand in at the beginning of class.

Important Note: Please note that this textbook was completed after all the normal steps in the *NFPA 70* review cycle—Proposals to Code-Making-Panels, review by Technical Correlating Committee, Report on Proposals, Comments to Code-Making-Panels, review by Technical Correlating Committee, Report on Comments, NFPA Annual Meeting, and ANSI Standards Council—and before the actual publication of the 2008 edition of the *NEC*®. Every effort has been made to be technically correct, but there are always the possibilities of typographical errors or appeals made to the NFPA Board of Directors after the normal review cycle that could change the appearance or substance of the Code.

If changes do occur after the printing of this textbook, these changes will be included in the *INSTRUCTOR'S GUIDE* and will be incorporated into the textbook upon its next printing.

Please note also that the Code has a standard method to introduce changes between review cycles, called "Tentative Interim Amendment," or TIA. These TIAs and typographical errors can be downloaded from the NFPA Web site, http://www.nfpa.org, to make your copy of the Code current.

ABOUT THE AUTHORS

One of the authors of *INTERPRETING THE NATIONAL ELECTRICAL CODE®*, Truman C. Surbrook, has extensive practical experience in electrical wiring, as well as many years of experience as an instructor in the electrical trade.

Truman C. Surbrook, Ph.D., is a Professor of Biosystems and Agricultural Engineering at Michigan State University, a registered Professional Engineer, and a Master Electrician. Dr. Surbrook developed an Electrical Apprenticeship Program at Michigan State University, and later served as chair for curriculum development for a statewide electrical inspector training short course. Dr. Surbrook developed a highly successful and comprehensive *NEC®* training course through Outreach Programs of Michigan State University.

Dr. Surbrook has spent his professional career teaching; authoring textbooks, training bulletins, and papers; working with youths, electricians, contractors, and inspectors; and conducting research in the areas of electrical wiring and electronics. He has been an active member and officer of several professional organizations and has served on numerous technical committees. Organizations in which he has been most active are the Institute of Electrical and Electronic Engineers, American Society of Agricultural and Biological Engineers, International Association of Electrical Inspectors, the National Fire Protection Association, and the Michigan Agricultural Electric Council. Dr. Surbrook has served on several Ad Hoc Technical Committees of the National Electrical Code, and he has been a member of National Electrical Code-Making Panels 13 and 19. For 15 years, Dr. Surbrook was writer and producer of a weekly radio program dealing with electrification. He has written many bulletins, articles, and technical publications on various subjects related to electrical wiring.

Jonathan R. Althouse, M.S., who is Dr. Surbrook's coauthor, is an Instructor of Biosystems and Agricultural Engineering at Michigan State University and a licenced Master Electrician and Electrical Contractor. Mr. Althouse is the Coordinator of the Electrical Technology Apprenticeship Program at Michigan State University.

Mr. Althouse has developed an electrical awareness program for high school students entitled *Teaching Electrification in Agribusiness Classes in High Schools* (T.E.A.C.H.S.). He has also developed and provided instruction for *NEC®* Update Courses and Journey and Master Electrician examination prep classes. Mr. Althouse has been involved with organizations such as the International Association of Electrical Inspectors, the American Society of Agricultural Engineers, and the Michigan Agricultural Electric Council. Mr. Althouse recently has developed a Michigan State University Internet site that provides technical information to personnel in the electrical trade: http://www.egr.msu.edu/age/.

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ACKNOWLEDGMENTS

It is with sincere gratitude that the authors express appreciation to the following individuals who have either helped with some aspect of the development of this text or have provided field testing and critical review of the material to ensure completeness and accuracy:

Lori A. Althouse, Editing Assistant
Eaton Rapids, MI
Matthew and Elizabeth Althouse
Eaton Rapids, MI
Dennis Cassady, Electrical Inspector
Kentwood, MI
John P. Donovan, Standard Electric Co.
Lansing, MI
David Filipiak, Sky Electric, Inc.
Lapeer, MI
George Little, Electrical Inspector
Farmington, MI
John Negri, Electrical Consultant
Bloomingdale, MI
Mary Surbrook, Editing Assistant
Williamston, MI
Bailey, Spencer, and Emma Surbrook
Lansing, MI
James Worden, Electrical Inspector
Port Huron, MI

UNIT 1

General Wiring and Fundamentals

OBJECTIVES

After completion of this unit, the student should be able to:

- name the sponsoring organization of the *National Electrical Code*®.
- know how and when to submit a proposal to change the *National Electrical Code*®.
- explain what is a tentative interim amendment.
- describe direct current and alternating current.
- calculate the unknown quantity if only two of these quantities are known: volts, current, or resistance.
- determine the current in a circuit or equipment if power, voltage, and power factor are known.
- determine the area of a conductor if the conductor diameter is given.
- calculate the total resistance of a circuit if the values of resistance in either series or in parallel are given.
- choose the correct ampacity table from *Article 310* to determine the minimum size of conductor required for a wiring application.
- answer wiring installation questions relating to *Articles 90*, *100*, *110*, *200*, *300*, *310*, *320*, *324*, *328*, *330*, *332*, *334*, *336*, *338*, *340*, *382*, *394*, *590*, or *Chapter 9*, *Tables 8* or *9*.
- state at least five significant changes that occurred from the 2005 to the 2008 Code for *Articles 90*, *100*, *110*, *200*, *300*, *310*, *320*, *324*, *328*, *330*, *332*, *334*, *336*, *338*, *340*, *382*, *394*, *590*, or *Chapter 9*, *Tables 8* or *9*.

ORIGIN OF THE *NATIONAL ELECTRICAL CODE*®

The first *National Electrical Code*® was developed in 1897. In 1911, the National Fire Protection Association (NFPA) became the sponsor, and the Code has been revised on numerous occasions since that date. Now it is revised every three years. The time schedule for revising the 2008 Code is listed in the back of the Code. The next revision will be the 2011 edition.

The *NEC*® is available for adoption as the electrical law in a governmental jurisdiction. That governmental jurisdiction may add one or more amendments to allow for local needs, preferences, or conditions. It is not the intent of this text to cover amendments to the Code made by local or state jurisdictions, but an instructor using this material for a course may cover these amendments as an addendum to this material.

Process of Revising the Code

The process of revising the Code begins with any interested person who submits a proposal for changing the Code not later than the closing date for accepting proposals. This closing date is given in each edition of the Code. Proposals are mailed to the Vice President of the Technical Council, National Fire Protection Association, Batterymarch Park, Quincy, MA 02269. A blank form for submitting proposals is available on the NFPA Web site, http://www.nfpa.org.

The proposals for changing a particular section or adding a new section or article are reviewed by the appropriate Code-Making Panel (listed in the front of the Code) at the date listed in the Code. The Code-Making Panel actions on proposals are published in a document titled the *Committee Report on Proposals*, which is usually available to the public in July of the year shown in the timetable of events in the Code. Any interested person can obtain a copy of this document and make public comment that must be received by the NFPA not later than the closing date listed for public comment. A comment form is in the front of the *Committee Report on Proposals.*

Code-Making Panels meet in December of every third year to act on public comments. The Panel is only permitted to take action on sections of the Code for which public comment was received. The Code-Making Panel's actions at these two meetings constitute the changes that occur in the Code. The *Committee Report on Comments* reports on the Panel action taken on public comment. The electrical section meeting of the National Fire Protection Association in May 2010 results in the adoption of the 2011 Code. Members present at that meeting are permitted to make motions to change Code-Making Panel action taken on a particular proposal published in the *Committee Report on Proposals* or change the action taken on a comment as published in the *Committee Report on Comments.* If the motion receives a majority vote of members present at the meeting, the change becomes a part of the new Code. A person who submitted a proposal that was rejected and made public comment that was rejected, can make a motion for adoption of the proposal at the annual meeting. Following this meeting of the electrical section of NFPA, the change process is completed, and NFPA publishes the Code. There is a brief period after the annual meeting when an appeal of panel action can be submitted to the *NEC® Correlating Committee.* The new edition of the Code is available for public sale by September of the year of the NFPA Annual Meeting when the Code was adopted. The *Committee Report on Proposals*, *Committee Report on Comments*, and a preliminary draft of the *NEC®* can be accessed on the NFPA web site at http://www.nfpa.org.

There is another means by which the Code may change in addition to the process previously described. This is by the issuing of a Tentative Interim Amendment or TIA. These are generally changes of such importance that they should not wait until the next Code. There is a process through which they are approved, and if approved, a TIA is added to the Code only for the duration of that edition. A TIA will automatically be submitted as a proposal for the next Code change, and it must go through the same process as all other proposals to remain as a part of the Code.

ELECTRICAL CALCULATIONS WITH A CALCULATOR

An electronic calculator is a valuable tool for making calculations required for electrical installations. It is important to become familiar with the proper use of your calculator. The procedures for making calculations may be different from one calculator to another. The following procedure is common for many calculators, but it may be different for your calculator. If this procedure does not work for your calculator, then check the calculator instructions for each example problem. Practice with your calculator until you become comfortable with its operation. This will help you with the problems in this text as well as eliminating errors in electrical calculations on the job. There are more efficient methods of making the following calculations on some calculators; however, the following method works on most calculators.

Example of String Multiplication

Calculate power (P) when the voltage (V), current (A), and power factor (pf) are known.

$$P = V \times A \times pf = 480\ V \times 22\ A \times 0.75 = 7920\ W$$

Step	Press	Display
1	480	480
2	×	480
3	22	22
4	=	10,560
5	×	10,560
6	.75	.75
7	=	**7,920** ←

Example of Addition and Multiplication

Determine the cost of several runs of conduit. The runs are 22 ft, 74 ft, and 15 ft, and the cost is $1.15 per ft.

$$\text{Conduit cost} = (22\text{ ft} + 74\text{ ft} + 15\text{ ft}) \times \$1.15 = \$127.65$$

Step	Press	Display
1	22	22
2	+	22
3	74	74
4	=	96
5	+	96
6	15	15
7	=	111
8	×	111
9	1.15	1.15
10	=	**127.65** ←

Example of String Multiplication and Division

Determine the full-load current of a 3-phase, 37.5-kVA transformer with a 208-volt secondary winding.

$$A = \frac{\text{kVa} \times 1000}{1.73 \times V} = \frac{37.5 \times 1000}{1.73 \times 208} = 104.21\text{ A}$$

Step	Press	Display
1	37.5	37.5
2	×	37.5
3	1000	1000
4	=	37,500
5	÷	37,500
6	1.73	1.73
7	=	21,676.3
8	÷	21,676.3
9	208	208
10	=	**104.21** ←

FUNDAMENTALS OF ELECTRICITY

An electrician must have a basic understanding of the fundamentals of electricity to perform most effectively in the field and also to pass electrical examinations. This section of the text is a brief review of minimum basic electrical fundamentals.

AC and DC

The Code refers to alternating current (ac) and direct current (dc). Direct current travels only in one direction in the circuit. A typical source of direct current is a battery or a rectifier. Figure 1.1 shows how the

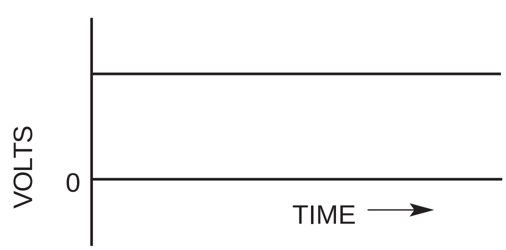


Figure 1.1 A plot of voltage in a direct current circuit over a period of time is a straight line.

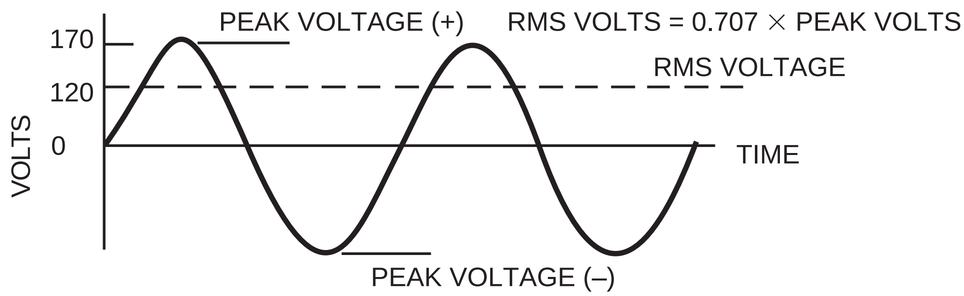


Figure 1.2 The plot of voltage in an alternating current circuit over a period of time is a sine wave, and the voltage that would show on a meter would be the rms voltage.

voltage in a direct current circuit would look if plotted on a graph over a period of time. An oscilloscope is an electrical instrument that can show the voltage and time plot of a direct current circuit. The voltage will be either a positive or a negative constant value. The level of voltage remains at a constant or a nearly constant magnitude. The polarity will remain either positive or negative. As long as the polarity does not change from positive to negative or from negative to positive, the electrical current will flow in one direction in the circuit. The polarity must change if the current is to reverse direction of flow in the circuit.

In the case of an alternating current circuit, the voltage is constantly changing. The voltage increases to a maximum, then decreases back to zero. Then the voltage builds to a maximum with opposite polarity, then decreases in magnitude back to zero. This completes one cycle. Normal electrical power operates at 60 cycles per second or hertz (Hz). A graph of an ac voltage varying with time is shown in Figure 1.2. This is what an ac voltage looks like if viewed on the screen of an oscilloscope, and the waveform is known as a sine wave from the mathematics of trigonometry. If an analog voltmeter with a needle or a digital voltmeter is connected to measure voltage across a component of an ac circuit, the voltmeter will indicate the root-mean-square (rms) voltage as indicated in Figure 1.2. The actual voltage is changing as shown in Figure 1.2, but the analog or digital voltmeter will register only a single value of voltage. The rms voltage is compared with the alternating voltage in Figure 1.2. The rms voltage is 0.707 times the peak of the varying voltage (sine wave) of the circuit. Or, the peak voltage of the sine wave is 1.414 times the rms voltage. Root-mean-square is used in the definition of voltage in *Article 100* of the Code. Alternating current frequencies other than 60 Hz are sometimes used for special applications in electrical equipment.

Many voltmeters are not true rms (root-mean-square) meters. The common hand-held voltmeter actually measures the average value of the alternating sine wave at 60 Hz, which is 0.637 times the peak value. The voltmeter output is calibrated to increase the average voltage value by 1.11 so the output will be equal to the rms voltage ($0.637 \times 1.11 = 0.707$). If the voltage is something other than a sine wave or if the power source is being altered by solid-state switching, the voltage indicated by the meter will be in error. It is also possible in some electrical systems for more than one frequency to be present at the same time. This is the case when harmonic frequencies are present on the same 3-phase, 4-wire circuits as mentioned in *NEC® 220.61(C)*. Under these conditions, an averaging voltmeter will not indicate an accurate rms voltage. The amount of the error will depend on the amount of harmonic distortion of the 60-Hz sine wave. True rms reading voltmeters are available.

Metric Conversions

Metric units are provided in the Code followed by the approximate equivalent English units. In most cases, the dimensions are distances, which are given in meters (m), centimeters (cm), and millimeters (mm). It is helpful to visualize the differences between common distances used in the English and Metric system. Figure 1.3 compares 1000 ft with 1 kilometer and 1 mile. Figure 1.3 also gives some useful conversion units.

For the most part, distances, areas, volumes, and weights are the same as given in the previous edition of the Code, except the metric units are listed first. Frequently, the metric units have been rounded to even numbers. In some areas of the Code, the metric units have not been rounded. A table has been included in *Annex A* as a quick reference to some of the common metric length conversions. The table also gives the actual metric conversions. The longer distances may have a difference between the English and Metric units as much as several in. because of rounding of the Metric conversion.

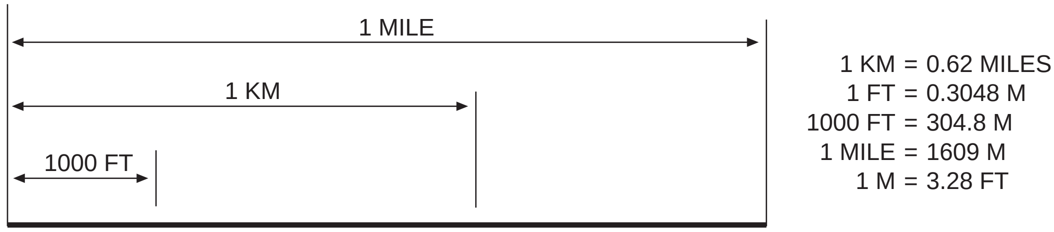


Figure 1.3 A comparison of common distances, Metric and English, used in the electrical trade.

Since many distance dimensions are given in the Code in millimeters, it is useful to have a comparison with the standard English units in fractions of an in. Figure 1.4 is a magnified version of the one-in. scale compared to millimeters.

Measurement units given in the Code are required to be SI units (Systeme International d'Unites) frequently called metric units. The SI units are to be followed by the units commonly used in the United States known in the Code as inch-pound units, and these units will be in parentheses. This requirement is found in *90.9(B)*, which calls for "hard conversions" from SI units to inch-pound units. "Soft conversions" for inch-pound units to SI units are permitted in some situations as given in *90.9(C)*. A soft conversion is an exact equivalent measurement in SI units and inch-pound units. Examples of hard conversions are switches to standard metric sizes such as metric conduit and tubing sizes and metric wire sizes. Another example of a hard conversion is the support of a cable within a certain distance of a box. The hard conversion may call for the support to be not more than 300 mm from the box. The SI dimension of 300 mm is a replacement for 12 in., which is actually 305 mm. For the moment, the support will be permitted to be 305 mm (12 in.) from the box, but sometime in the future the 12 in. will be deleted and the standard metric distance of 300 mm will be the maximum distance permitted. For now, either the standard SI units or the inch-pound equivalent units will be permitted according to *90.9(D)*. In this text, inch-pound units will be used followed by the SI units in parenthesis.

When trade sizes are used, these are not exact dimensions and a hard or soft conversion is not meaningful. In these cases, trade size designators are used. For example, in *300.1(C)* a trade size 1 in. conduit or tubing is given a trade size designator of 27. In this case, the 27 is the approximate inside diameter in mm. In some cases, an industry standard is to express a dimension as inch-pound units and there is no meaningful SI unit equivalent. An example is National Pipe Thread and thread taper of 3⁄4 in. per ft. The ratio of 1 to 16 given in *500.8(E)* is not a metric equivalent. *Annex A-1* of this text gives the rounded SI unit equivalent for typical dimensions used in the electrical trade.

Wire Dimensions

Conductor dimensions used in the electrical trade are overall conductor diameter, and the conductor cross-sectional area. Conductor diameter is given in millimeters (mm), and conductor cross-sectional area is given in square millimeters (mm^2). Conductor diameter using in. and cross-sectional area using square in. is still provided in the Code. In the future, there will be standard conductor sizes in square millimeters (mm^2) with an allowable ampacity listed for each standard size.

Wire dimensions are also given in American Wire Gauge (AWG) and in thousands of Circular Mils (kcmil). The **k** is the metric symbol for 1000. The **c** represents **circular** for Circular Mils. The **mil** is 1/1000. In the case of electrical wires, the mil represents 1/1000 of an in. The area of a wire is determined by taking the diameter of a wire using in., multiplying by 1000, and then squaring that number. Squaring a number

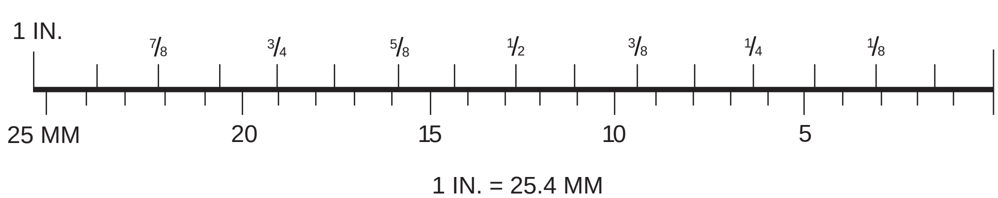


Figure 1.4 An expanded 1-in. scale compared to the equivalent dimensions in millimeters.

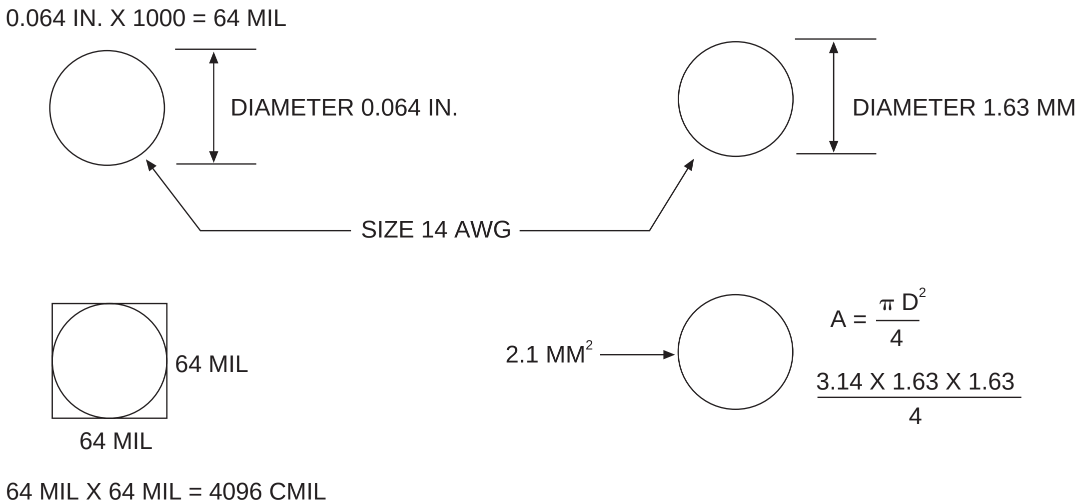


Figure 1.5 In the inch-pound system, the diameter of a wire in mils is squared to get Circular Mils, where in the Metric system the area is in square millimeters found using the formula for the area of a circle.

means the number is multiplied by itself. The old designation for thousands of Circular Mils is (MCM). The **M** is the Roman numeral for 1000. Some wires encountered in electrical wiring will be marked **kcmil** and some will be marked **MCM.** Both of these designations represent thousands of Circular Mils. Area of a wire is expressed as Circular Mils, not as a true area. Common wire sizes are listed in *Table 8, Chapter 9* of the Code. The area of the wire in square millimeters and Circular Mils is given in the table.

When the diameter of a wire is given using in. as shown in *Table 8, Chapter 9* of the Code, the diameter can be converted to mils by multiplying the diameter using in. by 1000. A mil is 0.001 in. A size 14 AWG solid wire has a diameter of 0.064 in., and therefore the diameter would be 0.064 times 1000, or 64 mils. This is illustrated in Figure 1.5.

The Circular Mil area of a wire is obtained by squaring the diameter of the wire in mils, or multiplying the diameter by itself. The area of a size 14 AWG solid wire would be 64 mils times 64 mils, or 4096 Circular Mils (4.096 kcmil) as shown in Figure 1.5. The values given in *Table 8, Chapter 9* of the Code are approximate, so they may not match exactly with a calculation.

In other parts of the world, wire sizes are in square millimeters (mm^2), but the Code does not give standard metric wire sizes or the metric equivalent sizes for standard AWG and kcmil sizes. Table 1.1 gives the metric equivalent sizes in mm^2 for standard AWG and kcmil sizes.

Table 1.1 Metric equivalent conductor sizes for common AWG and kcmil wire sizes.

AWG	mm^2	kcmil	mm^2
18	0.8	250	127
16	1.3	300	152
14	2.1	350	177
12	3.3	400	203
10	5.3	500	253
8	8.4	600	304
6	13.3	700	355
4	21.2	750	380
3	26.7	800	405
2	33.6	900	456
1	42.4	1000	507
1/0	53.5	1250	633
2/0	67.4	1500	760
3/0	85	1750	887
4/0	107	2000	1013

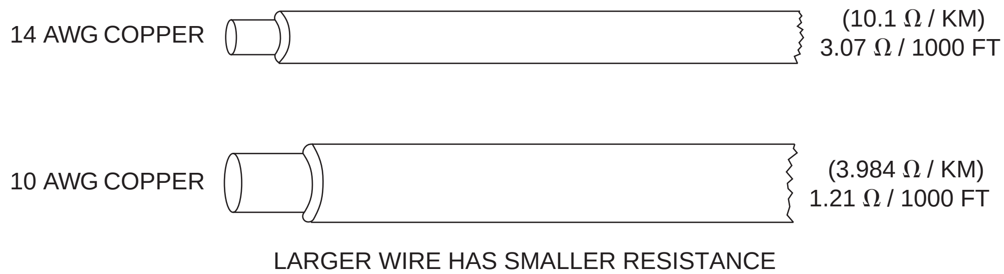


Figure 1.6 A wire with a larger cross-sectional area has a lower resistance for a given length.

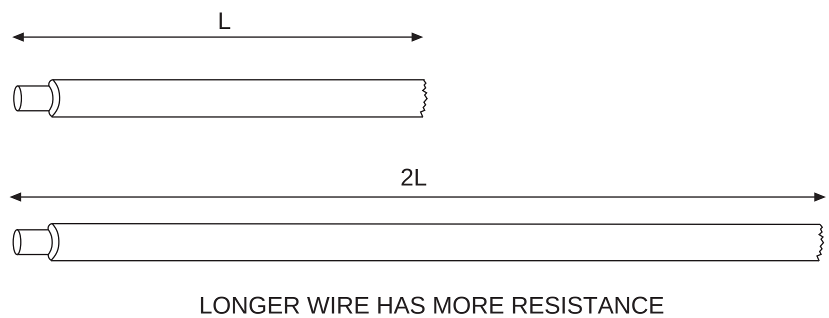


Figure 1.7 A long wire has a higher resistance than a shorter wire of the same size.

Wire Resistance

Conductor resistance is measured in ohms. The resistance of a conductor is different for different types of materials such as copper and aluminum. A conductor with a larger cross-sectional area than another conductor has a lower resistance for a given length. For example, the resistance listed for one kilometer of size 10 AWG solid uncoated copper conductor is 3.984 ohms (1.21 ohms per 1000 ft). A size 14 AWG copper conductor is smaller than a size 10 AWG, and a one kilometer (km) length of a size 14 AWG solid uncoated copper conductor has a resistance of 10.1 ohms (3.07 ohms per 1000 ft). The resistance of a conductor decreases as the cross-sectional area of the conductor increases. This is illustrated in Figure 1.6.

The resistance of a conductor increases as the length of the conductor increases. If one conductor of the same size is twice as long as another, the longer conductor will have twice the resistance of the shorter conductor. This is illustrated in Figure 1.7. The resistance of one kilometer (km) or 1000 ft of conductor at a temperature of 75°C is given in *Table 8, Chapter 9* of the Code. If the resistance of the length of conductor other than one kilometer or 1000 ft is desired, Equation 1.1 will be useful in determining the actual resistance of the conductor.

$$\mathbf{Resistance_{Desired\ length} = \frac{Desired\ length\ (m)}{1000\ m} \times Resistance_{1\ km}} \qquad \textbf{Eq. 1.1}$$

$$\mathbf{Resistance_{Desired\ length} = \frac{Desired\ length\ (ft)}{1000\ ft} \times Resistance_{1000\ ft}}$$

Temperature has an effect on the resistance of an electrical conductor. As the temperature of a copper or an aluminum wire increases, the resistance will also increase. The change in resistance of a wire as

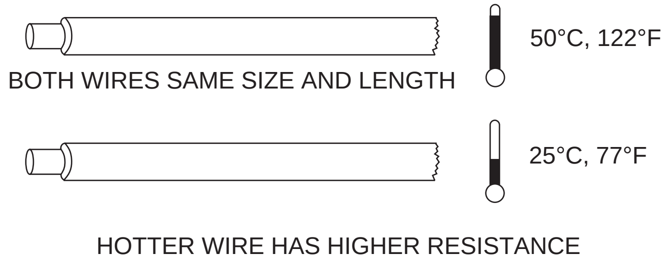


Figure 1.8 The resistance of a wire increases as the temperature of the wire increases.

temperature increases is illustrated in Figure 1.8. A wire carrying electrical current for several hours will have a higher temperature and a higher resistance than a wire not carrying electrical current. The temperature of the area where a wire is to be installed is frequently different from one area to another. For copper and aluminum wires, and most other wires, the resistance increases as the temperature increases. The resistivity (unit value of resistance of a material) of copper and aluminum wire is different, and it increases as the temperature increases. Table 1.2 gives values of resistivity for copper and aluminum at three different temperatures. Note that the resistivity increases as the temperature increases.

Table 1.2 Resistivity of copper and aluminum conductors at different temperatures.

Conductor type		Resistivity, K	
	25°C	50°C	75°C
		(ohm mm² / m)	
Copper	0.0180	0.0197	0.0214
Aluminum	0.0294	0.0323	0.0352
		(ohm cmil / ft)	
Copper	10.79	11.83	12.87
Aluminum	17.69	19.43	21.18

The resistance of a given length of a particular size of copper or aluminum wire also can be determined at a particular temperature using Equation 1.2. The equation gives the relationship between total wire resistance, the resistivity of the wire, the cross-sectional area of the wire, and the length of the wire. The Circular Mil area of the wire is found in *Table 8, Chapter 9.*

$$\mathbf{R = K \times \frac{L}{A}} \qquad \textbf{Eq. 1.2}$$

R = resistance in ohms
K = resistivity of material in ohm cmil / ft (ohm mm^2 / m)
L = length of conductor in ft (meters)
A = area of conductor in cmil (mm^2)

Example 1.1 Determine the approximate resistance of a 246 ft (75 m) length of size 3 AWG uncoated copper conductor which is at a temperature of 75°C.

Answer: Look up the area of a size 3 AWG conductor in *Table 8, Chapter 9* of the Code and find 52,620 cmil (26.67 mm^2). Look up the resistivity, K, for a copper conductor in Table 1.2 at 75°C and find 12.87 ohm cmil/ft (0.0214 ohm mm^2 / m). Use these values in Equation 1.2 and find the resistance of 246 ft (75 m) of size 3 AWG uncoated copper conductor to be 0.060 ohms.

$$R = 12.87 \text{ ohm cmil / ft} \times \frac{246 \text{ ft}}{52{,}620 \text{ cmil}} = 0.060 \text{ ohm}$$

$$R = 0.0214 \text{ ohm mm}^2 \text{ / m} \times \frac{75 \text{ m}}{26.67 \text{ mm}^2} = 0.060 \text{ ohm}$$

Since the resistance of 1000 ft and one kilometer of size 3 AWG uncoated copper conductor is given in *Table 8*, *Chapter 9*, another way to get the approximate resistance of a 246 ft (75 m) length is to multiply the resistance per one-thousand ft by 0.246 (resistance per kilometer by 0.075 km) to get 0.060 ohms (Equation 1.1).

Table 8 in *Chapter 9* gives the approximate cross-sectional area of the actual conductor in square millimeters in the second column and in circular mils in the third column. In the case of a stranded conductor, these are the approximate areas of a single strand multiplied by the number of strands. When determining the resistance of a conductor, the actual cross-sectional area of the conductor material is needed. There is an overall area column in *Table 8*. In the case of a stranded conductor, this is an area determined using the overall diameter of the strands bundled together. The overall diameter of a conductor made up of strands will be greater than the diameter of a solid conductor of the same material cross-sectional area. This can be seen by comparing the overall diameters for conductor sizes 8 AWG and smaller in *Table 8*. When determining fill of a raceway, the overall area of the conductor is needed. When determining resistance of a conductor, the actual cross-sectional area of the conductor material is needed. *Table 8* gives the actual area of conductors in both square millimeters and Circular Mils. Actual conductor area is needed for all sizes of conductors when making voltage drop calculations. Table 1.1 gives the conductor cross-sectional area in square millimeters for the complete range of conductor sizes.

Ohm's Law

It is important to understand the relationship between electrical current, voltage, and resistance of an electrical circuit. This relationship is known as Ohm's Law. Equation 1.3 is Ohm's Law arranged to solve for current. The current in amperes is equal to the voltage divided by resistance in ohms. Assume the resistance of a circuit is held constant but the voltage is changed. According to Equation 1.3, if the voltage is increased, the current will increase. If the voltage is decreased, the current will decrease. This is illustrated in Figure 1.9. Note when the voltage is doubled from 120 volts to 240 volts, the current in the circuit of Figure 1.9 doubles from 12 amperes to 24 amperes.

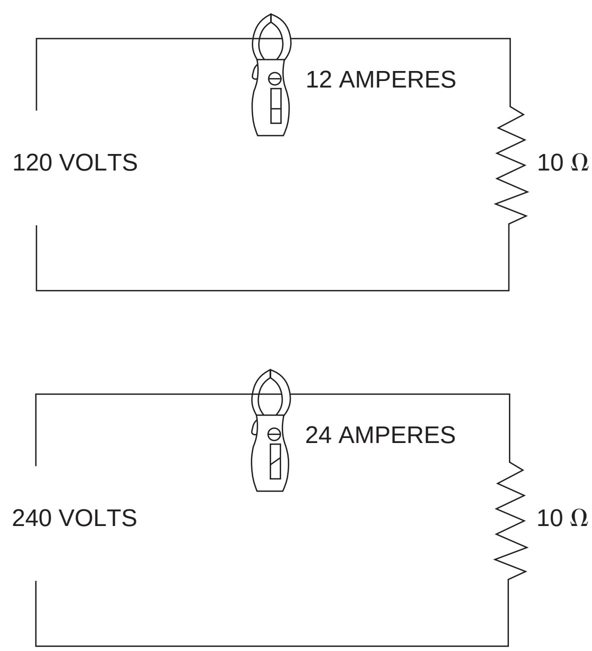


Figure 1.9 According to Ohm's Law, doubling the voltage will result in a doubling of the current in the circuit if the resistance remains constant.

$$\textbf{Current} = \frac{\textbf{Voltage}}{\textbf{Resistance}} \qquad \mathbf{I} = \frac{\mathbf{E}}{\mathbf{R}} \qquad \textbf{Eq. 1.3}$$

Ohm's Law can be written to solve for the voltage when the current flow and resistance are known. Equation 1.4 is Ohm's Law arranged to solve for voltage. If the current flow through a wire increases, the voltage drop along the wire will increase. Figure 1.10. Ohm's Law for a 10-ampere flow through wires with two different resistances. The voltage drop will be doubled for the wire with twice as much resistance when the current flow remains constant.

$$\textbf{Voltage} = \textbf{Current} \times \textbf{Resistance} \qquad \mathbf{E} = \mathbf{I} \times \mathbf{R} \qquad \textbf{Eq. 1.4}$$

The resistance of a circuit or a device can be determined using Equation 1.5. If the current flow and the voltage are known, the resistance can be calculated.

$$\textbf{Resistance} = \frac{\textbf{Voltage}}{\textbf{Current}} \qquad \mathbf{R} = \frac{\mathbf{E}}{\mathbf{I}} \qquad \textbf{Eq. 1.5}$$

Example 1.2 The voltage drop across an incandescent lightbulb is 120 volts, and the current flow through the lightbulb is 0.8 amperes. Determine the resistance of the lightbulb filament when it is lighted.

Answer: The resistance is desired, and the voltage and current are known; therefore, use Equation 1.5.

$$\text{Resistance} = \frac{120\text{ V}}{0.8\text{ A}} = 150\ \Omega$$

Some equations for Ohm's Law may read impedance (Z) instead of resistance (R). Impedance is in ohms, and it is the combined effect of resistance, inductive reactance, and capacitive reactance in a circuit.

Circuits

Electricity must always travel in a circuit from a source of voltage back to the source of voltage. A simple circuit contains a voltage source, resistance of the wires and the load, and electrical current flow. The relationship that governs these quantities is Ohm's Law, which was just discussed. Most electrical circuits

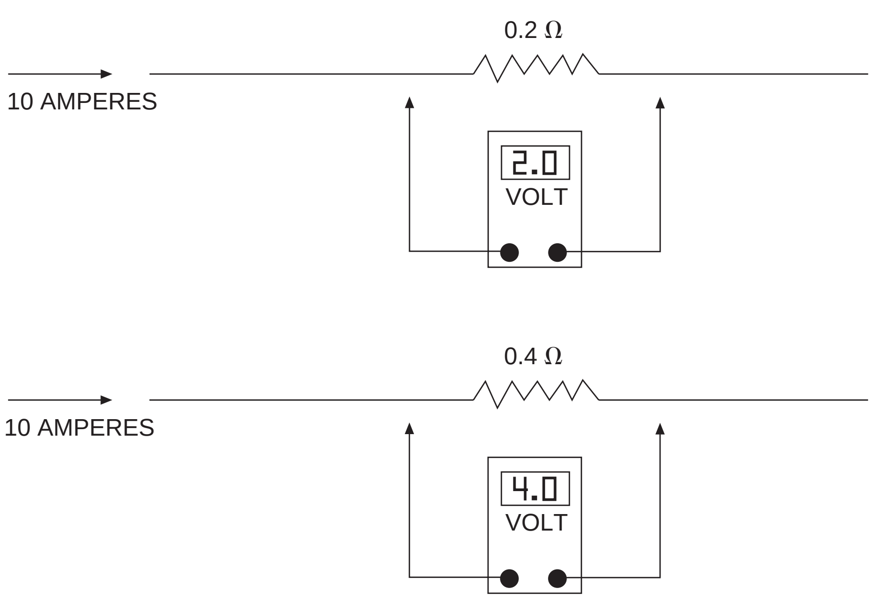


Figure 1.10 Increasing the resistance for a constant current flow will result in an increase in voltage along the circuit.

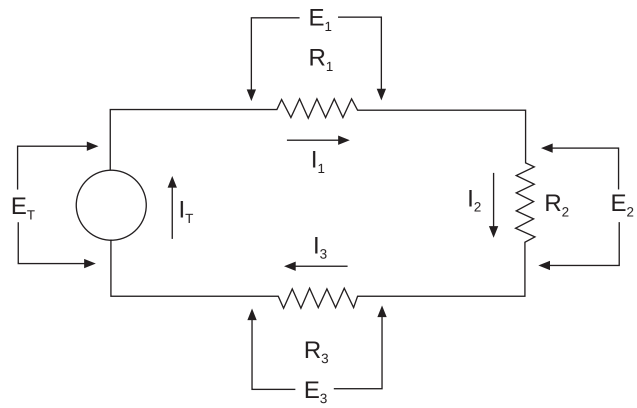


Figure 1.11 **There is only one path through a circuit where the loads or resistances are arranged in series.**

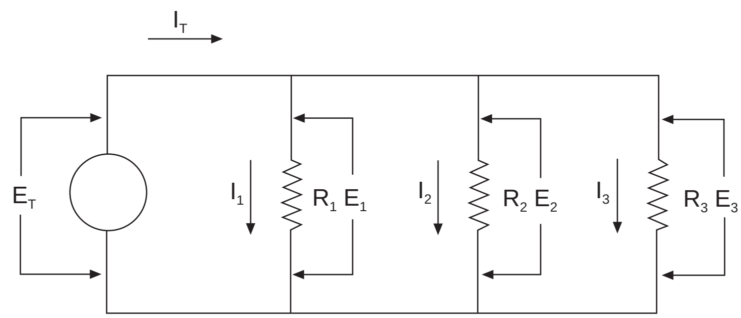


Figure 1.12 **There are multiple paths through a circuit where the loads or resistances are arranged in parallel.**

actually consist of several resistances in series or several resistances in parallel. Series and parallel circuits with three resistances are shown in Figure 1.11 and Figure 1.12. Troubleshooting electrical problems is much easier if the electrician has a basic understanding of series and parallel circuits.

A series circuit has all of the loads or resistances connected so there is only one path through the circuit. Therefore, if there is only one path, the electrical current is the same everywhere in the circuit, as illustrated with Equation 1.6. The combined resistance of the series circuit is the sum of the individual resistances, as represented by Equation 1.7. The voltage at the source of the circuit will drop across the individual series resistances. The sum of the voltage drops across all of the resistances in series will add up to the circuit source voltage, as indicated by Equation 1.8. Refer to the circuit of Figure 1.11 of a series circuit.

$$\mathbf{I_T = I_1 = I_2 = I_3} \quad \textbf{Eq. 1.6}$$

$$\mathbf{R_T = R_1 + R_2 + R_3} \quad \textbf{Eq. 1.7}$$

$$\mathbf{E_T = E_1 + E_2 + E_3} \quad \textbf{Eq. 1.8}$$

Example 1.3 Assume the resistances in the series circuit of Figure 1.11 are 4 ohm, 8 ohm, and 12 ohm, and the circuit is powered at 120 volts. Determine: (1) the total circuit resistance, (2) the current flow in the circuit, and (3) the voltage drop across the 8-ohm resistor.

Answer: (1) The resistors are in series; therefore, use Equation 1.7 to find the total resistance.

$$R_T = 4\ \Omega + 8\ \Omega + 12\ \Omega = 24\ \Omega$$

(2) Total voltage and total resistance are known; therefore, use Ohm's Law (Equation 1.3) to solve for current.

$$\text{Current} = \frac{120\ \text{V}}{24\ \Omega} = 5\ \text{A}$$

(3) Ohm's Law can be used to determine the voltage drop across the 8-ohm resistor (Equation 1.4). The current determined in (2) flows through each resistor because this is a series circuit.

$$\text{Voltage} = 5\ \text{A} \times 8\ \Omega = 40\ \text{V}$$

This is the voltage drop across the 8-ohm resistor. The voltage drop across the 4-ohm resistor is 20 volts, and across the 12-ohm resistor is 60 volts. The voltage drop across all series resistors adds to 120 volts.

A parallel circuit has all of the loads or resistances arranged so there are as many paths for the electrical current to follow as there are resistances in parallel, as shown in Figure 1.12. The total electrical current flowing in the circuit is the sum of the electrical current in each path of the circuit, as indicated by Equation 1.9. The total circuit resistance is the most difficult quantity to determine. The reciprocal of the total resistance is the sum of the reciprocals of each resistance in parallel, as indicated in Equation 1.10. The total resistance of the circuit will always be less than the value of the smallest resistance in parallel. The voltage across each parallel resistance will be equal and the same as the source voltage, as illustrated in Equation 1.11.

$$\mathbf{I_T = I_1 + I_2 + I_3} \qquad \textbf{Eq. 1.9}$$

$$\mathbf{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \qquad \textbf{Eq. 1.10}$$

$$\mathbf{E_T = E_1 = E_2 = E_3} \qquad \textbf{Eq. 1.11}$$

Example 1.4 Assume the parallel resistances in Figure 1.12 have the values of 4 ohm, 6 ohm, and 12 ohm, and the circuit is operated at 120 volts. Determine the following for the circuit: (1) total circuit resistance, (2) total circuit current flow, and (3) the current flow through the 6-ohm resistor.

Answer: (1) This is a circuit with all resistances in parallel. The total resistance of the circuit can be determined using Equation 1.10.

$$\frac{1}{R_T} = \frac{1}{4} + \frac{1}{6} + \frac{1}{12} = 0.250 + 0.167 + 0.083 = 0.500$$

$$R_T = \frac{1}{0.500} = 2\ \Omega$$

(2) Ohm's Law can be used to determine the total current flow in the circuit (Equation 1.3).

$$\text{Current} = \frac{120\ \text{V}}{2\ \Omega} = 60\ \text{A}$$

(3) All of the resistances are in parallel, and there are 120 volts across each resistor. The current flowing through the 6-ohm resistor is found by using Equation 1.3, and dividing 120 volts by 6 ohms to get 20 amperes. Using Equation 1.3, the current through the 4-ohm resistor is 30 amperes, and 10 amperes through the 12-ohm resistor. Note the current through each resistor adds to the total current, which was 60 amperes (20 A + 30 A + 10 A = 60 A). Another way to determine the total resistance of the parallel circuit is to first find the total current. For this circuit, the total current was 60 amperes. Then use Ohm's Law Equation 1.5 to find the total circuit resistance of 2 ohms (120 V / 60 A = 2 ohm).

Power and Work Formulas

Power is the rate of doing work, as represented by Equation 1.12. It will take twice as much power to lift a weight a given number of ft in one minute as it will to lift the same weight the distance in two minutes.

Horsepower (hp) is a common unit of measure of power, but watts (W) is also a unit of measure of power. The conversion from horsepower to several other units of power is shown as follows:

$$\textbf{Power} = \frac{\textbf{Work}}{\textbf{Time}} \qquad \textbf{Eq. 1.12}$$

$$\begin{aligned} 1\ \text{hp} &= 33{,}000\ \text{ft-lb/min} \\ &= 44{,}760\ \text{J/min} \\ &= 746\ \text{W} \end{aligned}$$

Electrical power in watts can be determined if the volts, amperes, and power factor of the circuit are known. For a direct current circuit or an alternating current circuit where the loads are resistance type, such as incandescent lights or electric resistance heaters, the power factor is 1.0. In the case of electric discharge lights, motors, and many other types of equipment, the power factor will be less than 1.0. A power factor meter can be used to determine the power factor of a particular circuit. Equation 1.13 is used to determine the single-phase power of a circuit, and Equation 1.14 is used to determine the power of a 3-phase circuit.

$$\textbf{Power}_{\textbf{Single-phase}} = \textbf{Volts} \times \textbf{Amperes} \times \textbf{Power Factor} \qquad \textbf{Eq. 1.13}$$

$$\textbf{Power}_{\textbf{3-phase}} = \textbf{1.73} \times \textbf{Volts} \times \textbf{Amperes} \times \textbf{Power Factor} \qquad \textbf{Eq. 1.14}$$

Example 1.5 A circuit of fluorescent luminaires (lighting fixtures) draws 15.4 amperes at 120 volts with a circuit power factor of 0.72. Determine the single-phase power in watts drawn by the circuit.

Answer: This is a single-phase power problem. Therefore, Equation 1.13 is used.

$$\text{Power} = 120\ \text{V} \times 15.4\ \text{A} \times 0.72 = 1331\ \text{W}$$

It is often useful to determine the current drawn by a particular load. This can be done by rearranging the power (Equation 1.13) to solve for current. The new form of the equation to determine current when the watts and voltage are known is given by Equation 1.15.

$$\textbf{Amperes} = \frac{\textbf{Power}}{\textbf{Volts} \times \textbf{Power Factor}} \qquad \textbf{Eq. 1.15}$$

The power factor is 1.0 for dc loads and resistance ac loads such as incandescent lamps and resistance heating elements. The use of Equation 1.15 is illustrated by an example.

Example 1.6 Determine the current drawn by a 100-watt incandescent lightbulb operating at its rated 120 volts.

Answer: Use Equation 1.15 and note that the power factor is 1.0 for an incandescent lightbulb.

$$\text{Amperes} = \frac{100\ \text{W}}{120\ \text{V} \times 1.0} = 0.83\ \text{A}$$

Heat is a form of work, and work is power multiplied by time. Heat is produced as electrical current flows through an electrical conductor. Equation 1.16 shows the relationship between heat (in watt-seconds), electrical current (in amperes), resistance (in ohms), and time (in seconds).

$$\textbf{Heat} = \textbf{I}^2 \times \textbf{R} \times \textbf{Time} \qquad \textbf{Eq. 1.16}$$

The kilowatt-hour (kWh) is a unit of measure of electrical work. A smaller unit of work is the watt-second. The watt-second is equal to one joule (J), which is the metric unit of measure of heat. The British thermal unit (Btu) is also a unit of measure of heat. The following are conversion factors for different units of measure of work or heat:

1 kWh	=	3413 Btu = 3,600,000 joules
1 watt-sec.	=	1 joule
1 watt-hr.	=	3600 joules
1 kilojoule	=	0.948 Btu

Example 1.7 A wire supplying power to an electric motor has a resistance of 0.2 ohm. Assume that a short circuit occurs at the electric motor controller, and the short-circuit current of 3500 amperes flows for one second. Determine the heat produced in the wire by the short-circuit.

Answer: The heat produced is determined by using Equation 1.16. For simplicity, assume the resistance of the wire remains constant during the short circuit.

$$\text{Heat} = 3500\text{ A} \times 3500\text{ A} \times 0.2\ \Omega \times 1\text{ s} = 2{,}450{,}000\text{ J}$$

This is 2450 kilojoules or 2323 Btu.

Efficiency

The efficiency of a system or equipment is the output divided by the input. Efficiency of an electric motor can be calculated using Equation 1.17 provided it is known exactly how much power is being developed by the motor. The watts drawn by the motor can be determined by using Equation 1.13 for a single-phase circuit, or Equation 1.14 for a 3-phase circuit.

$$\textbf{Efficiency} = \frac{\textbf{Power Out}}{\textbf{Power In}} = \frac{\textbf{Horsepower Developed} \times \textbf{746}}{\textbf{Watts}} \qquad \textbf{Eq. 1.17}$$

Example 1.8 A single-phase electric motor draws 9.8 amperes at 115 volts with a power factor of 0.82. The motor is developing $^1/_2$ horsepower. Determine the efficiency of the motor.

Answer: Efficiency is determined by dividing the power developed by the input power to operate the motor using Equation 1.17. The power out of the motor is in horsepower; therefore, it must first be converted to electrical power.

$$\textbf{Efficiency} = \frac{\textbf{0.5 hp} \times \textbf{746 W/hp}}{\textbf{9.8 A} \times \textbf{115 V} \times \textbf{0.82}} = \textbf{0.40 or 40\%}$$

Student Practice Problems

These practice problems on electrical fundamentals will help improve skills at working with the basic concepts of electricity previously discussed. Look for the equation from the previous discussion that relates to the problem. It is helpful to list the known information and the quantity desired. Then try to find an equation using that information. Refer to the example problems for help.

1. The resistance of 328 ft (100 m) of size 4 AWG uncoated copper wire with resistance as given in Code *Table 8, Chapter 9* is:
   A. 0.050 ohms. B. 0.101 ohms. C. 0.257 ohms. D. 1.250 ohms.

2. You observe a technician using an oscilloscope to measure the voltage at an outlet. The value of the peak voltage of the sine wave on the screen is 167 volts. If you were to measure this same voltage with your rms meter, the rms voltage would be:
   A. 95 volts. B. 110 volts. C. 118 volts. D. 130 volts.

3. A baseboard electric heater operates at 240 volts and draws 3.33 amperes. The resistance of the heating element is:
   A. 72 ohms. B. 95 ohms. C. 110 ohms. D. 240 ohms.

4. The current drawn by a 200-watt incandescent lamp operating at 120 volts is:
   A. 0.50 ampere. B. 1.00 ampere. C. 1.36 amperes. D. 1.67 amperes.

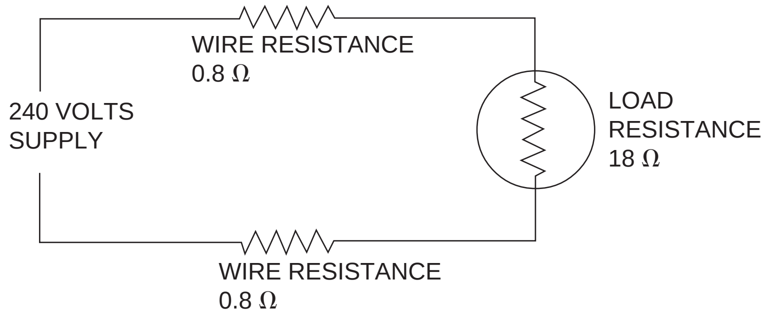


Figure 1.13 A typical series circuit is one in which the resistance of the wire supplying the load is in series with the resistance of the load.

5. An 18-ohm load is connected to a 240-volt power source using wires that each have a resistance of 0.8 ohm. The circuit is shown in Figure 1.13. The voltage across the terminals of the load is:
   A. 120 volts. B. 130 volts. C. 220 volts. D. 240 volts.

6. A 120-volt circuit supplies two loads connected in parallel. One load has a resistance of 20 ohms, and the other load has a current flow of 4 amperes. The circuit is shown in Figure 1.14. The total current flowing in the circuit is:
   A. 4 amperes. B. 5 amperes. C. 7.5 amperes. D. 10 amperes.

7. The total resistance of the circuit with the parallel loads shown in Figure 1.14 is:
   A. 6 ohms. B. 12 ohms. C. 18 ohms. D. 24 ohms.

8. A 3-phase electric motor draws 68 amperes and operates at 230 volts with a power factor of 0.78. The power in watts drawn by the motor is:
   A. 11,200 watts. B. 16,350 watts. C. 21,105 watts. D. 28,654 watts.

9. The 230-volt, 3-phase electric motor of Problem 8 is developing 25 horsepower. The efficiency of the motor is:
   A. 56%. B. 78%. C. 81.6%. D. 88.4%.

10. A house is operating six 100-watt incandescent lamps, four 60-watt lamps, and four 40-watt lamps for six hours. The amount of electrical energy used during the six hours is:
   A. 6 kWh. B. 8.4 kWh. C. 10 kWh. D. 12.5 kWh.

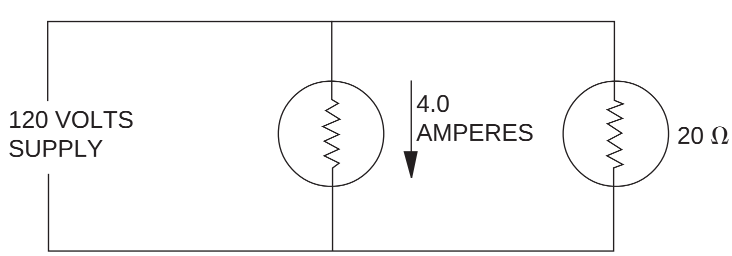


Figure 1.14 A typical parallel circuit is one in which the loads are all connected to the same voltage source, such as the luminaires (light fixtures) in a room.

CODE DISCUSSION

A person in the electrical trade who makes proper use of the Code must understand the background of the Code. Important information about the use of the Code is contained on the inside front cover and inside back cover. The first page of the Code and the last several pages of the Code also contain important information about the use of the Code, as well as the process by which it is maintained. The following information is from the front of the Code: Changes in the Code are indicated with gray shading. Where large blocks of text were added or given a major reorganization and rewriting, a vertical line is placed in the margin. Vertical lines in the margin are also used to indicate changes in tables and figures. Where one or more paragraphs of text was deleted or moved to a different location, a dot is placed in the margin where the text was originally located. When text originates in another NFPA standard, the original document is referenced in brackets at the end of the paragraph such as [**497**:3.3.5.1.4], where the number in bold is the standard, and the other set of numbers gives the specific paragraph location.

Article 80 is located in *Annex H* and is a set of rules available for adoption by a governmental jurisdiction for administering and enforcing the electrical code in that jurisdiction. *Article 80* is not to be considered to be a part of the Code unless specifically approved by a governmental jurisdiction. *NEC® 80.9* states to which installations the new electrical code applies. For example, the code applies to additions, alterations, and repairs, but not to the existing building unless the new work causes the existing building wiring to be unsafe. *NEC® 80.13* states what authority is placed upon the enforcing agency. For example, in *80.13(1),* the enforcing agency is permitted to make interpretations where a section of the Code may not be clear. This same rule is covered in *90.4* and is not new. *NEC® 80.13(13)* gives the enforcing agency the authority to order wiring or equipment be made exposed if it was concealed before an inspection could be performed. The makeup and duties of an electrical board are covered in *80.15*. The permit process is covered in *80.19*, and plan review requirements are covered in *80.21*. Qualifications of electrical inspectors are covered in *80.27*. Key points are that the inspector have experience in the electrical trade and the inspector be certified by a nationally recognized inspector certification program. There is no requirement in *Article 80* that the inspector hold an electrical license.

Article 90 sets the basic ground rules for understanding the remainder of the Code. The entire Code is directed at meeting the purpose stated in *90.1* which is the "practical safeguarding of persons and property from the hazards arising from the use of electricity." Following the rules of the Code will mean the installation is "essentially free from hazard." *NEC® 90.2* lists the installations covered by the Code and those that are not covered. Installations made on private or public property by a utility, such as area lighting, and is under the complete control of that utility for installation and maintenance, is generally not considered to be covered by the Code according to *90.2(A)(4)* and *90.2(B)(5)*. *NEC® 90.4* gives the local inspection agency authority to make interpretations when there seems to be a debate as to the meaning of a Code section. *NEC® 90.5(C)* states that fine print notes (FPN) are only explanatory and not enforceable. *NEC® 90.9* gives the Code rules relative to metric units. The Code will permit trade size designators rather than true metric conversions, such as in the case of raceway sizes. In some cases, English units only will be given where it is an established industry practice. It is very important to note that *90.9(D)* authorizes the use of approximate metric conversions. See the table of distances in *Annex A* of this text. In some cases, the Metric dimension and the English dimension may differ by several in. For example, "in sight from" is defined as a maximum distance of 50 ft (15 m). As illustrated in Figure 1.15, the difference between 15 m and 50 ft is 9 7/16 in. Whether this be used as a "not greater than" or a "not less than" requirement, either the English or Metric dimension is considered meeting the intent of the Code. A disconnect located 15.24 m from a motor controller is still considered to be located within sight of the controller according to *90.9(D)*.

Article 100 provides definitions of terms that are generally used in more than one article of the Code. If the term is used only in a specific article, the definition is usually provided in that article. There are several definitions in particular that will be helpful in understanding various sections throughout the Code. *NEC® 110.2* requires that conductors and equipment installed according to the Code shall be approved. **Approved** means acceptable to the authority having jurisdiction. *NEC® 110.3* gives a list of criteria the inspector can use to evaluate an installation or equipment for approval. **Listing** and **labeling** are given as criteria for judging suitability of equipment. Listed is defined in *Article 100*. Another important definition is **continuous load**. Any load that is expected to operate at a maximum for three hours or more is considered to be a continuous load.

A multiwire branch-circuit is common and there are several specific rules that apply to this type of circuit. A **multiwire branch-circuit** (branch-circuit, multiwire) has two or more ungrounded conductors with

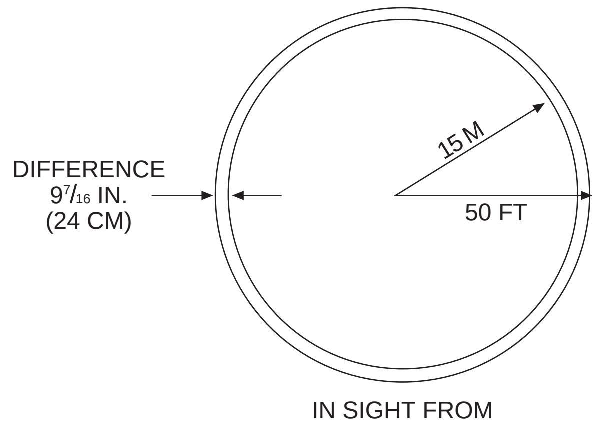


Figure 1.15 Approximate Metric conversions are permitted in the Code, and where there is a difference such as 50 ft (15 m), both dimensions are considered as meeting the intent of the Code.

a voltage between them, and share a common grounded (neutral) conductor as illustrated later in Figure 1.19. Two terms that can be confusing are receptacle and receptacle outlet. A **receptacle** is defined as a single contact device for cord and plug connected equipment. A **receptacle outlet** is a point on the electrical system where there may be one or more receptacles or other devices.

Article 110 contains general information about electrical installations. A section that is important for the sizing of conductors for a branch-circuit or feeder is *110.14(C)*. When determining the minimum size of conductor for a circuit, the insulation on the conductors frequently has a higher temperature rating than the conductor terminations. Conductor terminations may be marked with the maximum temperature rating, but often they are not marked. It is in the case when the termination temperature is not marked that *110.14(C)* becomes important. The basic rules are illustrated in Figure 1.16. According to *110.14(C)(1)(a)*, if a termination is not marked otherwise, it has a 60°C rating if the overcurrent device protecting the circuit is rated 100 amperes or less or if the conductor is size 1 AWG or smaller. *NEC®* *110.14(C)(1)(b)* specifies that if the overcurrent device protecting the circuit is rated greater than 100 amperes or if the conductor is size 1/0 AWG or larger, the termination is required to have a minimum rating of 75°C unless otherwise marked.

Article 110 also gives the minimum work space requirements of electrical equipment. For electrical equipment operating at not over 600 volts, the minimum work space requirements are provided in *110.26*.

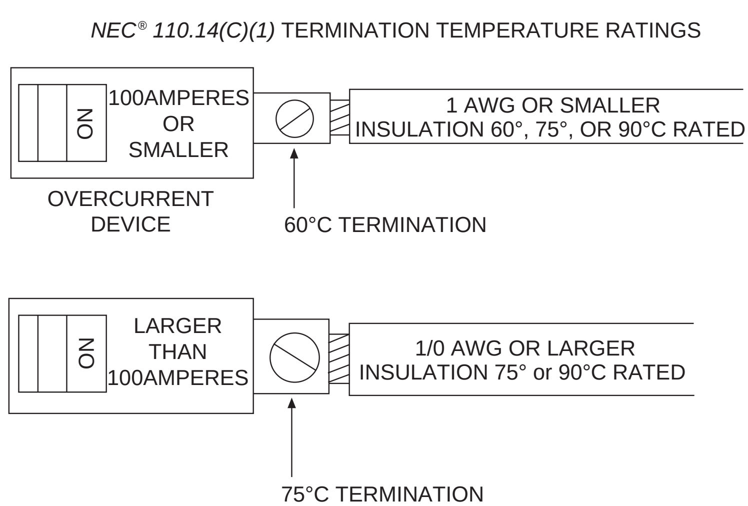


Figure 1.16 If a conductor termination does not have a marked temperature rating, *110.14(C)(1)* sets the temperature rating based upon the rating of overcurrent device or conductor size.

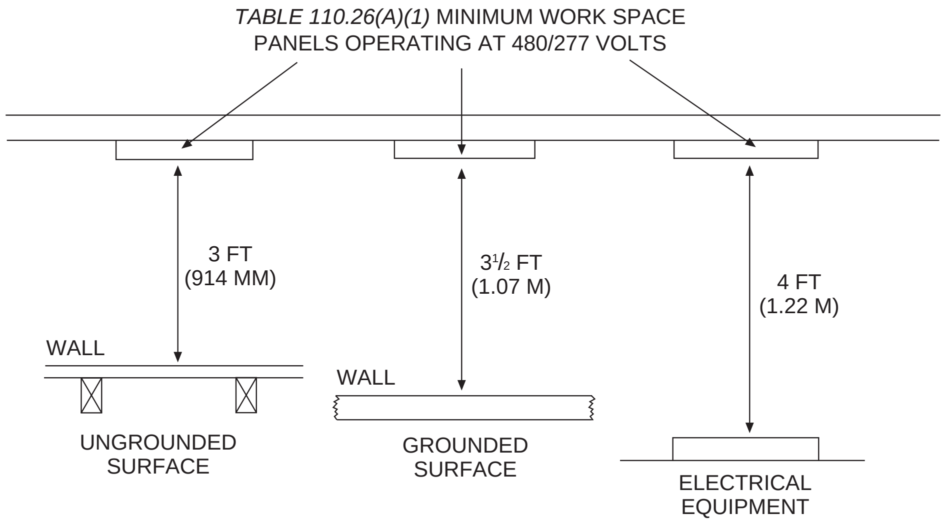


Figure 1.17 A minimum clear working space is required in front of electrical equipment based upon the voltage to ground in the equipment and whether it is facing an ungrounded surface, a grounded surface or equipment, or other equipment with exposed live parts.

Figure 1.17 illustrates minimum working space clear distances required to be provided in front of electrical equipment operating at over 150 volts to ground. For equipment operating over 600 volts, the minimum required working clearances are given in *110.34*.

Article 200 primarily covers the means of identification of the grounded-circuit conductor (usually the neutral), and grounded-circuit conductor terminations on devices. *NEC® 200.6(B)* permits a conductor with insulation with a color other than white or green to be identified as a grounded conductor by adding a white marking, which completely encircles the conductor, at each termination at the time of installation. In the case of switch loops, where multiconductor cable is used, *200.7(C)(2)* permits a white or gray conductor to be re-identified as an ungrounded conductor at all locations where the conductor is visible. The re-identified white conductor is also required to be the feed, supplying the source of power to the switch. Under no circumstances is it permitted to be the switched return conductor to the load. This rule is illustrated in Figure 1.18.

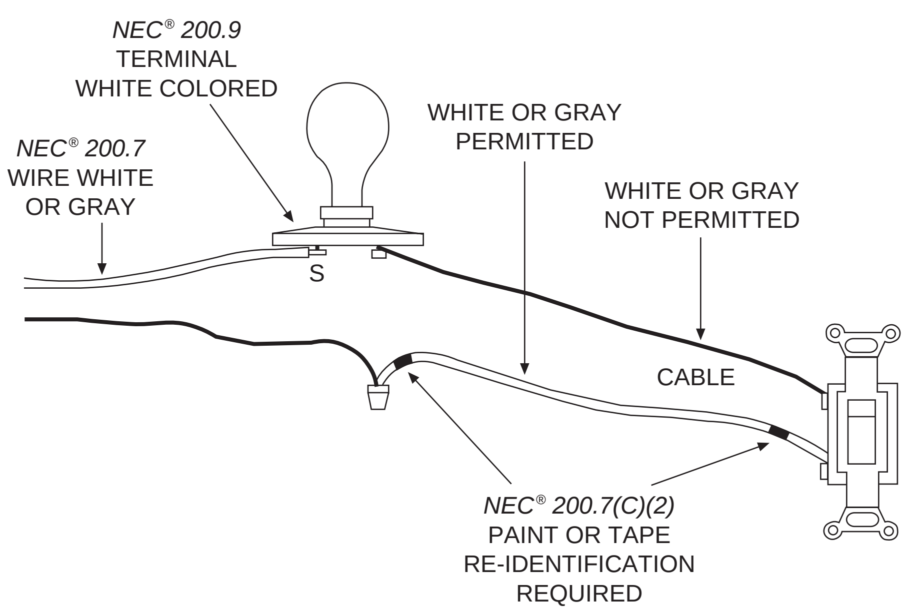


Figure 1.18 Grounded-circuit conductors shall be white or gray, but a white or gray conductor when part of a cable assembly is permitted to be re-identified as an ungrounded conductor when used as the feed to the switch.

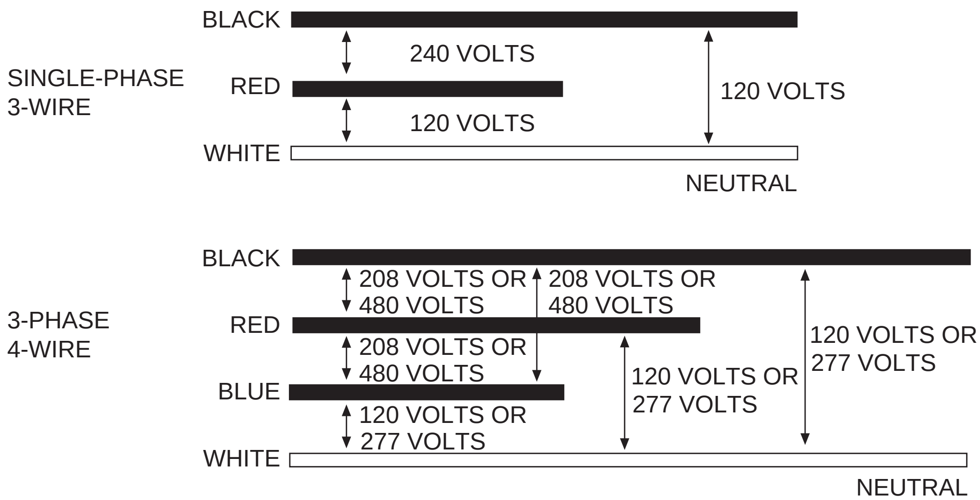


Figure 1.19 A common neutral wire is run with two or more ungrounded wires in multiwire circuits.

Article 300 is another section that covers general wiring installation methods. *NEC® 300.4* covers the protection of conductors passing through structural members. There are also minimum clearance requirements for the installation of cables and some raceways run on the surface of studs and joists. The issue is the protection of the conductors from damage from nails and other fasteners. Additional rules concerning boring holes and notching load-bearing structural members may be in the building code. Underground installations are covered in *300.5*. *Table 300.5* gives the minimum depth of burial permitted for different types of occupancies and different conditions. For farm and some commercial installations, *300.7* is particularly important for conditions in which a raceway is exposed to different temperatures. There can be problems of condensation in the raceway system, or there can be problems with damage to the conduit or separation of the conduit due to expansion and contraction.

A multiwire branch-circuit is defined in *Article 100* as a circuit that has two or more ungrounded conductors with a potential between them and sharing a common grounded conductor. Typical single-phase and 3-phase multiwire branch-circuits are illustrated in Figure 1.19. A requirement that deals with multiwire circuits is *300.13(B)*. Removing a device in a multiwire circuit is not permitted to interrupt the neutral wire. This is illustrated in Figure 1.20. Numerous other miscellaneous, but important, requirements are covered such as supporting conduit, preventing induced currents, traversing ducts, and preventing fire spread.

A minimum free length of 6 in. (150 mm) of conductor is required to be provided at each box to make up splices and to connect to devices and luminaires (fixtures). This rule is found in *300.14*. If the box has an opening dimension of less than 8 in. (200 mm), then there shall be at least 3 in. (75 mm) of conductor

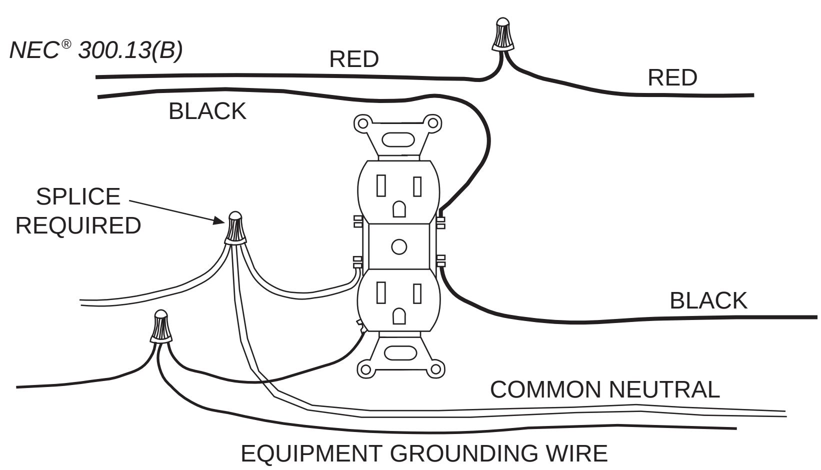


Figure 1.20 Device removal in multiwire circuits is not permitted to open the neutral conductor.

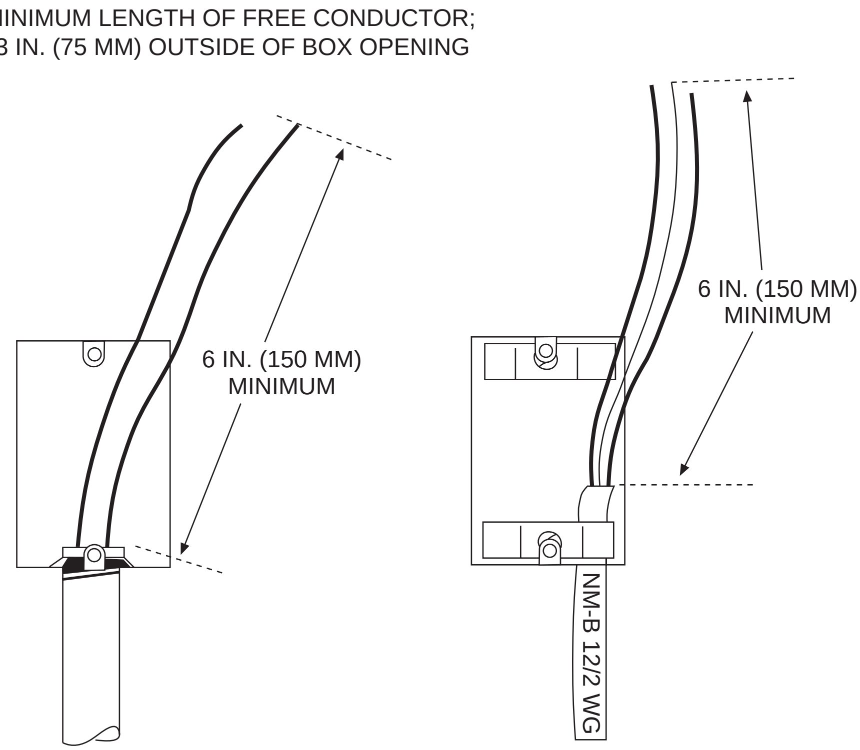


Figure 1.21 The 6 in. (150 mm) minimum length of free conductor is measured from the point where the conductor emerges from the raceway or cable sheath, and there must be a minimum of 3 in. (75 mm) of conductor extending outside of boxes with an opening less than 8 in. (200 mm).

extending outside the box. This would mean that in the case of a box that is more than 3 in. (75 mm) deep, the actual free length of conductor may be required to be more than 6 in. (150 mm). The measurement of the free length of conductor is from the point where the conductors emerge from the raceway, or the cable jacket as illustrated in Figure 1.21.

Article 310 is one of the most frequently used articles of the Code. This article contains the ampacity tables used to determine the minimum size of wire permitted for a circuit or load. Several methods can be used to determine the ampacity of electrical conductors, as stated in *310.15.* Generally, *Table 310.16*, *Table 310.17*, *Table 310.18*, *Table 310.19*, and *Table 310.20* will be used to determine the minimum size of wire for a particular circuit. *Table 310.16* can be used for all situations of not more than three wires in cable or raceway or in the earth. *Table 310.17* applies to single insulated wires in free air. This would be the case for single overhead conductors mounted on insulators. *Table 310.20* is for insulated conductors supported on a messenger such as triplex cable. *NEC® 310.15(C)* provides a method permitted to be used to determine the ampacity of a conductor when the calculations are performed by or checked by an engineer. A number of ampacity tables are contained in *Annex B* of the Code. These tables are not generally permitted to be used to determine the ampacity of a conductor unless the governmental jurisdiction specifically permits the *Annex B* ampacity tables to be used. Several examples will help in understanding which table is to be used for which situation. Keep in mind that the ampacity tables only apply directly to raceways and cables that contain not more than three current-carrying conductors. If there are more than three wires, or if the wires are exposed to a temperature greater than 30°C or 87°F, the ampacity as found in *Table 310.16* or *Table310.17* shall be reduced. Conductor derating for ambient temperature and number of wires in raceway or cable is covered in *Unit 2.*

The allowable ampacity of a conductor depends upon the size of the conductor, the type of insulation, and the temperature rating of the splices and terminations. The allowable current must be limited to a value that will not allow the temperature of the conductor to exceed the withstand temperature rating of the insulation. At points where conductors are spliced or terminated into a lug or under a screw terminal, the conductor operating temperature is not permitted to be higher than the maximum temperature limit of the termination. If a termination operates at more than the maximum temperature rating, it most likely will deteriorate and eventually fail. A fire may result. If the conductor terminations in a circuit are rated 75°C, and the conductor insulation has a different temperature rating, such as THHN at 90°C, generally the column of the table with a temperature matching the lowest temperature rating is used to find the allowable ampacity of the conductor for that circuit. That is not necessarily the case when applying adjustment and correction factors.

Another factor that determines the actual ampere rating of a conductor is the rating of the overcurrent device (fuse or circuit breaker) used to protect the conductor from overheating. The actual load or calculated load for a circuit is not permitted to exceed the rating of the overcurrent device no matter what size of wire is used. If a 20-ampere circuit breaker protects a circuit where the conductor is size 10 AWG copper with Type THHN insulation, the calculated load is not permitted to exceed 20 amperes, and if the actual load is continuous, it is not permitted to exceed 16 amperes for this circuit breaker. All of these factors must be considered when selecting the minimum size conductor for a particular circuit.

Copper conductor sizes 14, 12, and 10 AWG, and aluminum conductor sizes 12 and 10 AWG, when used for most circuits have an overcurrent device maximum limit. In a previous edition of the Code, this limit was given in a footnote at the bottom of *Table 310.16* and *Table 310.17*. Those overcurrent device limits are now in *240.4(D)*. The overcurrent device rating for size 14 AWG copper wire is 15 amperes, for size 12 AWG it is 20 amperes, and for size 10 AWG it is 30 amperes.

Example 1.9 Three size 10 AWG, Type THWN insulated copper conductors are contained in a conduit in a building. Determine the ampacity of the conductors if the ambient temperature does not exceed 30°C and all terminations are rated 75°C.

Answer: *Table 310.16* applies to this situation. Find the type of insulation in the copper conductor part of the table (75°C column), and find the ampacity that corresponds to size 10 AWG wire, which is 35 amperes.

Example 1.10 Type USE Aluminum Cable, size 2 AWG, consisting of three current-carrying conductors, is directly buried in the earth at a depth of 24 in. (600 mm). Determine the ampacity of the cable if all terminations are rated 75°C.

Answer: *Table 310.16* applies in this situation. Find the ampacity of size 2 AWG aluminum in the column headed with conductor insulation Type USE. The cable is rated at 90 amperes.

Example 1.11 Type XHHW aluminum wire, size 4 AWG, is installed overhead in free air as single conductors on insulators. Assume that the ambient temperature does not exceed 30°C and that at times this would be considered a wet location. Assume the terminations at the drip loop are rated at 90°C. Determine the ampacity of the aluminum wire in this situation.

Answer: *Table 310.17* is used in the case of single conductors in free air. Note that there are two columns of aluminum wire with Type XHHW insulation listed, the 75°C column and the 90°C column. It will be necessary to refer to Type XHHW insulation in *Table 310.13* for an explanation of when to use the two columns. Because this is considered at times to be a wet location, the 75°C column is used. The size 4 AWG aluminum wire is rated at 100 amperes.

When there are more than three current-carrying conductors in a raceway, cable, or trench in earth, the allowable ampacities in *Table 310.16* require an adjustment. *NEC® 310.15(B)(2)* gives the adjustment factors depending upon the number of current-carrying conductors. *NEC® 310.15(B)(4)* explains when the neutral is required to be counted as a current-carrying conductor. This subject will be discussed in detail in the next unit. *NEC® 310.60* provides directions for determination of ampacity of conductors operating at 2001 to 35,000 volts.

Article 320 covers Type AC Armored Cable. Type AC Cable generally consists of two or three insulated conductors and an equipment grounding conductor within a flexible metallic covering. The uses not permitted are covered in *320.12*. The cable shall be supported within 12 in. (300 mm) of the end of each run and at intervals not to exceed 4 1/2 ft (1.4 m) as illustrated in Figure 1.22. The cable is subject to damage similar to other cables, therefore, *320.15* requires that exposed runs of Type AC Cable closely follow the surface of the building, or that running boards be provided. In the case of an accessible ceiling space, Type AC Cable is permitted to be secured by support wires that are provided for the sole support of electrical wiring. As for exposed work, the cable in an accessible ceiling is required to be supported within 12 in. (300 mm) of each termination, and at intervals not to exceed 4 1/2 ft (1.4 m). Type AC Cable is permitted to be run through bored or punched holes in wood or metal framing members as well as notches in wood members. For other than vertical runs through framing members, the maximum support distance is 4$^1/_2$ ft (1.4 m). The cable is not required to be secured to the framing members. The maximum distance from a termination to a secure means of support is not permitted to exceed 12 in. (300 mm).

Article 324 provides specifications for the materials and installation for flat conductor cable, Type FCC, to be placed under carpet squares. This is a technique for extending power to work stations in a large open room. Definitions are given in *324.2*. Uses permitted and not permitted are covered in *324.10* and *324.12*. The maximum voltage permitted for flat conductor cable is 300 volts between ungrounded conductors and a maximum of 150 volts from any ungrounded conductor to the grounded conductor. General use circuits are not permitted to be rated in excess of 20 amperes. These voltage and current requirements are stated in *324.10(B)*. Flat Conductor Cable is permitted to be installed only under carpet squares defined in *324.41* as having a maximum dimension of 36 in. (914 mm) on each side.

Article 328 provides basic specifications and uses permitted for medium-voltage cable, Type MV, that is intended for use where energized at from 2001 to 35,000 volts. Type MV Cable is available as a single-conductor cable or as a multiconductor cable. The cable is permitted to be installed in raceway, cable trays, direct burial according to *328.10(4)*, *300.50*, and *310.7*, and supported by a messenger in air as

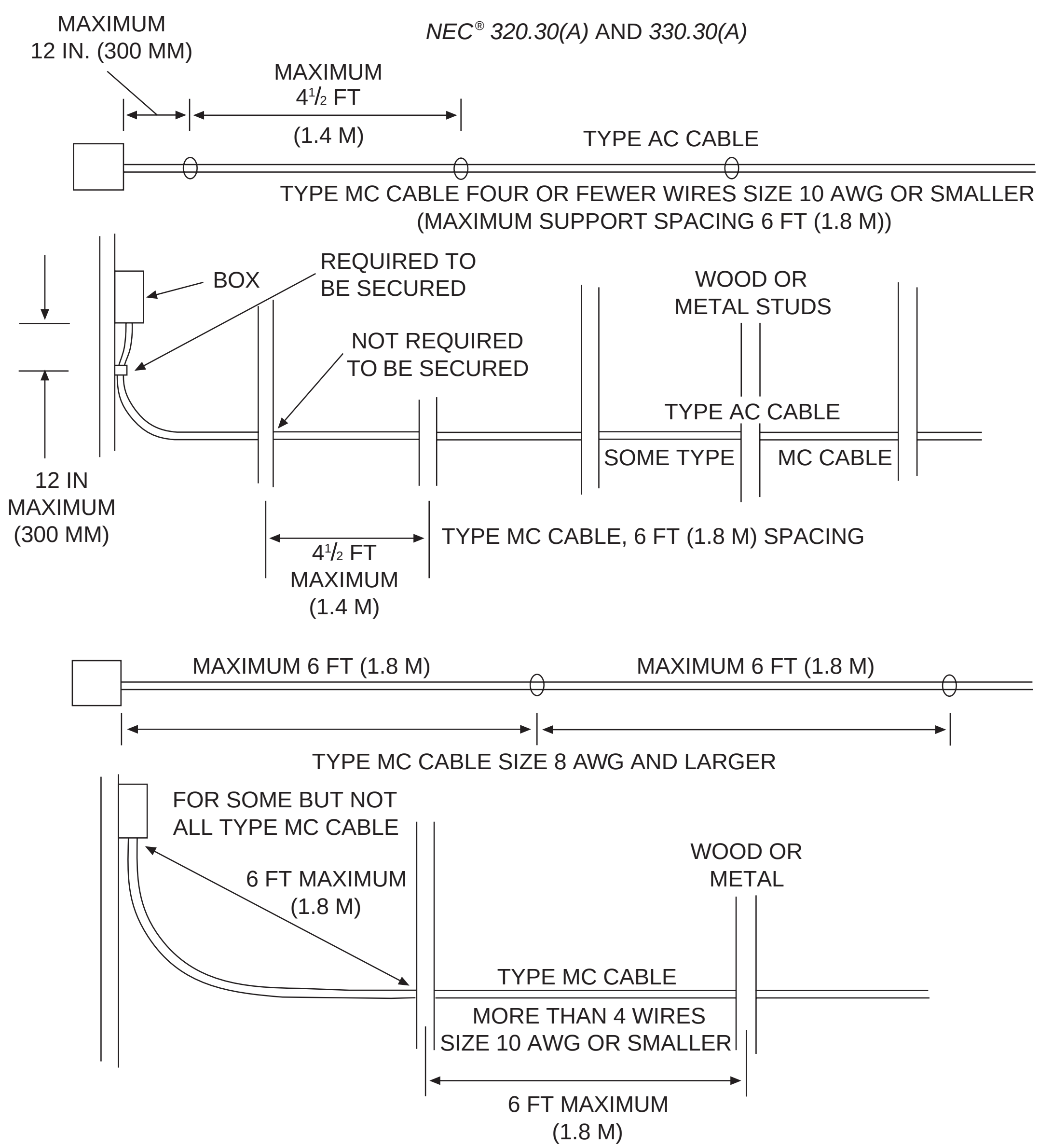


Figure 1.22 Type AC Armored Cable is required to be supported at intervals not exceeding 4$^1/_2$ ft (1.4 m), and Type MC Metal-Clad Cable is required to be supported at intervals not exceeding 6 ft (1.8 m).

specified in *Article 396*. When installed in tunnels, the rules for installation are found in *Article 110, Part IV*. General installation requirements and clearances from live parts and equipment are given in *Part III* of *Article 110*. The method of determining the ampacity of the conductors rated 2001 to 35,000 volts is specified in *310.60(B)*. It is permitted to use *Table 310.67* through *Table 310.86*, or the formula in *310.60(D)* under engineering supervision. *Annex B* gives examples of the use of the formula under engineering supervision.

Article 330 provides information on the uses permitted, installation, and construction of metal-clad Type MC Cable. The conductors are contained within a Flexible Metallic Sheath. It is permitted to be used for services, feeders, and branch-circuits. Type MC Cable is available with conductors operating at not more than 600 volts and also with conductors operating at more than 600 volts. *NEC® 330.30* requires that Type MC Cable be supported at intervals not to exceed 6 ft (1.8 m). If the conductors are size 10 AWG and smaller and there are four or fewer conductors, Type MC Cable is required to be supported within 12 in. (300 mm) of terminations. This is illustrated in Figure 1.22. If there are five or more conductors in the cable, or if conductors are size 8 AWG and larger, the distance from the termination to the first support is permitted to be up to 6 ft (1.8 m). Type MC Cable is permitted to be run through bored or punched holes in wood or metal framing members, as well as notches in wood members. For other than vertical runs through framing members, the maximum support distance is 6 ft (1.8 m). The cable is not required to be secured to the framing members, and the distance from a termination to the first framing member is permitted to be up to 6 ft (1.8 m). It is also permitted to be used as a luminaire (lighting fixture) or equipment whip in lengths up to 6 ft (1.8 m) within accessible ceiling spaces. In this case, the Type MC Cable is secured only at the box and at the luminaire (lighting fixture) or equipment supplied and again within 6ft (1.8 m) of the termination.

Article 332 covers the construction and installation of Type MI Mineral-Insulated, Metal-Sheathed Cable. Type MI Cable has the insulated conductors contained within a liquidtight and gastight continuous sheath with a densely packed mineral insulation filling the space between the conductors and the copper or alloy steel sheath. The cable can be cut to length with special fittings applied at the terminations. Type MI Cable has a wide variety of applications, and it is permitted to be fished into existing building spaces.

In the case of Type MI Cable, the termination fittings have a maximum temperature rating, generally 90°C. The cable itself is capable of operating at a much higher temperature. Rules for determining the allowable ampacity of Type MI Mineral-Insulated, Metal-Sheathed Cable are found in *332.80*. Temperature adjustment of the cable itself is generally not considered a problem unless heat is conducted to the terminal fittings such that their maximum temperature rating would be exceeded. *NEC® 332.80* permits Single-Conductor MI Cable assembled into a bundle to have the allowable ampacity to be determined from *Table 310.17*, even though that table is for single-conductors in free air. This is permitted as long as the cable is installed so that the maximum terminal fitting temperature is not exceeded. Portions of the cable itself, not terminations, may be permitted to be in an environment where the cable can operate up to 250°C according to *Table 310.13(A)*.

Article 334 deals with Nonmetallic-Sheathed Cable, usually Type NM. *NEC® 334.112* specifies that the conductors within the nonmetallic sheath shall have insulation rated at 90°C. These cables are marked Type NM-B. *NEC® 334.80* requires the allowable ampacity of a cable to be determined using the 60°C column of *Table 310.16*. Uses not permitted are given in *334.12*, and locations where Type NM-B cable is permitted to be installed are not directly stated. It is necessary to understand the basic types of construction in order to determine where Nonmetallic-Sheathed Cable is permitted to be installed. It is not permitted to be installed in buildings that are of Type I or Type II construction. Type I and Type II structures are required to be of noncombustible construction materials. Type III construction is a combination of combustible and noncombustible materials, Type IV is permitted to have heavy timber construction, and Type V is permitted to be wood frame construction.

Nonmetallic-Sheathed Cable is permitted to be used as a wiring method for one-family, two-family, and multifamily dwellings that are permitted to be of Type III, IV, or V construction. Type NM-B cable is permitted to be used as a wiring method concealed in walls, floors, and ceilings with a 15-minute fire rating for nondwelling buildings that are of Type III, IV, or V construction. It is not permitted to be installed as an exposed wiring method above suspended or dropped ceilings except for one-family, two-family, or multifamily dwellings of Type III, IV, or V construction. In *334.30(B)(2)* luminaires (lighting fixtures) and equipment installed in suspended ceilings of one-family, two-family, and multifamily dwellings are permitted to be supplied using Type NM-B cable provided the distance from the last point of support to the luminaire (fixture) or equipment does not exceed $4\frac{1}{2}$ ft (1.4m).

It is important to protect Nonmetallic-Sheathed Cable from damage. One form of damage is bending the cable in a small radius. The minimum radius of bend is five times the diameter of the cable, as stated in

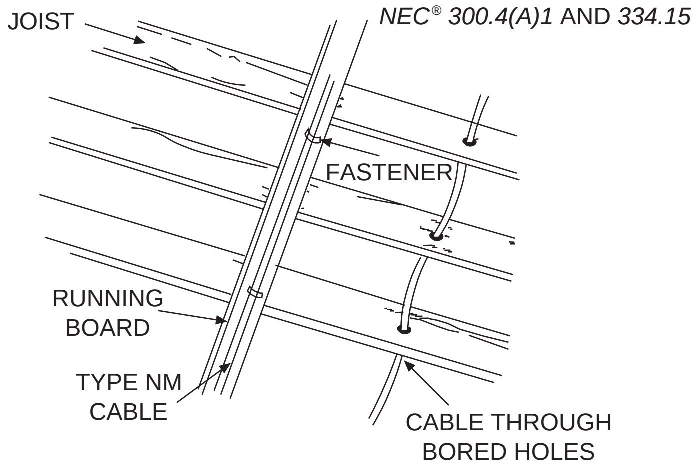


Figure 1.23 Small sizes of Type NM-B Cable are required to be attached to running boards or run through bored holes in joists.

334.24. *NEC® 334.30* requires Type NM-B Cable to be secured in place at intervals not exceeding 4 1/2 ft (1.4 m) and within 12 in. (300 mm) of terminations. According to *314.17(C) Exception*, the case of a nonmetallic single-gang box, where the cable is not secured directly to the box, the Nonmetallic-Sheathed Cable is required to be secured at a distance from the box of not more than 8 in. (200 mm) measured along the cable. Cables run through holes in metal or wood framing members are considered to meet the requirement of being supported and secured. Nonmetallic-Sheathed Cable is permitted to be attached to the underside of joists in basements for 2-wire size 6 AWG, or 3-wire size 8 AWG. Cables are permitted to be installed directly to the surface of joists and rafters in attics and crawl spaces, but protection is required near access openings as specified in *334.23*, and shown in Figure 1.23. *NEC® 334.30(B)(2)* permits Nonmetallic-Sheathed Cable to be run unsupported except at the terminations in lengths up to 4 1/2 ft (1.4 m) to supply power to a luminaire (fixture) or equipment in an accessible ceiling.

Article 336 covers the installation of Type TC Power and Control Tray Cable. The uses not permitted are the main emphasis of this article. The ampacity of Type TC Cable is specified in *336.80*. If the cable is smaller than size 14 AWG, the ampacity is determined using *Table 402.5* for fixture wire. Determination of conductor allowable ampacity when installed in cable trays will be discussed in *Unit 12*. Type TC Cable is available as a multiconductor cable and as single-conductor cable. Most single-conductor cables size 1/0 AWG and larger have a Type TC rating in addition to the normal conductor insulation rating.

Article 338 covers the use of Type SE Service-Entrance Cable and Type USE Underground Service-Entrance Cable. Type SE Cable is permitted for use as circuits and feeders within a building. The common types of Service-Entrance Cable in use are Type SE style U with two insulated conductors and a bare conductor within the nonmetallic covering, and Type SE style R, which has three insulated conductors and a bare equipment grounding conductor within the nonmetallic outer covering. These cable types are shown in Figure 1.24. According to *338.10(B)(4)(a)*, Type SE Cable when used for interior wiring is installed according to the same rules as for Type NM Cable.

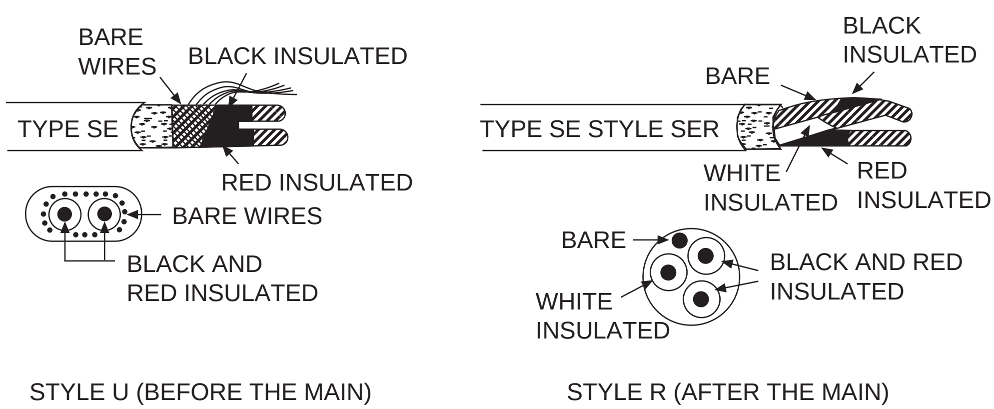


Figure 1.24 Type SE Service-Entrance Cable is available as style U or style R.

Article 340 covers Type UF Underground Feeder and Branch-Circuit Cable for use underground and within buildings. The installation of this cable within buildings is required to follow the requirements of Type NM-B Nonmetallic-Sheathed Cable in *Article 334* according to *340.10(4)*. It is important to note that there will be two grades of this cable in use. When Type UF Cable is installed within a building, the individual insulated wires in the cable are required to have a 90°C insulation temperature rating. This requirement on the 90°C rated insulation is stated in *340.112* where the conductor requirements for Type UF Cable are to be the same as for Type NM-B Cable. Cables are available with wires that have an insulation temperature rating of only 60°C. Both are permitted to be installed underground.

Article 382 deals with nonmetallic extensions, typically a Nonmetallic-Sheathed Cable installed on the surface of walls or ceilings. It is permitted to be attached as a nonmetallic extension to the exposed surface of walls and ceilings to extend power from an existing outlet of a 15- or 20-ampere circuit. This technique provides a means of extending wiring without having to enter the wall or ceiling cavity. This type of material is permitted to be messenger supported as an aerial cable for industrial buildings where the nature of the application requires a flexible means of connecting power to equipment.

Nonmetallic extensions are permitted to be applied to the surface of a wall or ceiling and concealed by covering with paint, wall paper, or other effective means. A listed cable is manufactured for this purpose with conductors that are a flat foil, with the ungrounded conductor sandwiched between the flat neutral conductor and enclosed within a flat equipment grounding conductor. The overall covering is nonmetallic. Listed devices are designed for terminating the flat cable assembly. This technique is only permitted on 15- and 20-ampere, 125 volt branch circuits in dwellings and office spaces, and not above the third floor unless listed for such locations. These concealable nonmetallic extensions originate at an existing outlet box and are applied to the surface of walls and ceilings. At the point where the concealable nonmetallic extension originates, overcurrent protection, arc-fault protection, ground-fault protection, and miswiring protection are required.

Article 394 covers a type of wiring called Concealed Knob-and-Tube Wiring. This type of wiring was used in buildings in the early years of wiring. Single-insulated conductors were held in place with insulators called knobs and cleats. The conductor then passed through a structural member and ran inside a porcelain tube. This type is encountered in existing older buildings.

Article 590 provides rules for the installation of wiring for temporary electrical power or lighting. This temporary power may be used for construction, remodeling, and similar activities. It may also be used to supply decorative lighting not generally intended for use for more than 90 days. *NEC® 590.4(A)* requires a service meeting the requirements of *Article 230* to supply a temporary wiring system. For a temporary electrical system at a construction site, *590.4(D)* does not permit receptacles to be installed on the same circuit with temporary lighting. In the case of a multiwire branch-circuit, all ungrounded conductors are required to be simultaneously disconnected according to *590.4(E)*. This means single-pole overcurrent devices as disconnects are not permitted for multiwire branch-circuits unless handle ties identified for the purpose are used. *NEC® 590.6(A)* requires ground-fault circuit-interrupter (GFCI) protection for all receptacles on 15-, 20-, or 30-ampere rated 125-volt circuits that are not part of the permanent wiring system. GFCI protection is also required for receptacles on circuits of the permanent wiring system that are used for temporary electrical power. This same section also permits listed GFCI cord sets to suffice as the required protection where permanent building circuits without such protection are used for construction purposes.

Table 8, in *Chapter 9,* is useful in that it provides a comparison of conductor sizes in AWG or kcmil and the equivalent area in square millimeters. The table also gives the cross-sectional area of the conductors using square in. This information is necessary when determining the minimum size of raceway when one or more of the conductors are bare. The table also gives the approximate resistance of copper and aluminum conductors. This information is useful especially when determining the voltage drop caused by conductors. Voltage drop will be covered later in the text. Resistance is affected by the temperature of the conductor. The temperature of a conductor will rise when current is flowing. *Table 8* resistances are based upon an operating temperature of 75°C. A formula is provided in the footnote to the table to adjust the resistance for another operating temperature.

Table 9 in *Chapter 9* provides information about the inductive reactance of conductors when supplying loads where the power factor is less than one. This information is used to determine the approximate voltage drop on conductors. When conductors are larger than size 1/0 AWG supplying ac loads with a power factor less than one, the inductive reactance of the conductor begins to have a significant effect on the voltage drop in addition to the resistance of the conductor. Even the type of raceway has an effect on the inductive reactance. The effect is greater in Rigid Steel Conduit as compared to Rigid Nonmetallic Conduit. A copper feeder conductor supplying an ac load with a power factor of 0.85 using size 500 kcmil conductors run in Rigid Steel Conduit will have as much voltage drop due to inductive reactance as due to resistance of the conductor. In this case, using the values from *Table 8* would give an inaccurate approximation of voltage drop. Generally, *Table 8* resistances are adequate for calculations of voltage drop for conductor sizes up to 1/0 AWG. It is recommended that impedance values from *Table 9* be used for voltage drop calculations for larger conductor sizes. There is a formula in the footnote of *Table 9* that can be used to determine the approximate impedance of conductors when supplying loads with a power factor other than 0.85. Some experience with using trigonometry is needed to apply that formula.

SIZING CONDUCTORS FOR A CIRCUIT

The size of conductors for a branch-circuit or a feeder depends upon the load to be served and the rating of overcurrent device chosen for the circuit. The rule for determining the minimum size overcurrent device permitted for a branch-circuit is found in *210.20(A)*. In the case of a feeder the minimum overcurrent device rating is determined according to *215.3*. In either case, the rule is the same. The overcurrent device shall have a rating not less than the noncontinuous load plus 1.25 times the continuous load. *NEC® 240.6(A)* lists the standard ratings of overcurrent devices. Choose an overcurrent device rating that is larger than the calculation of *210.20(A)* or *215.3*. The following example will illustrate the point:

Example 1.12 A feeder supplies 92 amperes of continuous load and 70 amperes of noncontinuous load. Determine the minimum rating of overcurrent device permitted for this feeder. The feeder consists of three Type THHN copper current-carrying conductors in raceway.

Answer: This is a feeder, so use the rule of *215.3*. Multiply the 92 amperes of continuous load by 1.25 and add to the noncontinuous load of 70 amperes to get 185 amperes.

$$\begin{aligned} 92\text{ A} \times 1.25 &= 115\text{ A} \\ 70\text{ A} \times 1.00 &= \underline{\;\;70\text{ A}} \\ &\;185\text{ A} \end{aligned}$$

The overcurrent device is required to have a rating not less than 185 amperes. From *240.6(A)*, the next higher standard rating is 200 amperes.

The next step is to determine the minimum size conductor for the feeder. *NEC® 240.4* requires the conductor be protected in accordance with the conductor ampacity as given in *310.15*. *NEC® 215.2(A)* specifies that for a feeder the minimum conductor size is not permitted to be smaller than the noncontinuous load plus 1.25 times the continuous load. This minimum size is determined without any consideration of adjustment or correction factors. Because the wiring method is conductors in raceway, *Table 310.16* will be used to determine conductor ampacity. The conductor insulation is 90°C rated, but it is necessary in this case to use the 75°C column of *Table 310.16*. The reason is that conductor termination temperature has not been specified for the circuit, in which case it is necessary to proceed according to the rules in *110.14(C)(1)(b)*. If the overcurrent device rating is greater than 100 amperes or the conductor is larger than size 1 AWG, the terminations are rated 75°C unless otherwise specified. The minimum size copper THHN conductor permitted for this feeder with a 200-ampere overcurrent device is 3/0 AWG. If this had been a branch-circuit rather than a feeder, the method of determining the minimum conductor size would have been the same, except the rule for branch-circuits is found in *210.19(A)*.

Table 310.16 gives the allowable ampacity of conductors when the conductors are run in raceway, in cable, or directly buried in the earth. If circuit conductors operate continuously carrying the listed allowable ampacity, the conductor insulation temperature rating given at the top of the column will not be exceeded. This holds true only if the temperature around the conductors does not exceed 86°F (30°C), and there are not more than three current-carrying conductors in the cable, raceway, or trench. If these limitations are exceeded, the values shown in *Table 310.16* must be adjusted. There are temperature correction factors at the bottom of *Table 310.16*. The following example will illustrate how the temperature correction factors are applied.

Example 1.13 A raceway containing copper conductors runs through an area of a building where the temperature is likely to reach 120°F (49°C) as shown in Figure 1.25. Determine the allowable ampacity of a size 3 AWG copper conductor with THWN insulation run through this area.

Answer: Look up the allowable ampacity of a size 3 AWG copper conductor in the 75°C column of *Table 310.16* and find 100 amperes. Now continue down that same column into the temperature correction section of the table. Fahrenheit temperatures are on the right-hand side, so continue down to

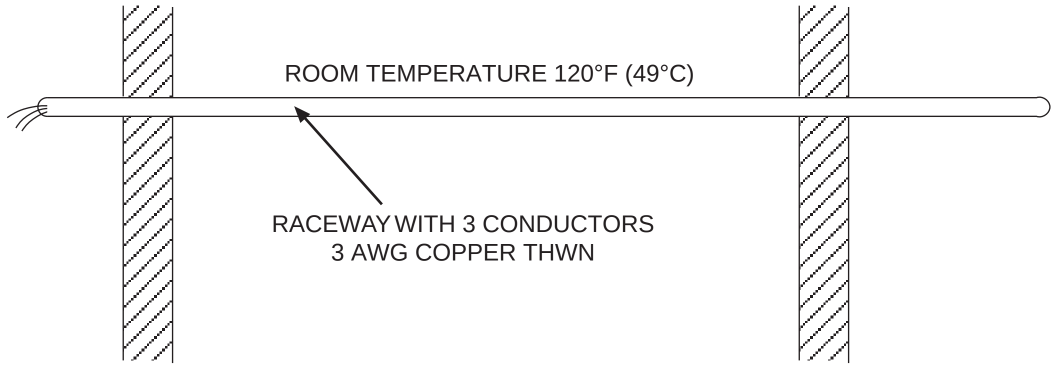


Figure 1.25 A raceway containing three size 3 AWG copper THWN conductors runs through a room with a typical temperature of 120°F.

the row that includes 120°F. Find the correction factor 0.75. Now multiply the 100 amperes by 0.75 to get 75 amperes, which is the allowable ampacity of a size 3 AWG copper THWN conductor under these conditions.

If there are more than three current-carrying conductors in the cable, raceway, or trench in earth, then the allowable ampacity given in *Table 310.16* must be adjusted. Each conductor produces some heat, therefore, the maximum insulation temperature is likely to be exceeded if the ampacity in the table is used without adjustment. *NEC® 310.15(B)(2)(a)* gives the rules for applying adjustment factors when there are more than three current-carrying conductors in a raceway or cable. This subject will be discussed in more detail in the next unit. The following example will illustrate how the adjustment factors are applied.

Example 1.14 A raceway contains nine size 8 AWG copper current-carrying conductors with THHN insulation, illustrated in Figure 1.26. Determine the allowable ampacity of these conductors in this raceway.

Answer: Look up the allowable ampacity of a size 8 AWG copper conductor in the 90°C column of *Table 310.16* and find 55 amperes. Look up the adjustment factor for nine current-carrying conductors in raceway from *Table 310.15(B)(2)(a)* and find 0.7. Now multiply 55 amperes by 0.7 to get 38.5 amperes, which is the allowable ampacity of a size 8 AWG copper THHN conductor under these conditions.

On occasion, a raceway or cable containing more than three current-carrying conductors runs through an area with a high ambient (surrounding) temperature. In this case, both a temperature correction factor and an adjustment factor for more than three current-carrying conductors must be applied to the allowable ampacity found in the table. The next example will illustrate the point.

Example 1.15 A raceway containing six size 10 AWG copper current-carrying conductors with THHN insulation passes through an area of a building where the temperature is expected to be 110°F for long periods of time. Determine the allowable ampacity of these conductors under these conditions.

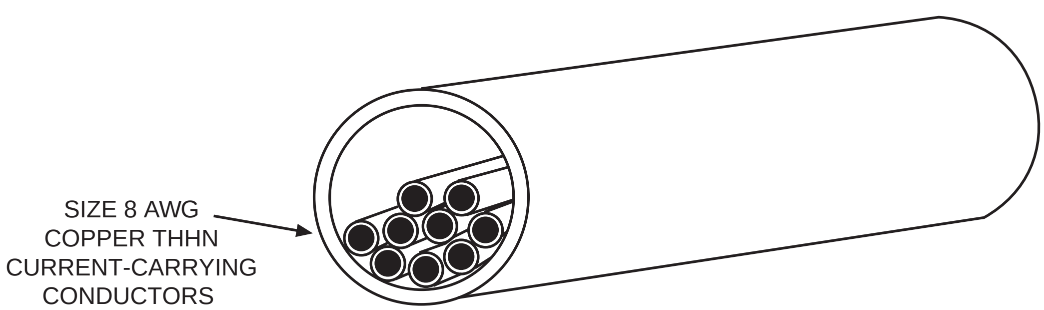


Figure 1.26 A raceway contains nine size 8 AWG copper THHN current-carrying conductors.

Answer: Look up the allowable ampacity of a size 10 AWG copper Type THHN conductor in the 90°C column of *Table 310.16* and find 40 amperes. Next, continue down the ampacity column to the temperature correction section of the table and find the correction factor for 110°F which is 0.87. Now look up the adjustment factor for six current-carrying conductors in *Table 310.15(B)(2)(a)* and find 0.8. Multiply 40 amperes from *Table 310.16* by 0.87 and 0.8 to get 27.8 amperes, which is the allowable ampacity of a size 10 AWG copper THHN conductor under these conditions.

Determining the allowable ampacity of a conductor is as simple as looking up the value in the appropriate table and applying adjustment or correction factors if necessary. Determining the minimum size conductor for a specific load and circuit involves the application of *240.4*. The conductor usually is required to be protected by a fuse or circuit breaker with a rating not higher than the allowable ampacity of the conductor. This subject will be discussed in more detail in the next unit when correction and adjustment factors are involved.

Example 1.16 A circuit supplies a continuous load of 38 amperes and is protected by a 50-ampere circuit breaker. All conductor terminations in the circuit are rated at 75°C. If the circuit conductors are THWN copper, determine the minimum size permitted for the circuit.

Answer: Look up a conductor in this case in the 75°C column of *Table 310.16* which has an allowable ampacity of not less than 50 amperes, which would be size 8 AWG.

The allowable ampacity of the conductor and the rating of the overcurrent device do not always match up exactly like the previous example. Consider a circuit supplying a continuous load of 50 amperes, which is required to be protected with an overcurrent device rated not less than 70 amperes. With the terminations rated at 75°C and copper THWN conductors, the allowable ampacity is found in the 75°C column of *Table 310.16*. According to *210.19(A)*, the minimum size conductor permitted for this circuit must have an allowable ampacity not less than 1.25 times the continuous load, which is 62.5 amperes (1.25×50 A = 62.5 A). The choices are size 6 AWG at 65 amperes and size 4 AWG at 85 amperes. One is a little too small for the overcurrent device, and the other is much too large. The size 6 AWG is permitted to be used in this case according to *240.4(B)*. If the overcurrent device protecting the circuit is rated not over 800 amperes, it is permitted to choose a conductor adequate to supply the load (62.5 amperes) and protect that conductor with the next higher standard rating of overcurrent device. The standard ratings of overcurrent devices are listed in *240.6(A)*. The allowable ampacity of the size 6 AWG copper THWN conductor does not match a standard rating of overcurrent device. It is then permitted to round up to the next standard rating, which in this case is 70 amperes. If this is a branch-circuit that supplies multiple receptacles for cord- and plug-connected loads, then the allowable ampacity of the conductor must be equal to or higher than the rating of the overcurrent device.

Example 1.17 A feeder conductor in a building supplies a 140-ampere load with aluminum Type THWN conductors in raceway. The feeder overcurrent device is only required to be rated 150 amperes. In this case, the installer decided to protect the feeder at 200 amperes. Determine the minimum size conductors permitted for the feeder.

Answer: *Table 310.16* is used because the wiring method is conductors in raceway. There is no mention of termination temperature, so the rule in *110.14(C)(1)(b)* will apply. The terminations will be 75°C rated because the overcurrent device is larger than 100 amperes. From the 75°C aluminum column of *Table 310.16*, find size 4/0 AWG rated 180 amperes and size 250 kcmil rated 205 amperes. Neither conductor corresponds to a standard rating of overcurrent device listed in *240.6(A)*. The size 4/0 AWG copper conductor has an allowable ampacity greater than the load, and the next higher rated overcurrent device is 200 amperes.

There is a rule in *240.4(D)* that restricts the size of conductor for some circuits. In the past, this rule was a footnote to some of the allowable ampacity tables. This rule sets the maximum rating of overcurrent device for a size 14 copper conductor at 15 amperes. For a size 12 copper conductor, the maximum overcurrent device rating is 20 amperes. And for size 10 copper, the maximum is 30 amperes. There are some exceptions to this rule, which will be discussed later in the text. The following example will illustrate the application of this rule:

Example 1.18 A circuit supplies 15 amperes of lighting load. The circuit is required by *210.20(A)* to be protected by a 20-ampere rated circuit breaker. Determine the minimum size copper THHN conductors permitted for this circuit if there are only two current-carrying conductors in raceway.

Answer: The termination temperature is not specified, therefore, the rule of *110.14(C)(1)(a)* will apply. The terminations will be assumed to be rated 60°C. The allowable ampacity will be found in the 60°C column of *Table 310.16.* This is a continuous load, therefore, the minimum conductor size, according to *210.19(A),* is required to be not less than 1.25 times the load, which is 18.8 amperes (15 A × 1.25 = 18.8 A). According to *Table 310.16,* a size 14 AWG copper conductor is rated 20 amperes. The rule in *240.4(D)* only permits a 15-ampere overcurrent device on a size 14 AWG copper conductor. In this case, a size 12 AWG copper conductor is the minimum permitted because the overcurrent device is rated 20 amperes.

USING THE CODE TO ANSWER QUESTIONS

The numerous people who write the Code attempt the difficult task of choosing words that prohibit unsafe installations while not excluding any of the numerous acceptable installation methods. They try to achieve this task with words that we can understand. The Code is constantly changing, however, because of the introduction of new materials and techniques and because unacceptable confusion and loopholes are discovered.

One point that has led to confusion and misunderstanding in the field is the phrase **approved for the purpose. Approved** is defined in the Code as meaning approved by the authority having jurisdiction (the inspector). In many cases, it simply means that a judgment call must be made based on the inspector's knowledge and background and local conditions. The Code has made an attempt to place more responsibility on the manufacturer to indicate the suitability of various products for a specific purpose. The Code now uses the phrase **listed for the purpose** rather than **approved for the purpose.** The following points will help in understanding the meaning of the Code.

1. Read each section carefully, and think about what the section is saying. Try not to let personal bias obscure the true meaning of the section.

2. Keep the purpose of the Code in mind as you read the Code, *90.1.* All sections of the Code are directed to this purpose.

3. Look for the word "shall" and how it is used in the section. For example, "shall not be permitted" is a prohibitive statement. "Shall be permitted" is a permissive statement. Another similar type of statement is "shall not be less than," which fixes a lower limit.

4. Fine print notes (FPNs) are scattered throughout the Code to either act as an advisory or clarify the previous Code material. These FPNs are not considered a legally binding part of the Code.

5. Be sure to read the **scope** at the beginning of each article. The specific sections apply only under the conditions specified in the scope.

6. Definitions are frequently provided in an article to add important clarity. Read these definitions, as they are often necessary to the understanding of a particular section. Most definitions are grouped in *Article 100* if they are used in two or more articles. If used only in a specific article, the definitions will be given only in that article. If a definition is not given in the Code, then it is permitted to use the definition from a dictionary.

7. Do not confuse **wiring specifications** with Code requirements. Just because in your experience you have seen only one particular wiring method for an application, do not automatically assume this is a Code requirement. It is the option of the owner, architect, or another code to specify a particular method or material providing it is not in conflict with the Code.

8. Footnotes to the tables are considered part of the table and are a binding part of the Code.

9. Local jurisdictions have the right to adopt amendments to the Code. Sometimes the electric utility will have a requirement not covered in the Code. The utility standards apply to the installation of service equipment.

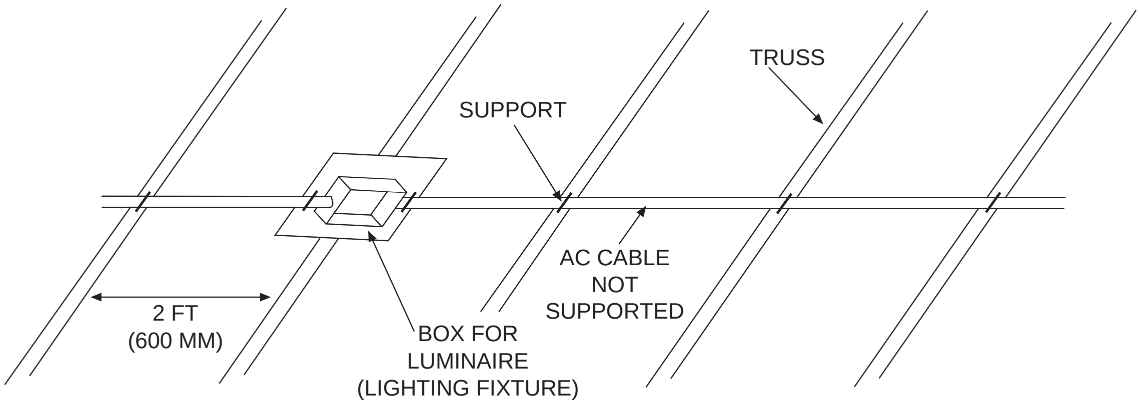


Figure 1.27 Type AC Armored Cable is run as exposed wiring on the under side of room trusses supported only by attachment to each truss.

10. It is important to remember the limitations placed on manufacturers' materials and equipment by the testing process and the physical behavior of materials and equipment in a particular environment. For example, Type THHN wire ampacity cannot be based on 90°C if the wire is connected to a circuit-breaker with a maximum temperature rating of 75°C. Some organizations providing testing services are Underwriters Laboratories (UL), Electrical Testing Laboratories (ETL), and Canadian Standards Association (CSA).

The following example question will help illustrate the technique of finding information in the Code. Look for key terms that state the subject of the question, then look them up in the Code index. After using the Code for a period of time, you will remember many of the article numbers.

Example 1.19 Type AC Armored Cable is to be installed as open exposed wiring to supply luminaires (lighting fixtures) in a building of truss construction with an open ceiling. The trusses are spaced 2 ft (600 mm) on centers with a luminaire (lighting fixture) attached to the bottom of every fourth truss. Is it permitted to run the Type AC Cable perpendicular to the trusses without any means of support between trusses as shown in Figure 1.27, or is it required to be attached to running boards?

Answer: The subject of this question is Type AC Armored Cable, open exposed wiring, and supports. If you know the article number, then it probably would be most efficient to go directly to that article. Otherwise, look up Armored Cable, Type AC, in the index. Look down the list of subtopics and exposed work is in *320.15*, and supports are covered in *320.30*. Type AC Cable is not a separate listing, although under cable, there is a listing for Armored Cable, Type AC. According to *320.15,* Armored Cable is permitted to be on the underside of each truss (joist) provided the support spacing is not exceeded and the cable is supported at each truss. In *320.30,* Armored Cable run in the manner described, is required to be supported within 12 in. (300 mm) of each box, and at intervals not to exceed $4\frac{1}{2}$ ft (1.4 m). If these requirements are also met, the Type AC Armored Cable is permitted to be run as shown in Figure 1.27.

STUDENT CODE PRACTICE

Answer the following wiring questions and give the Code reference where the answer is found. The answer will be found in the Code articles listed in the objectives at the beginning of this unit. Pick out the key words that describe the subject of each question and look them up in the Code index. When you are finished, check your skill by comparing with the key words and answers at the end.

1. A conductor with black insulation is permitted to be re-identified as a grounded conductor at the time of installation with a distinctive white marking that completely encircles the conductor at the conductor terminations for:
   A. any size conductor.
   B. sizes 6 AWG and larger.
   C. sizes 8 AWG and larger.
   D. sizes smaller than 6 AWG.
   E. sizes larger than 6 AWG.

   Key words ________________________________ Code reference ___________________

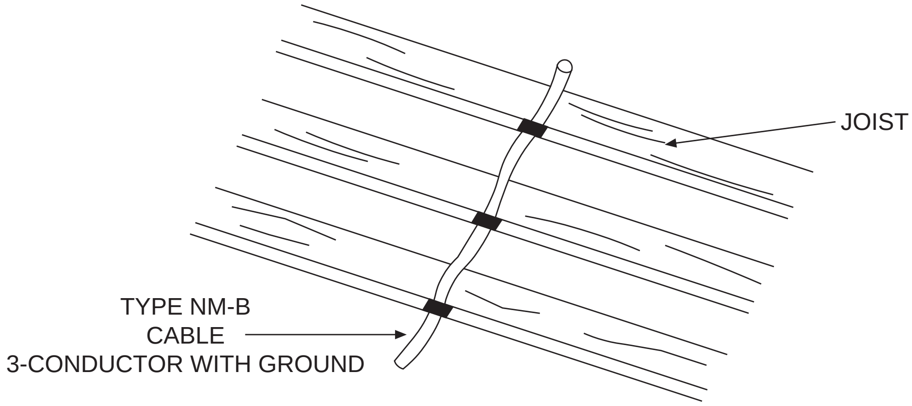


Figure 1.28 Type NM-B Nonmetallic-Sheathed Cable with three conductors and an equipment ground is run attached to the bottom of floor joists in an unfinished basement.

2. The maximum branch-circuit voltage permitted between conductors supplying luminaires (lighting fixtures) in a dwelling unit is:
   A. 120 volts.
   B. 208 volts.
   C. 240 volts.
   D. 277 volts.
   E. 480 volts.

   Key words ________________________ Code reference ________________________

3. The largest solid conductor generally permitted to be installed in raceway is size:
   A. 12 AWG.
   B. 10 AWG.
   C. 8 AWG.
   D. 6 AWG.
   E. 4 AWG.

   Key words ________________________ Code reference ________________________

4. The minimum size copper conductor permitted for a 120-volt general illumination branch-circuit in a dwelling is:
   A. not specified in the Code, but depends upon the load to be served.
   B. 18 AWG.
   C. 16 AWG.
   D. 14 AWG.
   E. 12 AWG.

   Key words ________________________ Code reference ________________________

5. A 3-conductor Nonmetallic-Sheathed Cable with ground run exposed at an angle to the joists of an unfinished basement and fastened to the lower edge of the joists, as shown in Figure 1.28, is permitted for sizes not smaller than:
   A. 14 AWG.
   B. 12 AWG.
   C. 10 AWG.
   D. 8 AWG.
   E. 6 AWG.

   Key words ________________________ Code reference ________________________

Answers to Code Practice: The first question is about grounded conductor identification. Look up grounded conductors, then identification. This can lead to the answer. Now look up conductors, grounded, then identification. This one leads to *200.6*, which gives the answer. Other ways to find the answer in the index are by looking under identification, grounded conductors, or conductor identification. The answer to the first question is **E** and the Code reference is *200.6(B)*.

The second question is about maximum branch-circuit voltages for dwellings. Start by looking up voltage, maximum. There is no reference for this subject, but there is a listing for branch-circuit limits, under voltage, which does lead to the answer. Another approach is to look up branch-circuits, voltage. This lists voltage limitations which leads to the answer **A** and the Code reference is *210.6(A)*.

The third question is about the largest solid conductor in raceway. If a conductor is not solid, it is stranded. One approach is to look up conductors, raceway, solid or stranded. There is an entry for stranded, which leads to the answer. Another approach is to look under raceway, conductors, solid or stranded, but this leads to a dead end. The answer is **B** and the Code reference is *310.3*.

Question four is about minimum size branch-circuit conductors in dwellings. Start by looking up conductors, minimum size, or conductors, branch-circuits, minimum size. The first reference leads to a reference that gives the answer. Another approach is to look under branch-circuits, conductors, minimum size. This gives a reference, but it is not the correct subject, so it is another dead end. The answer is **D** and the Code reference is *310.5* and *Table 310.5*.

Question five is about Nonmetallic-Sheathed Cable exposed in unfinished basements. Look under Nonmetallic-Sheathed Cable, exposed, basements. The reference is Nonmetallic-Sheathed Cable, exposed work, which leads to the answer. Another approach is to look up basements, Nonmetallic-Sheathed Cable, which will also lead to the answer. The answer is **D** and the Code reference is *334.15(C)*.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin. Any article covered in this unit, for which significant changes occurred, are included in the following discussion.

Article 100 **Definitions**

Branch-circuit overcurrent device is a new definition for fuses, circuit breakers, and other devices providing the same function to limit excessive current. The definition states that the range of overcurrent is from the rating of the device up to the maximum interrupting rating of the device. A device that opens the circuit at a level less than the device rating is not considered to be providing the function of a branch-circuit overcurrent device. The definition also states that the minimum permitted interrupting rating is 5000 amperes.

Clothes closet is now defined as a non-habitable room primarily for the storage of garments. This definition is important when providing outlets and lighting for walk-in closets in dwellings. Service equipment, for example, is not permitted to be installed in a clothes closet.

Electrical power production and distribution network refers generally to the utility portion of a connection to a premises power production system. There were references to such a network in the rules for photovoltaic systems, fuel cell system, and interconnected power production systems.

Ground was redefined to mean the earth. There is no longer a reference to some other conductive body in place of the earth. Ground in the Code simply means the earth.

Equipment grounding conductor was redefined to make the function clear. Two new fine print notes were added to make it clear that an equipment grounding conductor also performs the function of bonding, and that acceptable equipment grounding conductors are described in *250.118*.

Intersystem bonding termination is defined as a device that provides a means of connection of communications equipment bonding conductors.

Kitchen is now defined, and in previous editions of the Code it was necessary to imply the definition from the definition of dwelling. To be a kitchen, there must be a sink, and permanent provisions for food preparation and cooling. A small refrigerator, sink, and portable microwave on a counter are not considered permanent.

Neutral conductor is a term used in the Code, but until now was never defined. It is defined as a conductor that is intended to carry current and is connected to the neutral point of the electrical system.

Neutral point of an electrical system is now defined. It is essentially defined as a conductor that is common to two or more ungrounded conductors of the same system. It can be the common point of a 3-phase

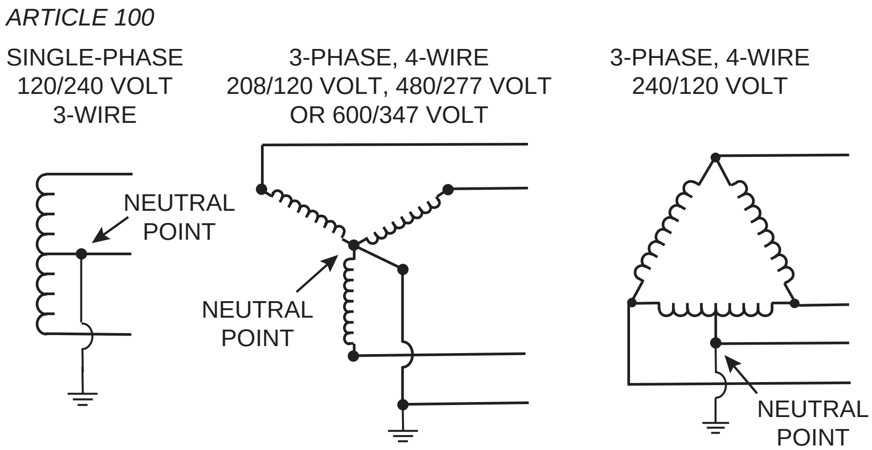


Figure 1.29 The neutral point of an electrical system is defined as the center point of a single-phase, 3-wire system; the common point of a 3-phase, 4-wire wye system; or the center point of one phase of a 3-phase, 4-wire delta system. The neutral is defined as the conductor that connects to the neutral point.

wye system, midpoint of a single-phase, 3-wire system, or the midpoint of the single-phase portion of a 3-phase, 4-wire delta electrical system as illustrated in Figure 1.29. It can also be the midpoint of a 3-wire direct current system. No reference is made to the neutral point being grounded in the definition; however, the systems described are required to be grounded. According to the definition, if a source has a single ungrounded wire and one grounded wire, the grounded wire is not considered to be a neutral. The definition also does not seem to include multi-wire 2-phase electrical systems as referenced in *220.61(A) Exception*. When an electrical supply is required to be grounded is provided in *250.20,* and which conductor is required to be grounded is stated in *250.26*.

Short circuit current rating is the expected fault current at nominal voltage that a device or equipment will sustain without suffering excessive damage.

Surge protective device (SPD) is defined as having the purpose of limiting transient voltages by diverting surge current. Four types are described with Type 1 suitable for connection on the line side of the service disconnecting means and Type 4 as being suitable only for installation within utilization equipment. This new definition is particularly useful when applying the rules of *Article 285*.

Ungrounded may seem obvious, but it is a new definition that makes it clear that the system or equipment is not connected to earth or to something conductive that is connected to earth.

Utility-interactive inverter is a device that is connected in parallel with a utility supply system to supply power to common loads. Those loads may be on the property, or they may be away from the property. This definition is important when applying *Article 690, Article 692,* and *Article 705* with respect to on-site power production systems.

Article 110 Requirements for Electrical Installations

110.20: A new *Table 110.20* was added that specifies enclosure types for switchboards, panelboards, industrial control panels, motor control center, meter sockets, and motor controllers. This was *Table 430.91* that only applied to motor control enclosures in the past and now applies to a wide range of electrical equipment enclosures. Manufacturers will be required to mark equipment with the enclosure type. There is a footnote to the table that explains some of the type letter designations. *Table 430.91* was deleted.

110.26: This section specifies the dimensions of the workspace about electrical panels and equipment. In the previous edition of the Code, the metric dimensions were rounded, such as 900 mm instead of the exact 914 mm. This rounding caused problems with enforcement, and now all metric dimensions are exact equivalents of the customary dimensions.

110.26(C): The words “egress from” were added to the title of this subsection and at several other locations. The section is not only concerned about access to electrical equipment, but also egress from the equipment in case of emergency. The addition of these words does not change the rule, except it does make the importance of the rules clear.

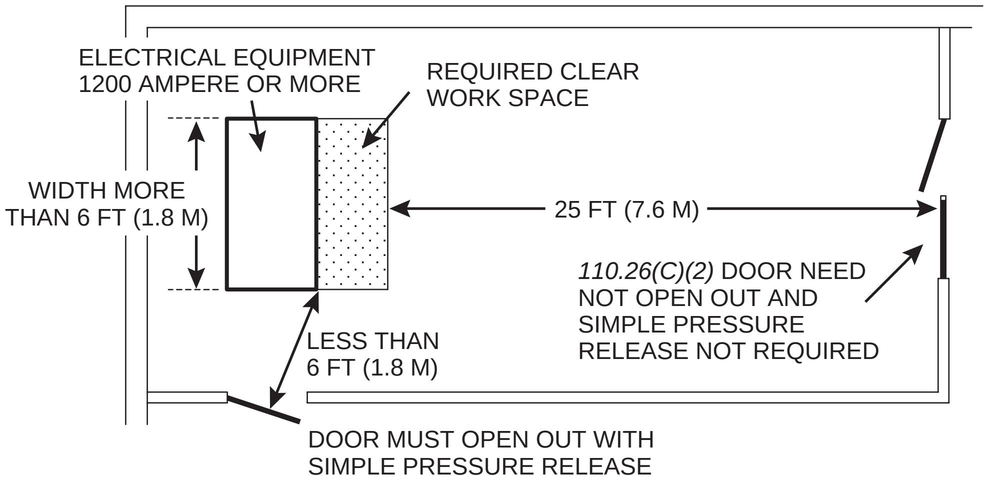


Figure 1.30 For an electrical equipment room with equipment rated 1200 amperes or more and more than 6 ft (1.8 m) wide, an exit door is not required to open out with a panic bar or simple pressure release if it is located more than 6 ft (1.8 m) from the edge of the work space.

110.26(C)(3): This subsection deals with the situation where two means of access and egress are required to a room or space containing large electrical equipment. There are two significant changes to this section. To be considered large electrical equipment, the rating must be 1200 amperes or more and also more than 6 ft (1.8 m) wide. This width requirement was taken out of the previous edition of the Code and now has been reinstated. The other change has to do with the direction the entrance/egress door opens. The previous edition of the Code required the door to open out of the work area where large electrical equipment was housed. Now the door must open out and be of the simple pressure plate type latch only if the door is not more than 25 ft (7.6 m) from the edge of the work space. These important changes are illustrated in Figure 1.30.

110.33(A): This paragraph specifies when an access door to electrical equipment operating at over 600 volts is required to open out of the space and be of the panic bar or simple pressure plate type latch. This requirement only applies when the door is located less than 25 ft (7.6 m) from the edge of the equipment work space.

110.34(A): This section specifies dimensions of the workspace around electrical equipment operating at over 600 volts. There are two significant changes. Some, but not all, of the metric dimensions are now exact equivalents of the customary dimension. The other change specifies that the workspace around equipment is required only when the equipment is likely to require examination, adjustment, servicing, or maintenance while energized.

Article 200 Use and Identification of Grounded Conductors

200.2(B): A grounded conductor such as a neutral is not permitted to have a portion of its path consist of a metal enclosure, raceway, or cable armor. There must be direct conductor to conductor contact through a listed terminal or splicing device. An example of where a metal enclosure would act as a part of the neutral path is where an equipment grounding terminal is added to a panelboard and a properly sized neutral wire is not run between the added terminal and the neutral terminal block as shown in Figure 1.31.

200.3 Exception: This is a new exception dealing with listed utility-interactive inverters used with on-site power generation systems such as photovoltaic systems and fuel cell systems. This section required that the power supply system connected to the premises wiring have a grounded conductor. That is the case since the utility supplies power as a 120/240 volt, 3-wire system with a grounded neutral conductor. The output of an inverter intended to be operated interactive with the utility system is frequently 240 volts, 2-wire ungrounded. It is common practice to connect this inverter line-to-line across the ungrounded conductors. This new exception permits that practice in a manner similar to the arrangement shown in Figure 1.32.

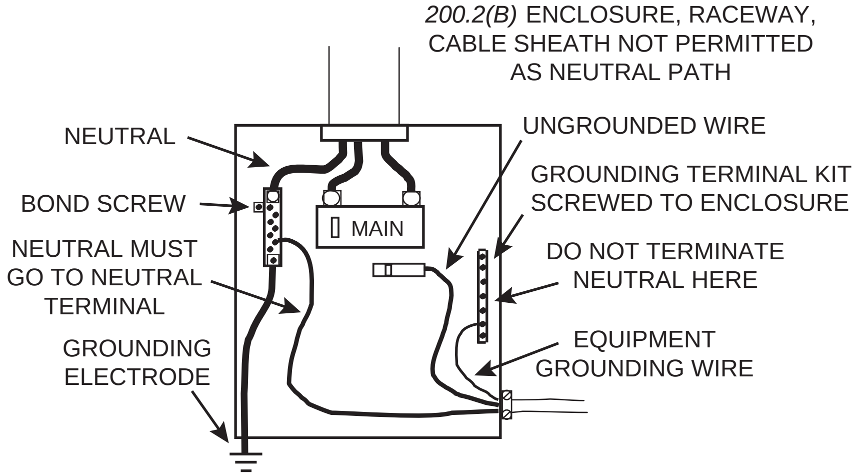


Figure 1.31 The grounded circuit conductor is not permitted to consist of a metal enclosure, metal raceway, or metal cable sheath for part of its circuit path as can be the case when a neutral conductor is terminated to an equipment grounding bus rather than the neutral bus in a panelboard.

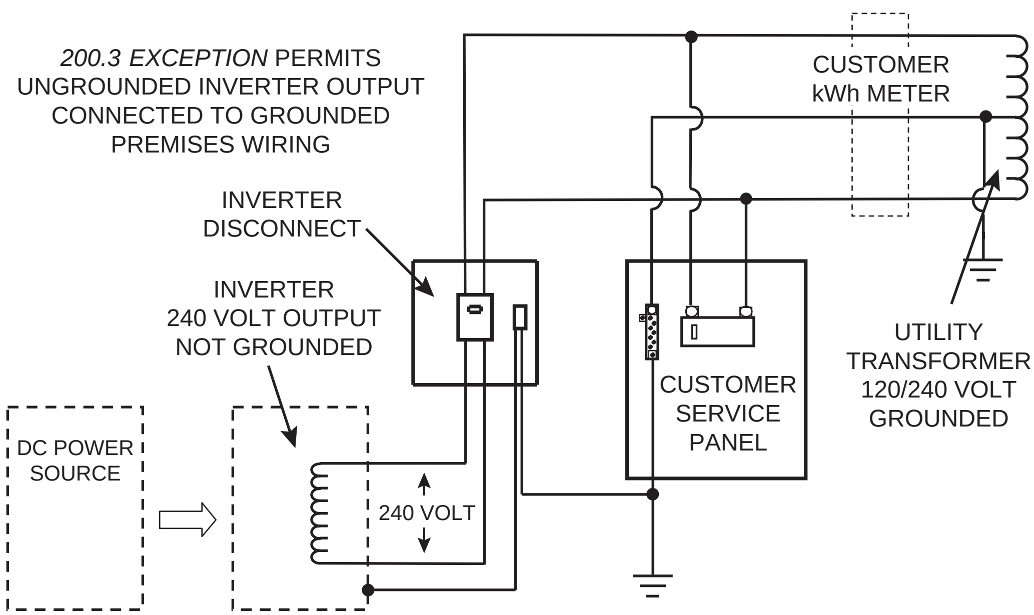


Figure 1.32 It is permitted to connect an ungrounded electrical source from a listed utility-interactive inverter to a grounded premises electrical utilization system.

Article 210 Branch Circuits (210.19(A)(1) and 210.20 only)

210.19(A)(1) Exception 2: The minimum ampere rating of an ungrounded conductor is required to be not less than any non-continuous load served plus 1.25 times any continuous load served. It is the overcurrent device protecting the ungrounded conductors that requires the continuous load to be multiplied by 1.25. In the typical case where there is no overcurrent device connected in series with a grounded conductor (neutral), this new exception permits both the non-continuous and continuous loads to be treated the same and it is not necessary to determine the minimum neutral ampere rating based upon 1.25 times the continuous load.

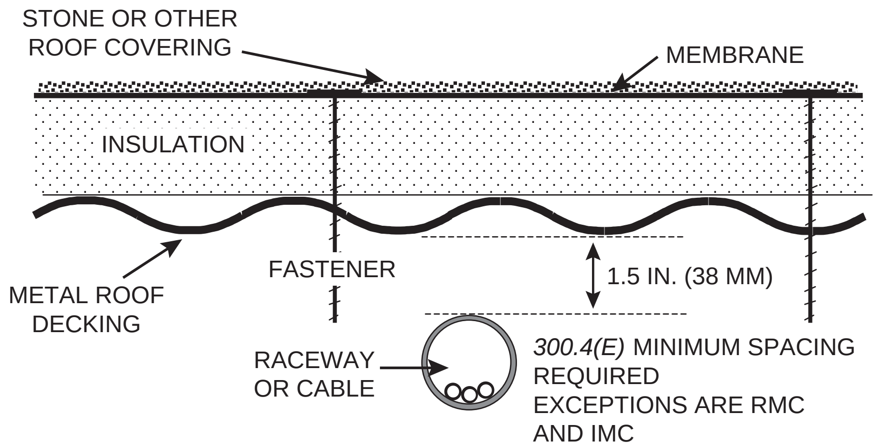


Figure 1.33 Cables and raceways installed beneath metal roof decking, except RMC and IMC, are required to be spaced a minimum of 1½ in. (38 mm) below the metal decking.

Article 300 Wiring Methods

300.4(E): This is a new paragraph that is concerned with protection of cables and raceways installed under roof decking. When new roofing is applied, the new materials above the existing decking are generally held in pace by fasteners that penetrate down through the metal decking. Most cables and many types of raceway will be damaged by the roof fasteners if the cable or raceway is installed close to the roof decking as can be seen in Figure 1.33. This new rule requires that cables and raceways, except rigid metal conduit and IMC, be installed not closer than 1½ in. (38 mm) from the metal decking.

300.9: When raceways are installed above ground in wet locations, the interior of the raceway is also considered to be a wet location, and the wires installed are required to be listed for use in wet locations. An example would be the use of THHW wire instead of THHN.

300.12 Exception 2: This is a new exception that permits conduits to extend up into open bottom equipment such as transformers and switchboards without being required to be secured to the frame of the equipment.

Article 310 Conductors for General Wiring

310.4: This section provides the rules for installing conductors in parallel. The entire section was rewritten and reorganized in an attempt to increase clarity. When conductors are run in parallel in separate raceways, an equipment grounding conductor is required to be run in each raceway, and each is to be sized in accordance with *Table 250.122*. That part is the same, but what is new is that now there are limitations on the installation of the parallel equipment grounding conductors similar to those of ungrounded conductors and grounded conductors. The parallel equipment grounding conductors are to be of the same length, the same material, the same cross-sectional area, and be terminated at both ends in the same manner.

310.13: The Code now recognizes the practice of installing equipment grounding conductors in listed multiconductor cables as more than one conductor (sectioned) within the outer jacket provided the total cross-sectional area of the equipment grounding conductor complies with *Table 250.122*.

Table 310.13(A): It now states in the title of the table that it applies in the case of up to 600 volts nominal. This was done to make room for high voltage cable insulation and covering specification tables which were in a *Table 310.61* through *Table 310.63*.

310.15(B)(2)(c): Conductors run horizontally above rooftops and exposed to sunlight experience a significant additional temperature above the ambient air temperature. This is a new paragraph that requires an additional temperature increment to be added to the typical air temperature for the purpose of adjusting the ampere rating of conductors. The conditions are illustrated in Figure 1.34. The temperature adjustments are provided in *Table 310.159B)(2)(c)*. The temperature adjustment is higher the

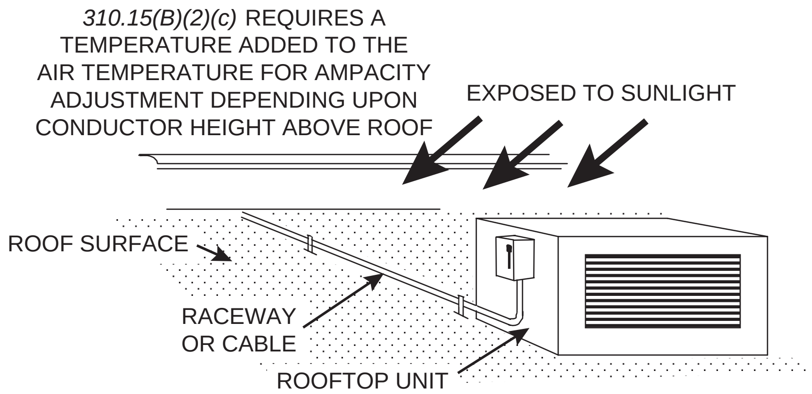


Figure 1.34 Cables and raceways run exposed to direct sunlight above rooftops experience additional heating above the air temperature, which is required to be added to the air temperature according to *Table 310.15(B)(2)(c)* for the purpose of adjusting conductor ampere rating.

closer the conductors are run to the rooftop. Example 1.19 will help to illustrate the method of determining the allowable ampere rating of conductors run horizontally across a rooftop and exposed to sunlight.

Example 1.19 Assume a size 10 copper THHN set of conductors are to be run to rooftop equipment in EMT that is mounted 3 in. (75 mm) above the roof surface. If the typical average summer temperature on a warm day is expected to be 95°F, determine the allowable ampere rating of the wires in these conditions.

Answer: From *Table 310.15(B)(2)(c)* find that it is required to add 40°F to the average ambient air temperature to determine the temperature adjustment. The wires in this EMT are considered to be in an ambient temperature of 135°F. From the correction factors at the bottom of *Table 310.16*, find 0.71. Next, look up the ampere rating of the conductor, and apply the adjustment factor to find an allowable ampere rating of 28.4 ampere (40A $\times$ 0.71 = 28.4A).

Article 328 Medium Voltage Cable: Type MV

328.10(3) Exception: Medium voltage cable, Type MV that has an outer metallic jacket and is dual listed as Type MC cable, is now permitted to be run in cable trays as an exposed cable. It is also permitted to be run as an exposed cable for messenger supported wiring if it has a dual listing as Type MC.

Article 330 Metal-Clad Cable: Type MC

330.104: Conductors in metal-clad Type MC cable are now permitted to be nickel or nickel-coated copper. These types of conductors are sometimes specified for fire-rated circuits.

Article 334 Nonmetallic-Sheathed Cable: Types NM, NMC, and NMS

334.12(A)(1) Exception: Type NM, NMC, and NMS cables are not permitted to be installed in multifamily dwellings where built of Type I or Type II construction. This exception permits their use in those buildings, provided the cables are run in raceways approved for the application.

334.15(C): Where there are cables containing two size 6 wires or three size 8 wires, the cable is permitted to be attached directly to the underside of the joists in the basement. The change is that this rule now also applies in the case of joists in a crawl space.

334.80: It has been reported that when several nonmetallic-sheathed cables pass through the same hole in wood framing where the hold has been closed with some material such as fire caulk, heat can build up at that passage due to current flow in the wires that can eventually result in damage to the wire insulation. This new rule requires the adjustment factors for more than three conductors in a raceway or

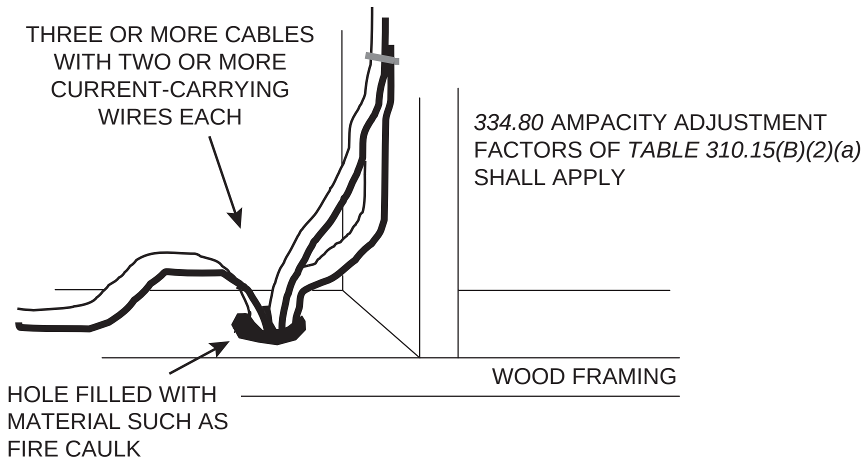


Figure 1.35 When three or more cables with two or more current-carrying wires are passed through a hold in wood framing where the hole is closed, such as the case when fire caulk is added, are required to have the total number of current-carrying wires counted for the purpose of adjusting the ampere rating of the cables according to *Table 310.15(B)(2)(a)*.

cable, *Table 310.15(B)(2)(a),* to apply when three or more cables pass through the same hole and the hole is closed as illustrated in Figure 1.35. Each of the cables must also have two or more current-carrying wires.

Assume, for example, that three 3-wire cables with size 14 AWG copper wire pass through the same hole in a wood framing member and the hole is closed with fire caulk. Consider the case of a multi-wire circuit where the neutral does not count. Consider too the case where 3-wire cable being used has two of the wires as switch loop travelers, in which case only one wire can carry current at any one time. Assume for the example that all of the insulated conductors are current carrying conductors, then the conductor count would be nine wires. From *Table 310.15(B)(2)(a),* the adjustment factor is 0.7. The second sentence of this same section states that for the purposes of derating the current from the 90°C column of *Table 310.16* is permitted. For the size 14 AWG copper wire, the current rating is 25 amperes. Multiply that value by 0.7 to get a current rating under these circumstances of 17.5 amperes. The overcurrent device on this circuit is only 15 amperes; therefore, there does not seem to be a problem. The problem most likely occurs when there are large numbers of cables passed through the same hole where the hole is closed.

There is still another paragraph that applies the same rule to three or more cables that are run without a maintained spacing (bundled for example) and in contact with thermal insulation. There is no definition as to what it means to be in contact with thermal insulation. The cables must have two or more wires rated as current-carrying conductors. In this case, the adjustment factors of *Table 310.15(B)(2)(a)* will apply.

Article 338 Service-Entrance Cable: Types SE and USE

338.10(B)(4)(a): The change involves the method of determining the ampere rating of Type SE cable when it is used as an interior wiring method. At the end of the sentence, the words "excluding *334.80*" were deleted. What this means is that for Type SE cable when used as an interior wiring method, the 60°C column of *Table 310.16* is required to be used to determine the ampere rating of the cable, even when it is marked 75°C on the outer jacket. In the past, it was permissable to use the 75°C column of *Table 310.16*.

338.12(A)(2): A new section on uses not permitted was created using rules that already existed elsewhere in the article. This is one new addition that clearly states that service entrance cable, Type SE, is not permitted to be installed underground either as direct burial or in raceway.

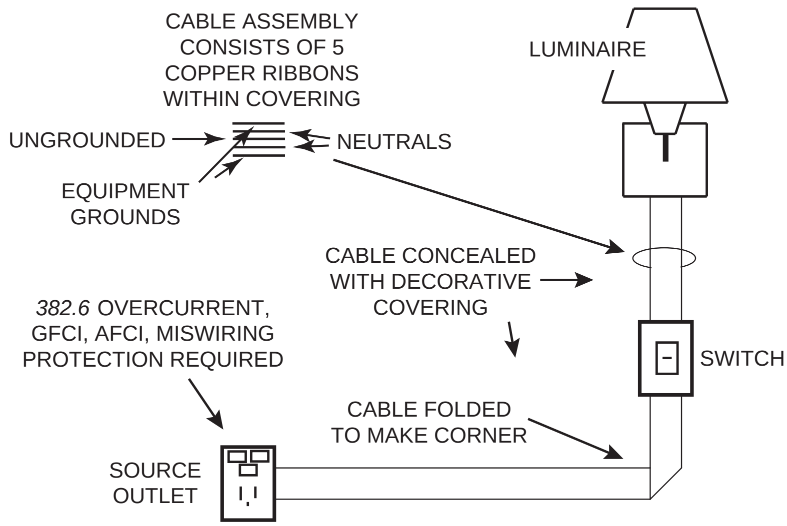


Figure 1.36 A nonmetallic extension from an existing outlet is permitted to consist of a listed flat ribbon type cable assembly that is permitted to be concealed with paint, wall paper, or other type of decorative wall or ceiling covering and terminated at listed outlets that provide for means of terminating the cable.

Article 382 Nonmetallic Extensions

382.2: A new definition of a concealable nonmetallic extension was added. It is a flat conductor cable so thin that it can be mounted directly on a wall or ceiling surface and covered with paint, wall paper, or some other decorative covering to make it practically invisible to the observer. The flat copper ribbon is encased in an insulating material and constructed in layers with an ungrounded conductor on the inside with a neutral conductor on both sides, and then an equipment grounding conductor on the outside of the neutral conductor, as illustrated in Figure 1.36. The entire assembly is encased in an extruded nonmetallic covering.

382.6: Concealable nonmetallic extensions are required to be listed and provided with supplementary overcurrent protection, GFCI protection, AFCI protection, and miswiring protection.

382.10(C): Concealable nonmetallic extensions are permitted only for dwellings and offices and, if identified for the purpose, are permitted to be installed more than three floors above grade.

382.26: Concealable nonmetallic extension cable is permitted to be folded back on itself, which is a means of making a square corner as illustrated in Figure 1.36.

382.42: Special devices are described that are self contained and provide a means of terminating the cable.

Article 590 Temporary Installations

590.6: This section requires ground-fault protection for installations used for temporary power to equipment during construction, remodeling, maintenance, and similar activities. The change is that a new sentence was added to make it clear that GFCI protection is required on circuits such as receptacle circuits, whether the power source is utility power or an on-site generator. It is not uncommon to find generators used for such purposes that do not provide GFCI protection.

WORKSHEET NO. 1—BEGINNING GENERAL WIRING AND FUNDAMENTALS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. The current drawn by a 250-watt incandescent lamp operating at 120 volts is:
   A. 0.40 amperes.
   B. 1.04 amperes.
   C. 1.56 amperes.
   D. 2.08 amperes.
   E. 3.00 amperes.

2. A copper conductor that is 150 meters in length has a resistance of 0.14 ohms. If the current flow through the conductor is 50 amperes, the voltage drop along the conductor is:
   A. 1.4 volts.
   B. 3.7 volts.
   C. 7 volts.
   D. 14 volts.
   E. 357 volts.

3. A 208/120-volt electrical panelboard is mounted on a concrete block wall and the panelboard faces metal equipment in the room that is mounted to the concrete floor as shown in Figure 1.37. The minimum distance from the front of the panelboard to the metal equipment is not permitted to be less than:
   A. 2 ft (610 mm).
   B. 3 ft (914 mm).
   C. 3.5 ft (1.07 m).
   D. 4 ft (1.22 m).
   E. 10 ft (3.05 m).

Code reference ___________________

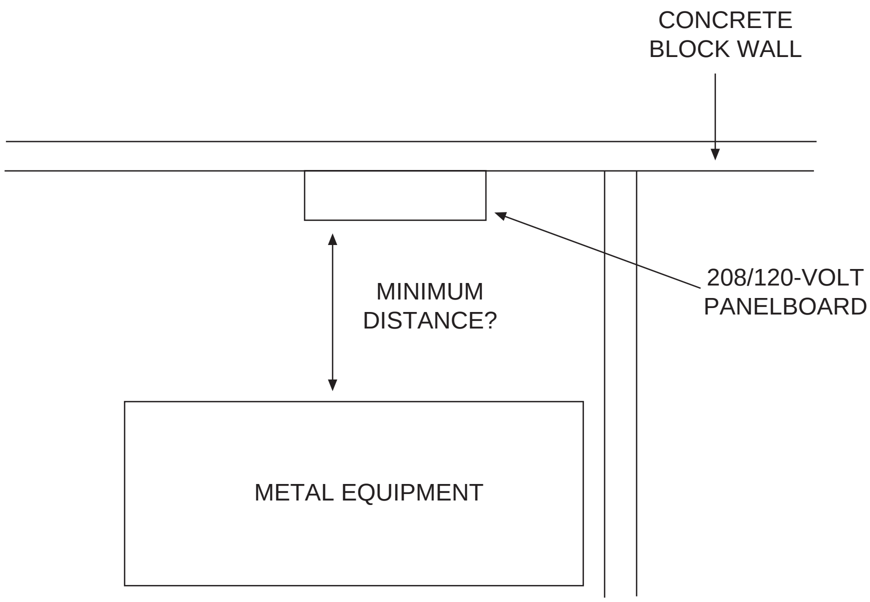


Figure 1.37 A 208/120-volt panelboard is mounted on a concrete block wall, and metal equipment is located in front of the panelboard.

4. A branch-circuit consists of three copper conductors with THHN insulation run in Electrical Metallic Tubing with no other conductors. The conductor terminations are rated for a maximum of 75°C. The ambient temperature in the area of this installation is not expected to exceed 30°C. If the conductors for this circuit are size 8 AWG, the maximum ampacity of the conductors permitted to be used to determine the minimum conductor size is:
   A. 40 amperes.
   B. 50 amperes.
   C. 55 amperes.
   D. 60 amperes.
   E. 65 amperes.

   Code reference ___________________

5. A 15-ampere, 120-volt branch-circuit consisting of Type UF Cable is supplied from the service panel in a dwelling, and the entire circuit is protected with a GFCI. The direct burial cable supplies a luminaire (lighting fixture) on a post in the yard, and is run under an unpaved drive used only for dwelling-related vehicles, shown in Figure 1.38. The cable is required to be buried to a minimum depth of:
   A. 1 ft (300 mm).
   B. 1.5 ft (450 mm).
   C. 2 ft (600 mm).
   D. 3 ft (900 mm).
   E. 4 ft (1.2 m).

   Code reference ___________________

6. Type MC Cable with three size 8 AWG copper conductors is run in a commercial building through metal studs in a wall. When terminating at a metal box, the cable is required to be supported a distance from the box of not more than:
   A. 1 ft (300 mm).
   B. 1.5 ft (450 mm).
   C. 3 ft (900 mm).
   D. 4.5 ft (1.4 m).
   E. 6 ft (1.8 m).

   Code reference ___________________

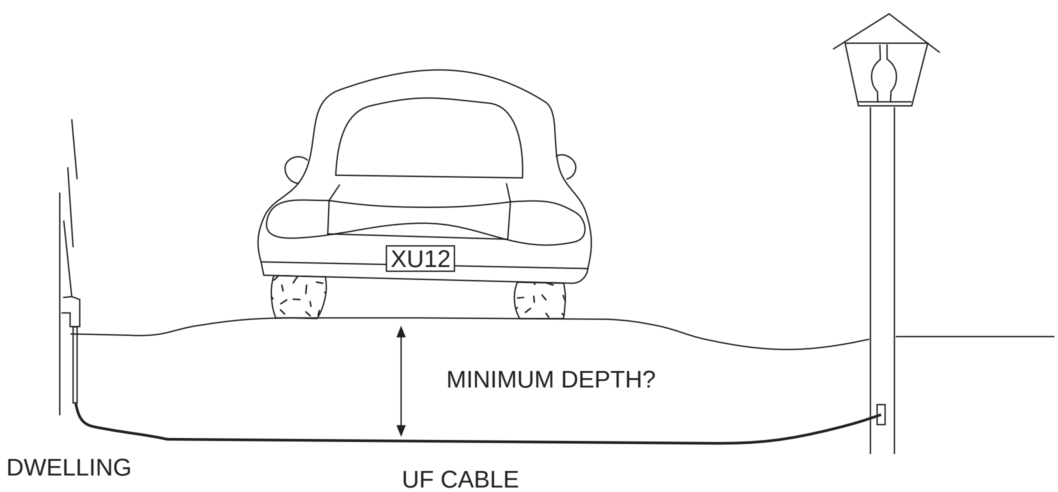


Figure 1.38 Determine the minimum depth of burial required for Type UF Cable under a dwelling drive with circuit rated 15 amperes and GFCI protected.

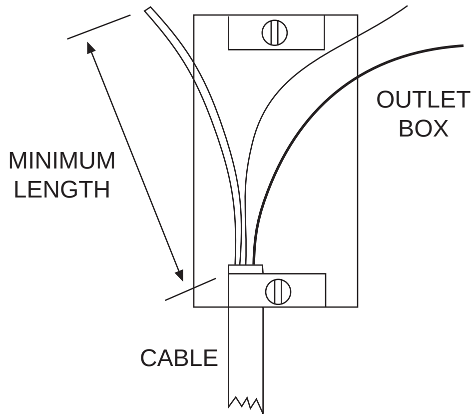


Figure 1.39 There is a minimum length of free conductor required at an outlet or junction box for making up splices and connections.

7. Type NM-B Cable enters a metal device box and is secured by a cable clamp at the bottom of the box. The cable is installed so the cable jacket extends 1/4 in. (6 mm) beyond the cable clamp and free conductors begin at the end of the cable jacket as shown in Figure 1.39. If the device box has a depth of 3.5 in. (90 mm), the minimum permitted length of free conductor in this box is required to be not less than:
   A. 3 in. (75 mm).
   B. 6 in. (150 mm).
   C. 6.5 in. (163 mm).
   D. 8 in. (200 mm).
   E. 12 in. (300 mm).

   Code reference ________________

8. Type NM-B Cable is used in a dwelling as a switch loop from a ceiling box at a lighting outlet to a single-pole switch on the wall. A 120-volt, black, insulated conductor and a white, insulated neutral conductor are run using Type NM-B Cable to the ceiling box as shown in Figure 1.40. The white, insulated conductor from the ceiling box to the switch box:
   A. is permitted to be either the 120-volt supply to the switch or the return to the light.
   B. is only permitted to be the return to the light.
   C. if marked to identify it as an ungrounded conductor, is permitted to be the return to the light.

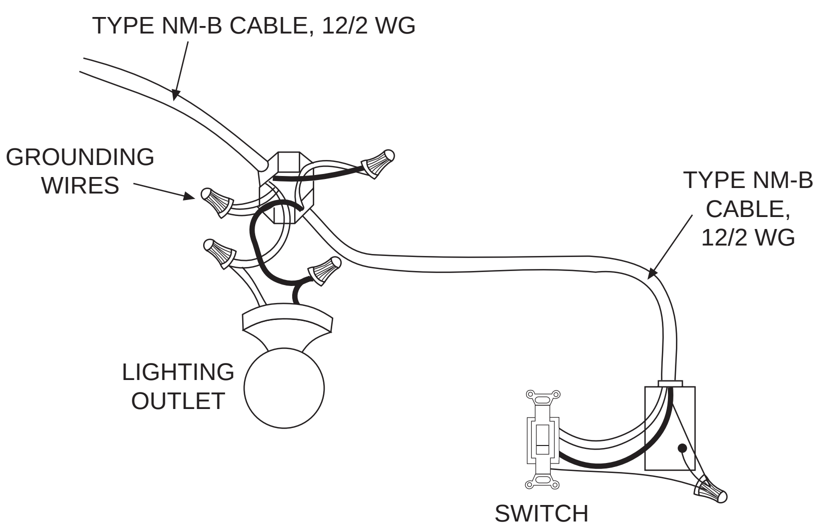


Figure 1.40 Nonmetallic-Sheathed Cable is used to wire a circuit containing a ceiling luminaire (lighting fixture) controlled by a single-pole wall switch.

D. is only permitted to be the return to the light and must be marked to identify it as an ungrounded conductor.
E. is only permitted to be the 120-volt feed to the switch and must be permanently marked to identify it as an ungrounded conductor.

Code reference ___________________

9. If a person wishes to submit a proposal to amend a section of the 2005 *NEC*®, which may become a part of the 2011 *NEC*®, the proposal must be received either by mail or fax at the NFPA office in Quincy, MA, not later than 5:00 PM EST on:
A. November 7, 2008.
B. October 26, 2009.
C. November 1, 2009.
D. May 15, 2010.
E. July 22, 2011.

Code reference ___________________

10. The cross-sectional area of a size 8 AWG solid copper conductor is:
A. 4110 cmil (2.08 mm^2).
B. 6530 cmil (3.31 mm^2).
C. 10,380 cmil (5.261 mm^2).
D. 16,510 cmil (8.367 mm^2).
E. 26,240 cmil (13.30 mm^2).

Code reference ___________________

11. A point on the wiring system at which current is taken to supply utilization equipment is called:
A. a tap.
B. a service point.
C. a circuit.
D. an appliance.
E. an outlet.

Code reference ___________________

12. In a dwelling, for the purpose of supplying cord- and plug-connected loads 1440 volt-amperes or less, or less than 0.25 horsepower, the nominal voltage between conductors supplying device terminals shall not exceed:
A. 120 volts.
B. 208 volts.
C. 240 volts.
D. 277 volts.
E. 480 volts.

Code reference ___________________

13. Type NM-B Nonmetallic-Sheathed Cable is required to be secured by staples, cable ties, straps, or similar fittings at intervals along the cable, shown in Figure 1.41, not exceeding:
A. 3 ft (900 mm).
B. 4 ft (1.2 m).
C. 4.5 ft (1.4 m).
D. 6 ft (1.8 m).
E. 8 ft (2.5 m).

Code reference ___________________

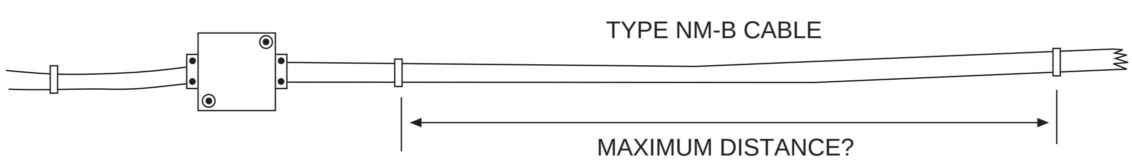


Figure 1.41 Determine the maximum support spacing for Nonmetallic-Sheathed Cable run along the surface of a building.

14. The ampacity of a size 8 AWG copper Type UF Cable installed within a building with 90°C insulation on the conductors and not in conditions requiring ampacity adjustment is:
    A. 35 amperes.
    B. 40 amperes.
    C. 45 amperes.
    D. 50 amperes.
    E. 55 amperes.

Code reference ___________________

15. Type AC Armored Cable entering a box is required to be fastened in place by an approved means within a distance of the box of not more than:
    A. 6 ft (1.8 m).
    B. 24 in. (600 mm).
    C. 18 in. (450 mm).
    D. 12 in. (300 mm).
    E. 8 in. (200 mm).

Code reference ___________________

WORKSHEET NO. 1—ADVANCED GENERAL WIRING AND FUNDAMENTALS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A 3-phase, 480-volt electric motor drawing 21 amperes with a power factor of 0.58 will be drawing power of approximately:
   A. 5260 watts. C. 7308 watts. E. 11,190 watts.
   B. 5846 watts. D. 10,114 watts.

2. Three resistors are connected in parallel, as shown in Figure 1.42, and they have resistances of 6 ohms, 9 ohms, and 18 ohms. The total resistance of the circuit is:
   A. 2 ohms. C. 4 ohms. E. 33 ohms.
   B. 3 ohms. D. 11 ohms.

3. The terminal for a size 1/0 AWG copper conductor without any markings to indicate the temperature rating of the terminal is assumed to have a minimum terminal temperature rating of:
   A. 30°C. C. 60°C. E. 90°C.
   B. 40°C. D. 75°C.

   Code reference ___________________

4. An aluminum overhead triplex feeder conductor supplies a building with a calculated load of 135 amperes and the feeder is protected at the supply end with a 150-ampere circuit breaker. If the conductor insulation has a rating of 75°C, the smallest conductor permitted for this feeder is size:
   A. 1 AWG. C. 2/0 AWG. E. 4/0 AWG.
   B. 1/0 AWG. D. 3/0 AWG.

   Code reference ________________________

5. A 20-ampere rated branch-circuit supplies fluorescent luminaires (lighting fixtures) with a total load of 14.2 amperes. All terminations are 75°C rated, there are only three current-carrying conductors in EMT, and the conductor insulation is THHW as shown in Figure 1.43. The minimum size copper conductor permitted for this branch-circuit is:
   A. 16 AWG. C. 12 AWG. E. 8 AWG.
   B. 14 AWG. D. 10 AWG.

   Code reference ___________________

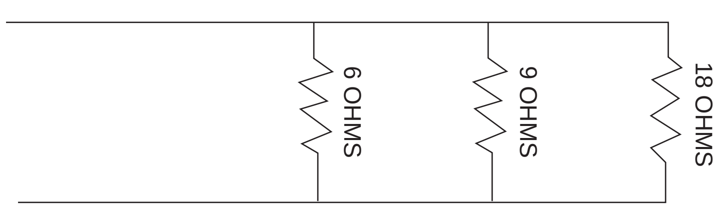


Figure 1.42 Three resistors are arranged in parallel with values of 6 ohms, 9 ohms, and 18 ohms.

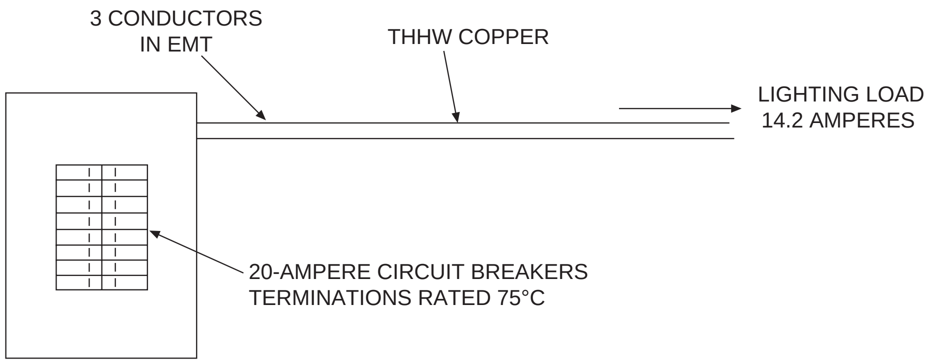


Figure 1.43 Three Type THHW copper conductors are run in Electrical Metallic Tubing to supply a lighting load of 14.2 amperes on a 20-ampere rated branch-circuit with all terminations rated 75°C.

6. Receptacles rated 120 volts and 15- or 20-amperes installed on construction sites for the purpose of supplying power for portable equipment are not permitted to be:
   A. of the grounding type.
   B. GFCI protected.
   C. supplied with Type NM-B Cable if the building is more than three floors in height.
   D. supplied with Type NM-B Nonmetallic-Sheathed Cable for other than dwellings.
   E. installed on branch-circuits that also supply temporary lighting.

   Code reference ___________________

7. An electrical panel is installed on a wall in a room of a commercial building where the distance from the floor to the structural ceiling is 15 ft (4.5 m). The distance from the floor to the top of the panelboard is 6 ft (1.8 m). An air-handling duct that will not cause dripping due to condensation is:
   A. not permitted to be installed above the panelboard.
   B. permitted to be installed above the panelboard.
   C. permitted to be installed not less than 3 ft (900 m) above the panelboard.
   D. permitted to be installed not less than 4 ft (1.2 m) above the panelboard.
   E. permitted to be installed not less than 6 ft (1.8 m) above the panelboard.

   Code reference ___________________

8. Type FCC Flat Conductor Cable is to be installed on the surface of a concrete floor and covered with carpet squares to supply general-purpose branch-circuits for work stations in a large room. The maximum rating permitted for the branch-circuits is:
   A. not specified in the Code.
   B. 15 amperes.
   C. 20 amperes.
   D. 30 amperes.
   E. 40 amperes.

   Code reference ___________________

9. Type MI Mineral-Insulated Cable with three size 8 AWG copper conductors is installed as concealed wiring inside a building in a dry location. The end seal fittings for the cable and terminals have a 90°C rating. The maximum permitted allowable ampacity of the cable is:
   A. 40 amperes.
   B. 35 amperes.
   C. 30 amperes.
   D. 50 amperes.
   E. 55 amperes.

   Code reference ___________________

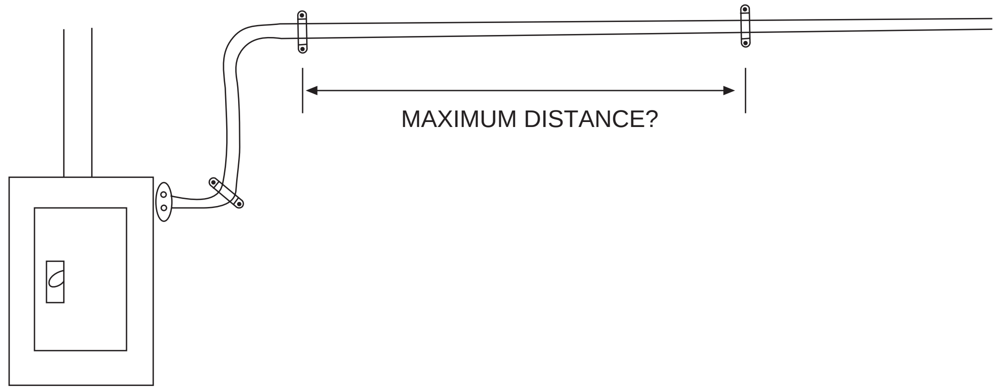


Figure 1.44 Type SE style R Service-Entrance Cable is run along the flat surface of the interior of a building as a feeder to another location in the same building.

10. Type SE-R Service-Entrance Cable with three insulated conductors and a bare equipment grounding conductor contained within the outer nonmetallic sheath is used as a feeder to provide power from the service panel to a panelboard located in another part of the building as shown in Figure 1.44. The cable run inside the building along the flat surface of structural materials is required to be supported at intervals not to exceed:
    A. 6 ft (1.8 m).
    B. $4^1/2$ ft (1.4 m).
    C. 3 ft (900 mm).
    D. 24 in. (600 mm).
    E. 12 in. (300 mm).

    Code reference ___________________

11. In an industrial building with a staff of maintenance electricians, Type TC-ER Power and Control Tray Cable with the same crush and impact requirements as Type MC Cable is permitted to be installed as open wiring between a cable tray and a machine and where not subject to physical damage, provided the maximum distance between supports does not exceed:
    A. 50 ft (15 m).
    B. 25 ft (7.5 m).
    C. 20 ft (6 m).
    D. 15 ft (4.5 m).
    E. 6 ft (1.8 m).

    Code reference ___________________

12. The *National Electrical Code*® does not apply to wiring installations in:
    A. underground mines.
    B. floating buildings.
    C. carnivals.
    D. recreational vehicles.
    E. public buildings.

    Code reference ___________________

13. Type UF Cable is installed as surface wiring in a building where damp conditions are likely to exist. The cable is used with nonmetallic boxes and fittings that prevent the entrance of moisture. The cable is required to be supported at intervals not to exceed:
    A. 10 ft (3 m).
    B. 6 ft (1.8 m).
    C. $4^1/2$ ft (1.4 m).
    D. 3 ft (900 mm).
    E. 24 in. (600 mm).

    Code reference ___________________

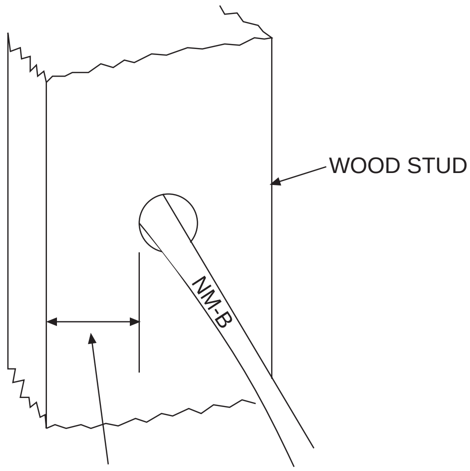


Figure 1.45 Type NM-B Nonmetallic-Sheathed Cable is run through bored holes in wood studs.

14. Nonmetallic-Sheathed Cable, Type NM-B, run through bored holes in wood studs in a dwelling, are only permitted to be installed without a metal plate or bushing protecting the cable from penetration by screws or nails if the distance from the edge of the hole, shown in Figure 1.45, to the nearest edge of the stud is not less than:
    A. 3/4 in. (19 mm).
    B. 7/8 in. (22 mm).
    C. 1 in. (25 mm).
    D. 1 1/4 in. (32 mm).
    E. 2 in. (50 mm).

    Code reference ___________________

15. A dwelling is wired with Type NM-B Nonmetallic-Sheathed Cable. In the case of a lighting outlet controlled from two locations, a switch loop from the lighting outlet runs to the first 3-way switch with a cable with two insulated conductors and an equipment ground, and between the 3-way switches with cable containing three insulated conductors and an equipment ground. The ungrounded conductor that originates at the lighting outlet runs to the common terminal of the second 3-way switch as shown in Figure 1.46. For this particular installation, the traveler conductors connecting the 3-way switches are required to be the red conductor and:
    A. either the white conductor with a permanent marking at each end or the black conductor.
    B. only the white conductor with a permanent marking at each end.
    C. only the black conductor with a red marking at each end.
    D. only the black conductor with a white marking at each end.
    E. only the black conductor.

    Code reference ________________________

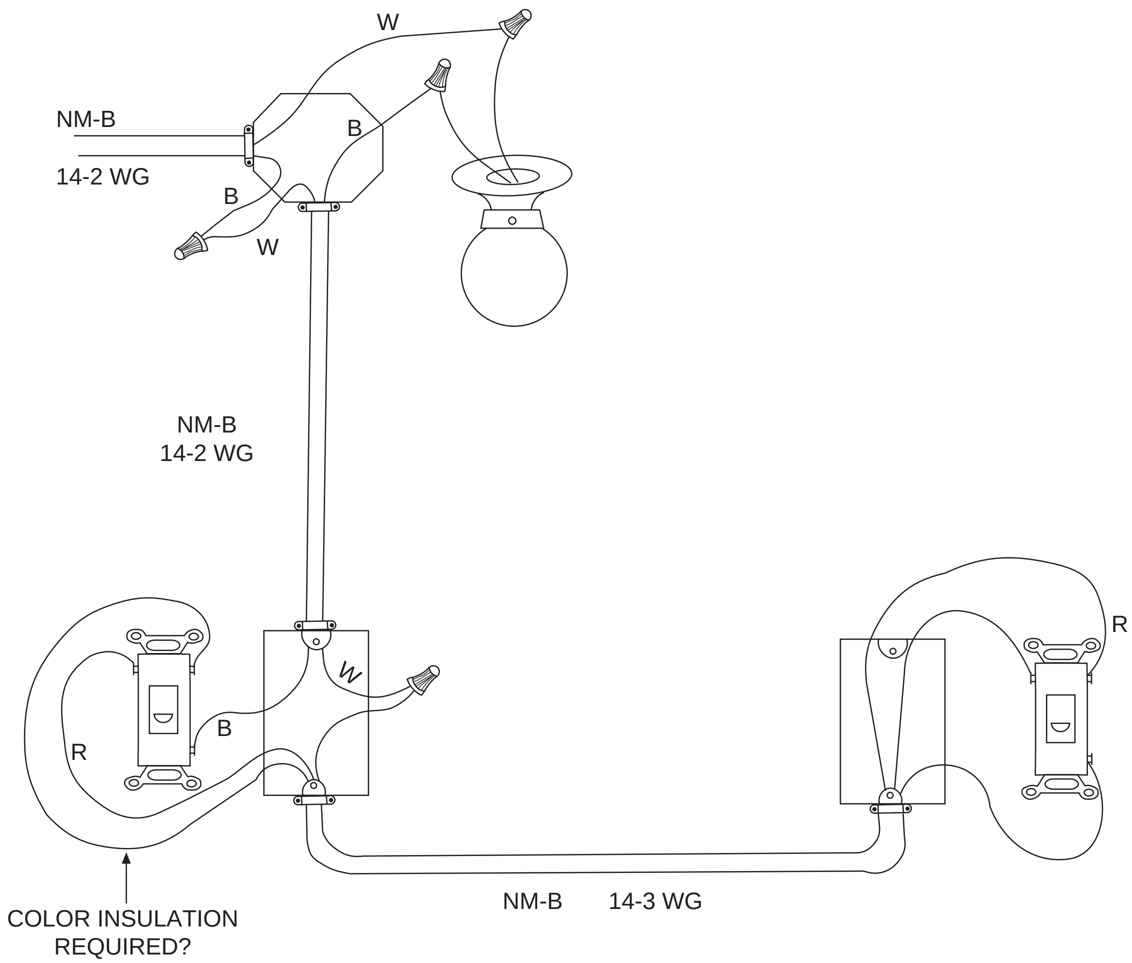


Figure 1.46 **Two 3-way switches are used to control a luminaire (lighting fixture) using Type NM-B Nonmetallic-Sheathed Cable. Note the colors of conductors connected to the switches and luminaire (lighting fixture).**

UNIT 2

Wire, Raceway, and Box Sizing

OBJECTIVES

After completion of this unit, the student should be able to:

- determine the size of a conductor for a circuit considering ambient temperature and more than three conductors in the raceway, cord, or cable.
- determine the minimum size conduit permitted when the conductors are all the same size and type of insulation.
- determine the minimum size conduit permitted when the conductors are different sizes and different types of insulation.
- determine the minimum size wireway and conduit nipples permitted for conductors.
- determine the minimum size junction box or device box permitted to take conductor fill into consideration.
- determine the minimum dimensions for pull boxes for straight pulls and angle pulls permitted.
- determine the minimum dimensions permitted for conduit bodies for various applications.
- answer wiring installation questions relating to *Articles 312, 314, 342, 344, 348, 350, 352, 353, 354, 355, 356, 358, 360, 362, 366, 376, 378, 386, 388, Chapter 9 Tables 1, 2, 4, 5,* and *5A,* and *Annex C.*
- state at least five significant changes that occurred from the 2005 to the 2008 Code for *Articles 312, 314, 342, 344, 348, 350, 352, 353, 354, 355, 356, 358, 360, 362, 366, 376, 378, 386, 388,* or *Chapter 9 Tables 1, 2, 4, 5,* and *5A,* or *Annex C.*

CODE DISCUSSION

The emphasis of this unit is to determine the minimum size of conductors for specific circuit and feeder applications if the actual or calculated load current is known. The ampacity tables in *Article 310* were discussed in *Unit 1*. Emphasis of this unit is on determination of the size and the installation of conductors, raceway systems, and boxes. A brief discussion of some key points made in the article dealing with raceways, cabinets, and boxes follows, with example calculations later in this unit.

Article 312 is on cabinets and cutout boxes used to enclose electrical equipment. Wire bending space and space requirements for wires in gutters within the enclosures are covered in *312.6*. When a wire or wires leave a lug or terminal and leave the enclosure through the wall opposite the lug, the distance from the lug to that enclosure wall is determined from *Table 312.6(B)*. When the conductors leave an enclosure wall adjacent to the lug, the distance from the lug or terminal to the opposite wall is found in *Table 312.6(A)*. These wire bending space requirements are illustrated in Figure 2.1.

Article 314 applies to outlet devices and junction boxes, pull boxes, and conduit bodies. It also covers requirements for handhole enclosures. Fittings permitted to contain splices or devices as permitted elsewhere in the code are required to meet the requirements of this article. Boxes, conduit bodies, and handhole enclosures shall be installed such that, after installation, they are accessible without removing any part of the building, or excavating, according to *314.29*. Boxes are permitted to be installed behind easily removable panels such as ceiling tiles in suspended ceilings where the ceiling tiles are easily removed.

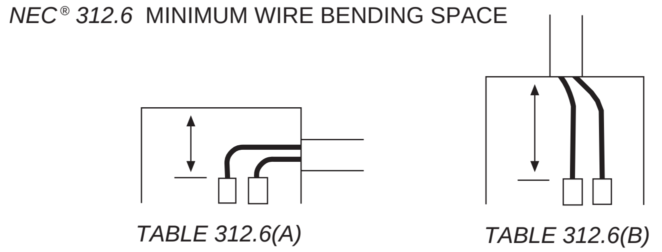


Figure 2.1 Minimum wire bending space is required from a lug or terminal to the opposite wall of the enclosure.

Minimum requirements for volume for the wires, devices, and fittings are given in *314.16*. In the case of standard device boxes, the maximum number of wires permitted in a box is given in *Table 314.16(A)*. The issue is that there is adequate physical space to prevent damage to conductors, prevent unnecessary pressure on splices and terminations, and prevent excessive heat produced within the box from current flowing in the wires and devices. If different sizes of wire enter a box or if a standard box is not used, then the minimum permitted volume of the box is determined using *Table 314.16(B)*. When wire sizes 4 AWG and larger are contained in a box, the minimum size permitted is determined on the basis of physical length and width of the box, according to the rules of *314.28*. Now the box is known as a pull box.

The rules for supporting boxes are given in *314.23*. Cable or raceway is required to be secured to metal boxes according to *314.17(B)*. Nonmetallic-Sheathed Cable and Type UF Cable are permitted to enter a single-gang nonmetallic box with dimensions not exceeding 2¹/₄ in. by 4 in. (57 mm by 100 mm) without being secured to the box, according to the *Exception* to *314.17(C)*. The cable is required to be fastened at a distance along the cable of not more than 8 in. (200 mm) from the box, and the cable sheath is required to extend into the box opening a distance of not less than $1/4$ in. (6 mm), as shown in Figure 2.2. This only applies for single-gang boxes in walls and ceilings.

Article 342 is on Intermediate Metal Conduit (IMC). It is a metal raceway that is permitted to be threaded. It is permitted to be used in essentially the same applications as Rigid Metal Conduit. This type of conduit has a smaller wall thickness than Rigid Metal Conduit. Intermediate Metal Conduit is available in trade sizes $1/2$ through 4 (16 through 103). It shall be supported within 3 ft (900 mm) of a box, fitting, or cabinet, and at intervals not more than 10 ft (3 m) unless threaded couplings are used. The 3 ft (900 mm) spacing requirement for supports at IMC terminations is permitted to be increased to not more than 5 ft (1.5 m) when building structural supports do not permit supporting the IMC within 3 ft (900 mm) of the termination according to *342.30(A)*. When threaded couplings are used, straight runs of IMC are permitted to be supported with the same maximum intervals as Rigid Metal Conduit, which are given in *Table 344.30(B)(2)*. Exposed vertical risers with threaded couplings are permitted to be supported at intervals not to exceed 20 ft (6 m), provided no other means of support is available for industrial machinery and fixed equipment.

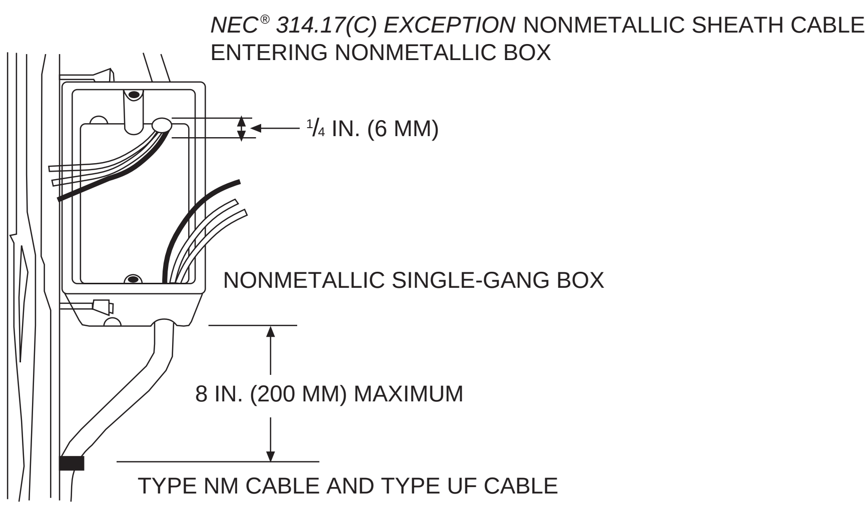


Figure 2.2 Nonmetallic-Sheathed Cable and Type UF Cable are not required to be secured to a single-gang nonmetallic box if it is secured within 8 in. (200 mm) of the box and extends into the box at least $1/4$ in. (6 mm).

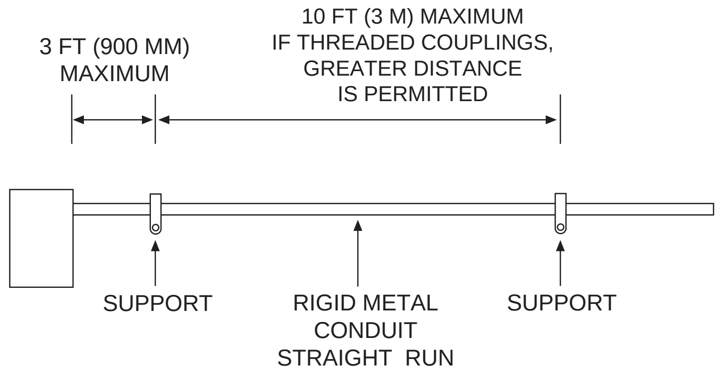


Figure 2.3 Maximum support spacing for Rigid Metal Conduit is 10 ft (3 m) unless threaded couplings are used; then maximum spacing is found in *Table 344.30(B)(2)*.

Article 344 covers Rigid Metal Conduit (RMC) that has thicker walls than other types of metal conduit and tubing, and it is permitted to be threaded. Galvanized Rigid Steel Conduit is generally used where high mechanical strength is needed, and rigid aluminum conduit is often used where weight is required to be minimized. Rigid Metal Conduit is available in trade sizes from 1/2 through 6 (16 through 155). There is a minimum radius of bend permitted for all field bends. The minimum bend radius depends on the trade diameter (metric designator) of the conduit as given in *Table 2, Chapter 9*. There is a minimum radius of bend for one-shot and full shoe benders, and another minimum radius required if other methods of bending are used such as a hickey style bender. The minimum radius is measured to the centerline of the conduit.

Rigid Metal Conduit shall be supported within 3 ft (900 mm) of a box, fitting, or cabinet, and at intervals not to exceed 10 ft (3 m). For straight runs of RMC with threaded couplings, the maximum support spacing is permitted to be increased to the distances given in *Table 344.30(B)(2)*. This is illustrated in Figure 2.3. The 3 ft (900 mm) spacing requirement for supports at conduit terminations is permitted to be increased to not more than 5 ft (1.5 m) when building structural supports do not permit supporting the conduit at a lesser distance, according to *344.30(A)*. Exposed vertical risers with threaded couplings are permitted to be supported at intervals not to exceed 20 ft (6 m) if no means of intermediate support is available for connection to industrial machinery and fixed equipment.

Article 348 is on Flexible Metal Conduit (FMC). It is of a spiral metal construction to provide flexibility and mechanical strength. This type of raceway is permitted for use in dry locations, and it is popular for use where flexibility is needed to connect raceway wiring systems to luminaires (lighting fixtures) and equipment. The minimum trade diameter generally permitted to be used is trade size 1/2 (16); however, there are several applications given in *348.20(A)* where trade size 3/8 (12) is permitted.

Flexible Metal Conduit shall be supported within 12 in. (300 mm) of a box, fitting, or enclosure with some exceptions. Where limited flexibility is necessary, as shown in Figure 2.4, lengths up to 3 ft. (900 mm) are permitted to be supported only at the end connectors. Flexible Metal Conduit taps to luminaires (lighting fixtures) are permitted in lengths up to 6 ft (1.8 m), supported only at the terminals. An equipment grounding conductor is generally required to be installed because the Flexible Metal Conduit is usually not considered to be an acceptable equipment grounding conductor. The only condition is that, where the fittings are listed for grounding, circuit conductors within the listed Flexible Metal Conduit, not more than 6 ft (1.8 m) in length, are protected from overcurrent at not more than 20 amperes as provided in *250.118*.

Article 350 and *Article 356* describe Liquidtight Flexible Metal Conduit (LFMC) and Liquidtight Flexible Nonmetallic Conduit (LFNC) as having a nonmetallic liquidtight outer covering. Liquidtight Flexible Metal Conduit is available in trade sizes up to 4 (103). Both Liquidtight Flexible Metal Conduit and Liquidtight Flexible Nonmetallic Conduit are permitted for use for exposed and concealed wiring when the conditions of installation, operation, or maintenance require flexibility or require protection from liquids, vapors, or solid materials. Liquidtight Flexible Nonmetallic Conduit shall be listed and marked for the purpose when installed outdoors or for direct burial. Liquidtight Flexible Nonmetallic Conduit Type LFNC-B is permitted to be installed in lengths greater than 6 ft (1.8 m).

Liquidtight Flexible Conduit installed as a fixed wiring system is required to be supported at a distance of not more than 12 in. (300mm) from a box, fitting, or enclosure. Liquidtight Flexible Metal Conduit

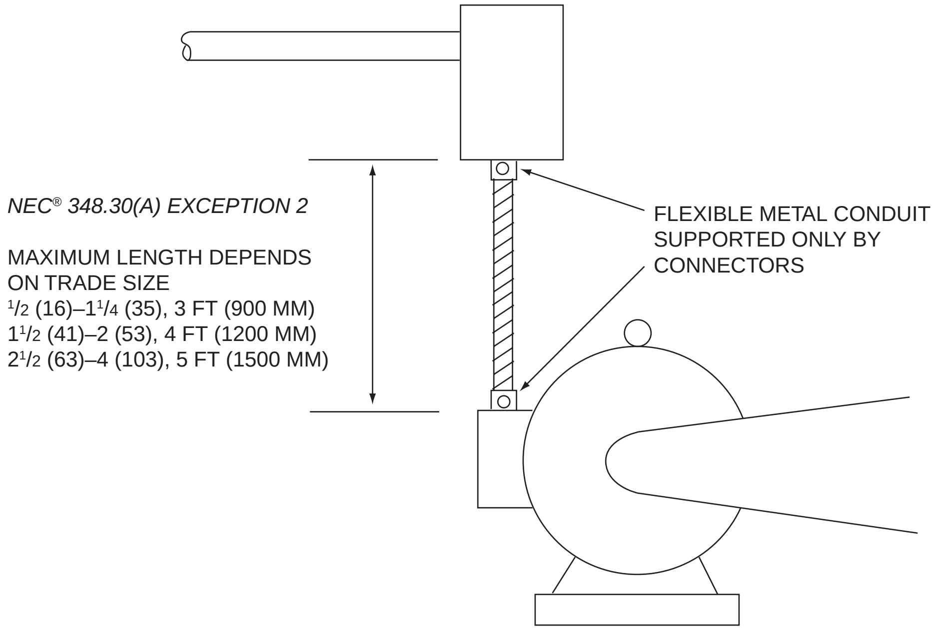


Figure 2.4 Flexible Metal Conduit is permitted to be supported only at the ends for limited lengths when flexibility is necessary.

(LFMC) as a fixed wiring system is permitted to be supported at intervals not to exceed 4 1/2 ft. (1.4 m). Liquidtight Flexible Nonmetallic Conduits, Type LFNC-A and Type LFNC-C, are not permitted to be installed in lengths greater than 6 ft (1.8 m), and are permitted to be supported only by the connectors. Liquidtight Flexible Nonmetallic Conduit, Type LFNC-B is permitted to be installed in lengths greater than 6 ft (1.8 m) as a fixed wiring system with a maximum support spacing of 3 ft (900 mm). Type LFNC-B is only permitted to be installed as a flexible connection to equipment supported only by the connectors in lengths not greater than 3 ft (900 mm). It is permitted to be installed in lengths up to 6 ft (1.8 m) supported only by the connectors to luminaires (lighting fixtures) or to other equipment in accessible ceilings.

An equipment grounding conductor is required to be installed through the Liquidtight Flexible Nonmetallic Conduit if the equipment or circuit supplied is required to be grounded. In the case of Liquidtight Flexible Metal Conduit, it is not permitted to be used as an equipment grounding conductor unless both the conduit and the fittings are listed for equipment grounding, and the length does not exceed 6 ft (1.8 m). If these requirements are met, then trade sizes of 3/8 and 1/2 (12 and 16), are not required to have a supplemental equipment grounding conductor, provided the circuit conductors are protected from overcurrent at not more than 20 amperes. Trade sizes of 3/4 through 1 1/4 (21 through 35) are not required to have an equipment grounding conductor if the circuit overcurrent protection is not more than 60 amperes. Where necessary because flexibility is required, an equipment grounding conductor must be installed. These rules are found in *250.118*.

Article 352 concerns Rigid Nonmetallic Conduit (RNC), which is resistant to corrosion from moisture and most chemicals and made of polyvinyl chloride and designated PVC. PVC is available as Schedule 40, which is the standard wall thickness, and as Schedule 80, which has a thicker wall and thus will generally withstand greater impact before damage will occur. PVC is available in trade sizes 1/2 through 6 (16 through 155). Standard lengths are 10 ft (3.048 m), although it is available as a continuous length from reels. The conduit is not threaded. It is joined to fittings by brushing an adhesive solvent on the conduit and then placing the conduit into the fitting. If done properly, this will form a watertight seal at the fitting. The conduit is bent by applying heat to the area to be bent until the conduit softens. Then the conduit is placed in a form to make the desired bend and allowed to cool and harden. Factory-made bends are available.

Rigid Nonmetallic Conduit of the PVC type changes length when it is exposed to changes in temperature. If an installation will be subject to a large temperature variation during normal use, then it may be necessary to install expansion fittings to allow for the thermal expansion and contraction. It is important to remember thermal expansion and contraction when installing Rigid Nonmetallic Conduit, especially when installing conduit supports. If PVC is installed in a location where it will experience a change in temperature, supports must be of a type that will allow the PVC to move as expansion and contraction occur. *Table 352.44* gives the change in length of PVC when exposed to different temperature changes. The expansion rate for

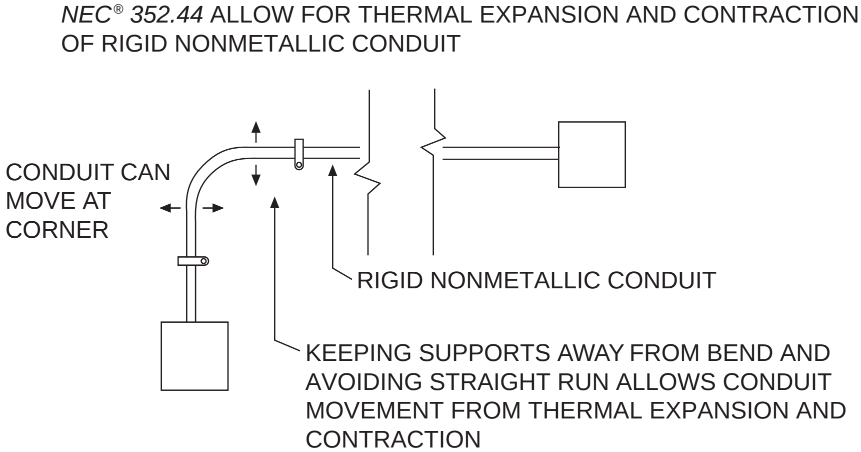


Figure 2.5 Install PVC Rigid Nonmetallic Conduit so it can move due to thermal expansion and contraction if it will be exposed to a large temperature variation.

PVC Rigid Nonmetallic Conduit in *Table 352.44(A)* is 0.04056 in./100 ft °F or 0.06084 mm/m °C. The temperatures in *Tables 352.44* are temperature differences. One column is in degrees Celsius and the other is in degrees Fahrenheit. If the temperature difference is known in Fahrenheit degrees, multiply by 5 and divide by 9 to convert to Celsius degrees. A temperature difference of 45°F is equal to 25°C (45°F × 5 / 9 = 25°C). If the temperature difference is known in Celsius degrees, multiply by 9 and divide by 5 to get Fahrenheit degrees. A temperature difference of 75°C is equal to 135°F (75°C × 9 / 5 = 135°F).

If Rigid Nonmetallic Conduit supports are installed in the correct locations, the conduit can move when the temperature changes without damage. If possible, avoid confining the conduit so expansion and contraction will occur without applying stress to boxes, fittings, cabinets, and supports, as shown in Figure 2.5. If a straight run of Rigid Nonmetallic Conduit is installed so it cannot expand and contract with a change in temperature, then an expansion fitting is required if the length due to temperature change will be more than $^1/_4$ in. (6 mm) according to *352.44*. A 120 ft (36.58 m) long straight section of PVC type Rigid Nonmetallic Conduit will change in length 4.87 in. (124 mm) if the temperature change is 100°F (55.6°C). Look up the expansion factor of 4.06 in. per 100 ft (3.38 mm/m) for PVC in *Table 352.44(A)*. Then multiply the expansion factor by hundreds of feet (120/100 = 1.2 hundreds) to get 4.87 in. (124 mm) of length change. Table 2.1 gives the change in length of PVC Rigid Nonmetallic Conduit for both customary and metric units. Verify the numbers in the previous example by looking up the values in Table 2.1 on the next page.

A disadvantage of using PVC Rigid Nonmetallic Conduit is that it tends to sag between supports; therefore, supports are required to be closer together than for comparable sizes of metal conduit and tubing. The maximum permitted support spacing for different trade diameters is given in *Table 352.30(B)*. The maximum support spacing permitted for PVC Rigid Nonmetallic Conduit is shown in Figure 2.6. For trade

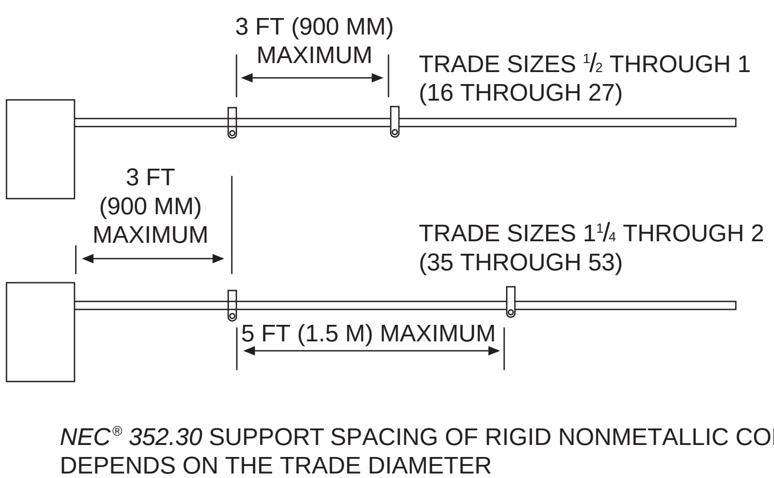


Figure 2.6 Support spacing for PVC Rigid Nonmetallic Conduit depends on the trade diameter of the conduit.

Table 2.1 Change in length of PVC Rigid Nonmetallic Conduit with change in temperature.

Temperature change °C	Length change (mm/m)	Temperature change °F	Length change (in./100ft)	Temperature change °C	Length change (mm/m)	Temperature change °F	Length change (in./100ft)
2.8	0.17	5.0	0.20	47.2	2.87	85.0	3.45
5.0	0.30	9.0	0.37	48.0	2.92	86.4	3.50
5.6	0.34	10.0	0.41	49.0	2.98	88.2	3.58
6.0	0.37	10.8	0.44	50.0	3.04	90.0	3.65
7.0	0.43	12.6	0.51	51.0	3.10	91.8	3.72
8.0	0.49	14.4	0.58	52.0	3.16	93.6	3.80
8.3	0.51	15.0	0.61	52.8	3.21	95.0	3.85
9.0	0.55	16.2	0.66	53.0	3.22	95.4	3.87
10.0	0.61	18.0	0.73	54.0	3.29	97.2	3.94
11.0	0.67	19.8	0.80	55.0	3.35	99.0	4.02
11.1	0.68	20.0	0.81	55.6	3.38	100.0	4.06
12.0	0.73	21.6	0.88	56.0	3.41	100.8	4.09
13.0	0.79	23.4	0.95	57.0	3.47	102.6	4.16
13.9	0.85	25.0	1.01	58.0	3.53	104.4	4.23
14.0	0.85	25.2	1.02	58.3	3.55	105.0	4.26
15.0	0.91	27.0	1.10	59.0	3.59	106.2	4.31
16.0	0.97	28.8	1.17	60.0	3.65	108.0	4.38
16.7	1.01	30.0	1.22	61.0	3.71	109.8	4.45
17.0	1.03	30.6	1.24	61.1	3.72	110.0	4.46
18.0	1.10	32.4	1.31	62.0	3.77	111.6	4.53
19.0	1.16	34.2	1.39	63.0	3.83	113.4	4.60
19.4	1.18	35.0	1.42	63.9	3.89	115.0	4.66
20.0	1.22	36.0	1.46	64.0	3.89	115.2	4.67
21.0	1.28	37.8	1.53	65.0	3.95	117.0	4.75
22.0	1.34	39.6	1.61	66.0	4.02	118.8	4.82
22.2	1.35	40.0	1.62	66.7	4.06	120.0	4.87
23.0	1.40	41.4	1.68	67.0	4.08	120.6	4.89
24.0	1.46	43.2	1.75	68.0	4.14	122.4	4.96
25.0	1.52	45.0	1.83	69.0	4.20	124.2	5.04
26.0	1.58	46.8	1.90	69.4	4.22	125.0	5.07
27.0	1.64	48.6	1.97	70.0	4.26	126.0	5.11
27.8	1.69	50.0	2.03	71.0	4.32	127.8	5.18
28.0	1.70	50.4	2.04	72.0	4.38	129.6	5.26
29.0	1.76	52.2	2.12	72.2	4.39	130.0	5.27
30.0	1.83	54.0	2.19	73.0	4.44	131.4	5.33
30.6	1.86	55.0	2.23	74.0	4.50	133.2	5.40
31.0	1.89	55.8	2.26	75.0	4.56	135.0	5.48
32.0	1.95	57.6	2.34	76.0	4.62	136.8	5.55
33.0	2.01	59.4	2.41	77.0	4.68	138.6	5.62
33.3	2.03	60.0	2.43	77.8	4.73	140.0	5.68
34.0	2.07	61.2	2.48	78.0	4.75	140.4	5.69
35.0	2.13	63.0	2.56	79.0	4.81	142.2	5.77
36.0	2.19	64.8	2.63	80.0	4.87	144.0	5.84
36.1	2.20	65.0	2.64	80.6	4.90	145.0	5.88
37.0	2.25	66.6	2.70	81.0	4.93	145.8	5.91
38.0	2.31	68.4	2.77	82.0	4.99	147.6	5.99
38.9	2.37	70.0	2.84	83.0	5.05	149.4	6.06
39.0	2.37	70.2	2.85	83.3	5.07	150.0	6.08
40.0	2.43	72.0	2.92	84.0	5.11	151.2	6.13
41.0	2.49	73.8	2.99	85.0	5.17	153.0	6.21
41.7	2.54	75.0	3.04	86.0	5.23	154.8	6.28
42.0	2.56	75.6	3.07	86.1	5.24	155.0	6.29
43.0	2.62	77.4	3.14	87.0	5.29	156.6	6.35
44.0	2.68	79.2	3.21	88.0	5.35	158.4	6.42
44.4	2.70	80.0	3.24	88.9	5.41	160.0	6.49
45.0	2.74	81.0	3.29	89.0	5.41	160.2	6.50
46.0	2.80	82.8	3.36	90.0	5.48	162.0	6.57
47.0	2.86	84.6	3.43	91.0	5.54	163.8	6.64

sizes 1/2 through 1 (16 through 27), the maximum permitted spacing is 3 ft (900 mm). PVC Rigid Nonmetallic Conduit of all trade diameters shall be supported within 3 ft (900 mm) of a box, fitting, or cabinet.

Several types of Rigid Nonmetallic Conduit are intended only for underground installations. Type A is a thin-walled Rigid Nonmetallic Conduit that must be installed underground embedded in concrete. Type EB is also a thin-walled Rigid Nonmetallic Conduit that has a stiffer wall thickness than Type A. It too must be installed underground encased in concrete. Type HDPE schedule 40 Rigid Nonmetallic Conduit is permitted to be installed without concrete encasement, but only for underground direct burial applications. Rules for installing High Density Polyethylene Conduit, Type HDPF, are given in *Article 353.* It is also important to note the designation markings on reinforced thermosetting resin conduit Type RTRC. If it is marked underground, it is only permitted to be installed underground.

Article 354 describes the construction, use, and installation of a preassembled cable in nonmetallic underground conduit. This is a smooth outer surface nonmetallic conduit, which comes in continuous lengths usually on reels. The cable or conductors are already installed in the conduit. It is permitted to be used only for underground installations, except for terminating in a building, and above ground when encased in concrete. This type is designated NUCC. The purpose of this product is the ease of installation of underground circuits to minimize the possibility of damage to the conductors during installation. This product is available in trade sizes from 1/2 to 4 (16 through 103). The same fill requirements apply as for other Rigid Nonmetallic Conduit installations. It is permissible to remove the conductors at a later time and replace them with new conductors.

Article 355 provides construction, use, and installation specifications for Reinforced Thermosetting Resin Conduit, Type RTRC, which is a type of Rigid Nonmetallic Conduit. The rules on installation are nearly the same as for PVC type Rigid Nonmetallic Conduit. This product is stiffer than PVC and is not as brittle as PVC at low temperatures. The support spacing, as given in the Code, is the same as for PVC; however, it is permitted to be listed for greater support spacing. A significant advantage of RTRC over PVC is that the thermal expansion and contraction of RTRC are less than half the expansion and contraction rate of PVC. In locations where the conduit will be exposed to extreme changes of temperature during normal use and room for expansion and contraction is limited, RTRC would be a better choice than PVC. The percentage conductor fill requirements for RTRC are the same as for other conduits and tubing; however, there is no table in Chapter 9 giving the inside area of RTRC or the number of conductors permitted to be installed in *Annex C.* Previous editions of the Code allowed use of the same inside area as PVC Schedule 40 Rigid Nonmetallic Conduit.

Article 358 deals with Electrical Metallic Tubing (EMT), and it is frequently used where the raceway is not exposed to physical damage. The tubing is not permitted to be threaded. This type of raceway is popular because it is easy to cut, bend, and install. Electrical Metallic Tubing is available in trade sizes 1/2 through 4 (16 through 103). Minimum bending radius to the centerline of the tubing is the same as for Rigid Metal Conduit. If the bends are made in the field, the minimum bending radius is found in *Table 2* of *Chapter 9.*

The maximum support spacing for Electrical Metallic Tubing is 10 ft (3 m). The tubing shall also be supported within 3 ft (900 mm) of a box, fitting, or enclosure. There is an exception that permits the support to be up to 5 ft (1.5 m) from the box, fitting, or enclosure if a practical means of support is not available at a lesser distance.

Article 360 deals with a Flexible Metallic Tubing (FMT) that is liquidtight. It is important to read the list of uses permitted and uses not permitted covered in *360.10* and *360.12*. This material is not permitted to be used in lengths to exceed 6 ft (1.8 m) as stated in *360.12(6)*. The use of Flexible Metallic Tubing as an equipment grounding conductor is covered in *250.118(7)*. An equipment grounding conductor is required to be installed unless the circuit conductors in the tubing are protected from overcurrent at not more than 20 amperes, the fittings are listed for grounding, and the total length of Flexible Metallic Tubing in any grounding path is not more than 6 ft (1.8 m). Radius of bends is given in *360.24*, and the radius depends on whether the bend is fixed or may be infrequently flexed after installation.

Article 362 deals with Electrical Nonmetallic Tubing (ENT), which is a pliable corrugated raceway that can be bent by hand. It is available in trade sizes 1/2 through 2 (16 through 53). The uses permitted are discussed in the article; however, in general, it is intended for use as exposed wiring, or as a concealed wiring method in walls, floors, and ceilings, and above suspended ceilings. If the building is more than three floors above grade, then walls, ceilings, floors, and suspended ceilings must have a 15-minute finish fire rating. An ENT installation is illustrated in Figure 2.7. Electrical Nonmetallic Tubing is permitted to be installed as surface wiring, provided it is not subjected to physical abuse and provided the building is not over three floors in height. Electrical Nonmetallic Tubing shall be supported at intervals not exceeding 3 ft (900 mm), and it shall be supported within 3 ft (900 mm) of a termination at a box, fitting, or enclosure.

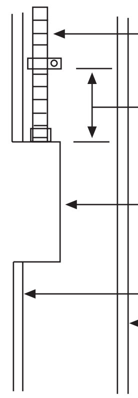


Figure 2.7 A minimum 15-minute finish fire rating is required when Electrical Nonmetallic Tubing is installed as concealed wiring in buildings of more than three floors above grade level.

Article 366 is about auxiliary gutters, which are the same material as wireway except the purpose is different. Auxiliary gutters are limited to 30 ft (9 m) in length, and their purpose is to contain wiring between enclosures and devices such as at a motor control center or to connect the wiring and make taps for a group of enclosures making up a service entrance to a building. Auxiliary gutters constructed of metal are to be supported at intervals not to exceed 5 ft (1.5 m). *NEC® 366.22(A)* permits up to 30 current-carrying wires in a metal auxiliary gutter without applying the derating factors of *310.15(B)(2)(a)*, provided that the conductor cross section does not exceed 20% of the cross-sectional area of the metal auxiliary gutter. For nonmetallic auxiliary gutter, there is no 30 current-carrying conductor limit, but the derating factors of *310.15(B)(2)(a)* must be applied whenever there are more than three current-carrying conductors at any one cross section. *NEC® 366.100(A)* requires adequate electrical and mechanical continuity of the complete auxiliary gutter system. This requirement would indicate that the auxiliary gutter would be considered to be acceptable to serve as an equipment grounding conductor. Conductors entering or leaving an auxiliary gutter that are bent or deflected more than 30 degrees as they enter are required to have a wire bending space determined according to *Table 312.6(A)*. When conductors size 4 AWG and larger enter and leave an auxiliary gutter, the distance between cable or conduit entries are not permitted to be less than given in *314.28* as illustrated for wireway in Figure 2.8.

Article 376 and *Article 378* cover wireways, which are raceways of square cross section with a removable or hinged cover along one side. These are used as a raceway for conductors from one location to another. Metallic and nonmetallic wireway is available. Change in length due to change in temperature must be considered when nonmetallic wireway is installed in locations where it will be exposed to a change in temperature. The cross-sectional area of the wire is not permitted to exceed 20% of the cross-sectional area of the wireway. The derating factors of *310.15(B)(2)(a)* do not apply if there are not more than 30 current-carrying wires in the metal wireway and the fill is not over 20%. For nonmetallic wireway, there is no 30 current-carrying conductor limit, but the derating factors of *310.15(B)(2)(a)* must be applied whenever there are more than three current-carrying conductors at any one cross section. Wireways are not permitted to serve as equipment grounding conductors unless they are listed for the purpose.

Metallic wireway mounted horizontally is required to be supported at each end and at intervals not to exceed 5 ft (1.5 m) unless listed for greater support spacings. If the wireway is manufactured as one solid length of more than 5 ft (1.5 m), the support spacing is permitted to be at the ends but at intervals not to exceed 10 ft (3 m). Vertical runs of wireway are permitted to be supported at intervals of not more than 15 ft (4.5 m) with not more than one joint between supports. Nonmetallic wireway is required to be supported at terminations and at intervals not to exceed 3 ft (900 mm) unless listed for greater support intervals up to 10 ft (3 m). For a vertical run, the maximum support spacing is every 4 ft (1.2 m).

The minimum size of wireway for an application will depend upon not only the size, type, and number of conductors at any cross-section, but also how the wireway is used. The total cross-sectional area of the conductors is not permitted to exceed 20% of the inside cross-sectional area of the wireway. Nonmetallic wireways are required to have the inside cross-sectional area marked. Conductors frequently enter perpendicular to the wireway as shown in Figure 2.8. The minimum distance from the raceway entry to the opposite wall of

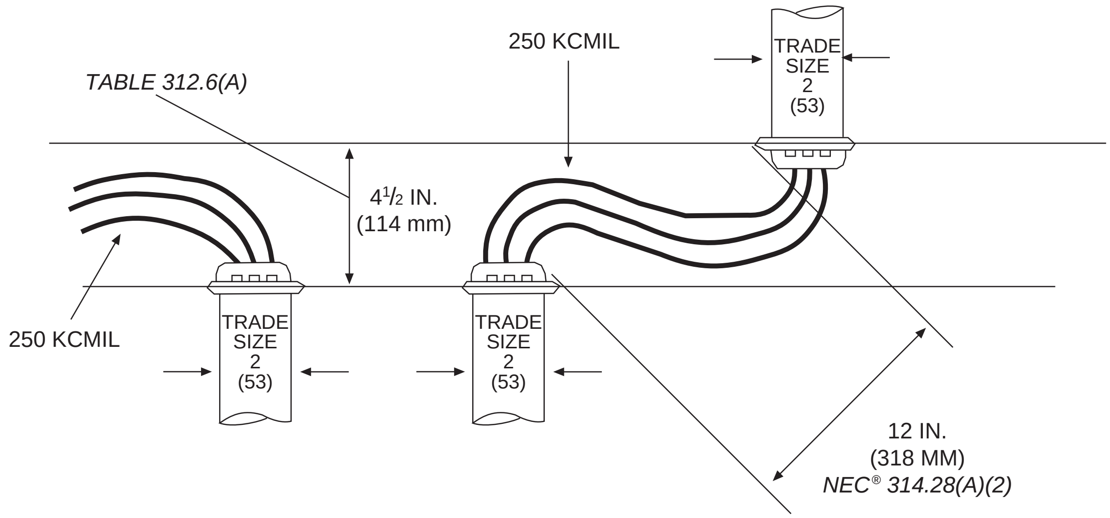


Figure 2.8 For a raceway entry or a conductor passing through an Auxiliary Gutter or Wireway with offset raceway or cable entries, the distance between raceway or cable entries shall not be less than given in *314.28.*

the wireway is required to be not less than the wire bending requirements of *Table 312.6(A)* for one conductor per terminal. When conductors size 4 AWG and larger enter and leave a wireway, the distance between cable or conduit entries is not permitted to be less than given in *314.28* as illustrated in Figure 2.8. The distance is six times the trade diameter of the largest raceway when the entries are offset, and eight times the trade diameter of the largest raceway when the entries are straight across from each other. Another way to deal with a straight pull through a wireway is to run the raceway straight through without the conductors actually entering the wireway. This will avoid having to install a wireway with a dimension greater than necessary for the conductors run in the wireway.

Article 386 and *Article 388* are about surface metal raceways and surface nonmetallic raceways. These are raceways attached to the surface of walls or ceilings. A typical application is where the raceway is run on the surface to extend from an existing outlet to a new outlet location. Equipment grounding for surface metal raceway is covered in *386.60*. It is not permitted to be used as an equipment grounding conductor unless the surface metal raceway is specifically listed for the purpose. Raceway support requirements are not stated in this article. In *386.30* and *388.30*, it states that support is to be according to manufacturer instructions.

Chapter 9, Table 1 Notes provide information necessary for the use of the tables. *Notes 3* and *4* are of particular interest. *Note 3* states that equipment grounding conductors, if present, are to be counted when determining conduit or tubing fill. *Note 4* covers conduit and tubing nipples. As illustrated in Figure 2.9, conduit or tubing not more than 24 in. (600 mm) in length is considered to be a nipple. The wire fill is permitted to be 60% of the conduit or tubing total cross-sectional area. Also, the derating factors of *310.15(B)(2)(a)* do not apply in the case of a conduit or tubing nipple.

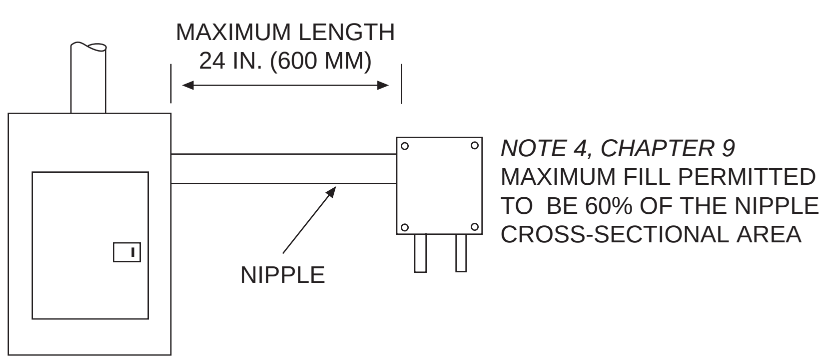


Figure 2.9 Conduit or tubing between enclosures that is not more than 24 in. (600 mm) in length is considered to be a nipple.

Table 2 of *Chapter 9* gives the minimum bending radius permitted for conduit and tubing. For the case of factory bends or field bends made with a one-piece bending tool, the first column of *Table 2* is used. When bends are made with a tool that makes bends in multiple steps, the column marked “other bends” is used. In all cases, the minimum radius of bend is measured to the centerline of the conduit or tubing. In the case of Flexible Metal Conduit (FMC), Liquidtight Flexible Metal Conduit (LFMC), Liquidtight Flexible Nonmetallic Conduit (LFNC), and Flexible Nonmetallic Tubing (FNT), the minimum bending radius is measured to the centerline of the conduit, but the other bend column is used. In the case of Rigid Nonmetallic Conduit, where field bends can be made by various methods, there is no specification of which column of *Table 2* is to be used. As long as the cross-section of the conduit is not distorted, the first column of *Table 2* can be used.

Tables in *Chapter 9* or *Annex C* are used to determine the maximum number of wires and cables permitted to be installed in raceway. The total cross-sectional area of the conductors including the insulation is not permitted to exceed a maximum percentage of the cross-sectional area of the conduit or tubing. For most applications, the maximum is 40% fill. *Table 1* gives the maximum permitted percentage of cross-sectional area the wires are permitted to fill in conduit and tubing. *Table 4* gives the internal diameter and cross-sectional area for the common types of conduit and tubing. The available trade diameter for the different types of conduit and tubing are provided. The table also gives the maximum cross-sectional area permitted for each size and type of conduit or tubing for one, two, and three or more conductors. Specific directions are provided in the notes of this table that tell how to determine the minimum conduit or tubing diameter permitted for specific wires or cable. *Note 9* tells how to determine the cross-sectional area of conduit or tubing for a multiconductor cable with an elliptical cross section.

Example 2.1 A Type NM-B Cable with two insulated size 14 AWG conductors and one bare conductor has a maximum dimension of 3/8 in. (0.375 in. or 9.5 mm). Determine the cross-sectional area of the cable to find the minimum trade diameter Rigid Metal Conduit permitted to be installed, as shown in Figure 2.10.

Answer: *Note 9* of *Table 1*, *Chapter 9* requires that for the purpose of determining conduit or tubing fill, the maximum dimension of the cable is to be used as though it was the diameter of a circular cable. The minimum trade diameter Rigid Metal Conduit required is trade size 1/2 (16). Look up the area in the “one conductor” column of *Table 4*. The area of a circle is as follows:

$$\text{Area of a circle} = \frac{3.14 \times \text{Diameter} \times \text{Diameter}}{4}$$

$$= \frac{3.14 \times 0.375 \times 0.375}{4} = 0.110 \text{ in.}^2$$

$$= \frac{3.14 \times 9.5 \text{ mm} \times 9.5 \text{ mm}}{4} = 70.8 \text{ mm}^2$$

When the wires are all of the same size and type of insulation, the cross-sectional area of the wires will be identical. In this case, *Note 1*, *Chapter 9*, specifies that the appropriate table in *Annex C* is permitted to

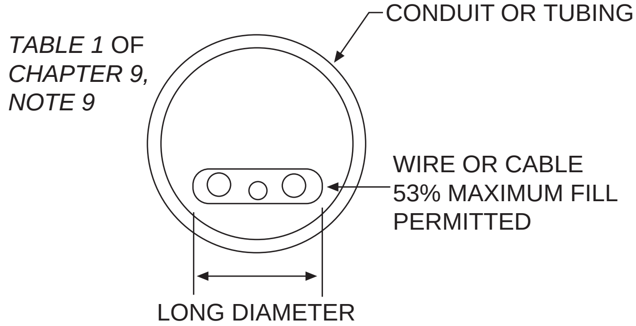


Figure 2.10 A Type NM-B Cable is installed in conduit or tubing.

be used to look up the minimum size of conduit or tubing for the wires. There are separate tables in *Annex C* for each type of conduit or tubing. Conductor strands may be made compact with no void space, or they may be round. The conductors with compact strands have a smaller cross-sectional area than conductors of the same wire gage with round strands. The tables in *Annex C* for compact wires are designated with the letter A such as *Table C1(A)* through *Table C12(A)*.

If the wires are different sizes and different insulation types, the cross-sectional areas of each size or type will be different. In this case, it will be necessary to calculate the total cross-sectional area of the conductors. *Tables 5* and *5A* give the diameter and cross-sectional area of conductors and their insulation. For aluminum conductors with compact conductor configuration, the values are found in *Table 5A*. Then *Table 4* is used to determine the minimum permitted size of conduit or tubing for the wires. *Table 4* provides data on trade sizes (metric designator) of conduit and tubing, such as internal diameter and internal cross-sectional area. The table gives values of area that are percentages of the total area, for example, 1.342 sq. in. (866 mm^2) is 40% of the total cross-sectional area of trade size 2 (53) Electrical Metallic Tubing.

SAMPLE CALCULATIONS

Methods for making the calculations to select the minimum size permitted for conductors, conduit, and boxes for specific installations are discussed. These methods are the same as those used in the Code, but, as the Code often uses the trial and error method for minimum size determination, the methods presented in this unit use direct calculations from which the minimum permitted size may be determined. It is suggested that the student copy the various formulas in the margin of the Code page where the size is to be determined for easy reference in the future.

Protecting Conductors

Electrical wires are required to be protected to prevent insulation damage. There are three common ways that insulation damage can occur, and insulated conductors are required to be protected from such damage.

- Protect insulation from excessive temperature (*310.10*).
- Protect insulation and wire from physical damage (*300.4*).
- Prevent deterioration of insulation by environmental factors such as chemicals and moisture (*110.11*).

The ampere rating of a conductor will have an effect on the operating temperature of a conductor. A conductor heats as electrical current flows through the conductor. The amount of heat produced by current flow can be calculated using Equation 1.16. Figure 2.11 represents current flow through a conductor.

$$\text{Heat} = I^2 \times R \times t$$

Where: I = current, in amperes
R = resistance, in ohms
If **t** is in hours, heat is in watt-hours
If **t** is in seconds, heat is in joules

Watt-hours can be converted to British thermal units (Btu) by multiplying by 3.413. As electrical current flows through a conductor, the temperature will rise. It takes approximately three hours of steady current flow for the temperature of the wiring system to reach a maximum operating temperature. This is why, in the Code, continuous load is considered a load operating for three hours or longer. The Code is concerned about heat produced under various conditions, such as 100% of the rated maximum conductor ampacity,

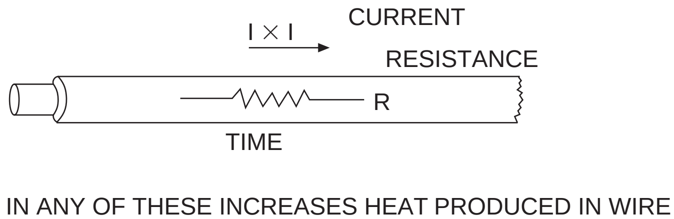


Figure 2.11 Heat produced in a conductor is proportional to the square of the current times the resistance of the conductor times the amount of time the current flows through the conductor.

Table 2.2 Approximate heat produced by current flow along 100 ft of size 12 AWG copper wire.

Circuit rating	Amperes	Heat produced
50%	10	16 J/s
80%	16	41 J/s
100%	20	64 J/s

80% maximum conductor ampacity, and 50% conductor ampacity. Table 2.2 compares the joules of heat produced in 100 ft of size 12 AWG copper with a wire resistance of 0.16 ohm.

Compare the amounts of heat produced by the wire, as shown in Table 2.2. Conductors produce only one-quarter as much heat when operating at 50% load as they do at 100% of the rated maximum conductor ampacity. The conductors produce only 64% as much heat at 80% of conductor ampacity as at 100%. These percentages were determined based on the heating of 100 ft of size 12 AWG wire using Equation 1.16.

Ambient or surrounding temperature has an effect on the operating temperature of a wire. The ampacity of conductors for conditions specified in the tables of *Article 310* is determined at a specified ambient temperature. Temperature correction factors are provided at the bottom of the ampacity tables of *Article 310*, which are used to adjust the ampacity of the table for ambient temperatures other than those specified for the table. For example, consider a copper wire, size 3 AWG, which is in conduit in free air with 60°C insulation with an ambient temperature of 120°F (49°C). The ampere rating of the wire is found in *Table 310.16* as 85 amperes. The ampacity correction factor at the bottom of the table for 120°F (49°C) is 0.58, which results in an allowable ampere rating of the wire under these conditions of 49 amperes.

$$\text{Allowable wire ampacity} = 85\text{ A} \times 0.58 = 49\text{ A}$$

The environment around a conductor affects the rate at which heat produced by current flow is removed from the conductor. This is the reason why several ampacity tables are in *Article 310* of the Code. Heat is removed from the conductors at different rates if the conductors are overhead in free air, in cable, or directly buried in the earth. If the conductors are wet or dry, the rate at which heat is removed from the conductor changes under certain conditions. For example, referring to *Table 310.16*, conductors with insulation Type XHHW are permitted to have the ampacity determined as a 90°C rated conductor, but if the conditions are wet, it is considered a 75°C conductor.

When there is more than one conductor in cable or raceway carrying electrical current, the overall temperature of the conductors builds more rapidly because each conductor is producing heat. The ampacity tables of *Article 310* were based on a maximum of three current-carrying conductors. When there are more than three current-carrying conductors in a cable or raceway, an adjustment factor is used to determine the allowable ampere rating for a conductor. These adjustment factors are found in *310.15(B)(2)(a)*. When there are ten current-carrying conductors in cable or raceway, the adjustment factor drops to 50%. Because of the significant drop in the adjustment factor from nine to ten conductors in a single run of cable or conduit, there is a real incentive to limit the number of wires to not more than nine.

There may be a situation where all of the conductors will not be energized at the same time. This is called load diversity. If the load diversity is not more than 50%, then other adjustment factors can be used. A 50% load diversity would mean that in any given cable or run of conduit or tubing, only 50% of the conductors would be energized at any time. The fine print note in *310.15(B)(2)(a)* calls attention to *Table B-310-11*, which is in *Annex B* at the end of the Code. These adjustment factors are permitted to be used only when there is a load diversity of at least 50% and approved by the authority having jurisdiction.

Neutral as a Current-Carrying Conductor

Consider the case of more than three conductors in conduit, tubing, cord, or cable. The first step is to actually determine the number of current-carrying conductors. A neutral conductor, when serving as a common conductor to more than one ungrounded conductor, may carry only the unbalanced load between the ungrounded conductors. *NEC® 310.15(B)(4)* discusses this issue of when to count the neutral. Frequently, in the case of multiwire feeders and branch-circuits, the neutral conductor is not considered a current-carrying conductor. Therefore, it is not counted for the purpose of derating. The following discussion explains when to count the neutral conductor for the purpose of derating for more than three conductors in raceway or cable.

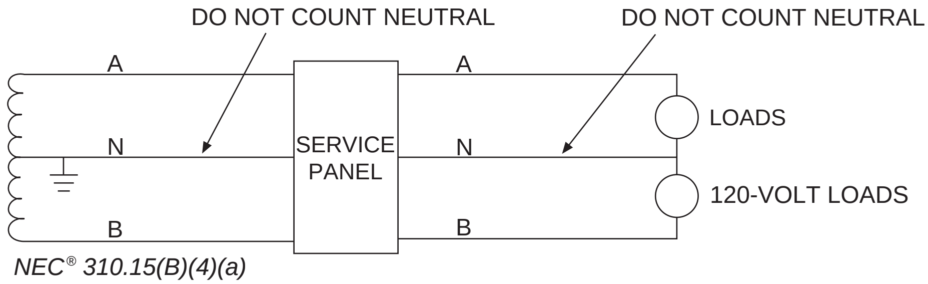


Figure 2.12 The neutral is not counted as a current-carrying conductor for a single-phase, 120/240-volt feeder or multiwire branch-circuit.

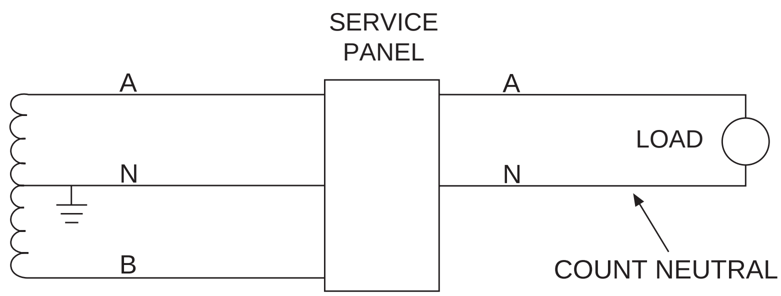


Figure 2.13 The neutral is counted as a current-carrying conductor for a 2-wire, single-phase, 120-volt branch-circuit or feeder.

The single-phase, 120/240-volt 3-wire feeder, or multiwire branch-circuit, does not require the neutral to be counted as a current-carrying conductor. This is true even if the major portion of the load is electric discharge lighting or nonlinear loads such as data processing equipment. This type of circuit or feeder is shown in Figure 2.12.

For the case of the 120-volt 2-wire circuit, the neutral is counted as a current-carrying conductor, as illustrated in Figure 2.13. It does not matter if the neutral is from a 3-wire 120/240-volt single-phase system, or from a 208/120-volt 3-phase system, the neutral is counted as a current-carrying conductor. The neutral also is counted as a current-carrying conductor of a 2-wire 277-volt circuit.

A 3-wire feeder, or multiwire branch-circuit, can be obtained from a 3-phase, 4-wire wye electrical system with the feeder or branch-circuit operating at 208/120 volts. Balancing the 120-volt loads will not reduce the current on the neutral *(310.15(B)(4)(b))*. The neutral will always carry significant current, and the neutral is counted as a current-carrying conductor. Figure 2.14 shows this 3-wire circuit derived from a wye electrical system.

The 3-phase, 4-wire delta 240/120-volt feeder has a neutral conductor that serves as a common conductor for two of the ungrounded conductors, just like the 120/240-volt 3-wire single-phase system of Figure 2.12. The 4-wire, 240/120-volt delta system is shown in Figure 2.15. The neutral is not counted as a current-carrying conductor because the neutral only carries current due to the unbalance between the 120-volt loads on each of the ungrounded conductors (ungrounded conductors A and C). The 120-volt loads are not required to be balanced. The heat produced by current in the 120-volt circuit conductors is not greater in the unbalanced condition than when in the balanced condition.

For the 3-phase, 4-wire wye, 208/120-volt and 480/277-volt electrical systems, the neutral is not counted unless the major portion of the load consists of nonlinear loads such as electronic computers, data processing equipment, or electric discharge lighting. In the case of a 4-wire set of branch-circuits with a common neutral serving electric discharge lights in a room, the neutral is required to be counted as stated in *310.15(B)(4)(c)*. If less than half of the line-to-neutral load in a building was electric discharge lighting, electronic computers, or data processing equipment, then the feeder neutral most likely would not be required to be counted as a current-carrying wire. The feeder and multiwire branch-circuits of a 4-wire wye system are shown in Figure 2.16.

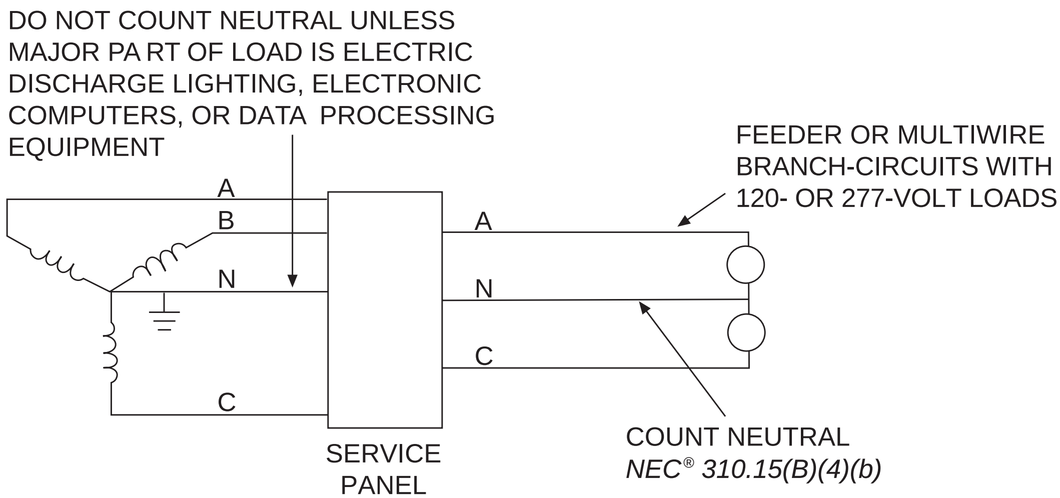


Figure 2.14 The neutral is counted as a current-carrying conductor for a 3-wire feeder or branch-circuit derived from a wye system.

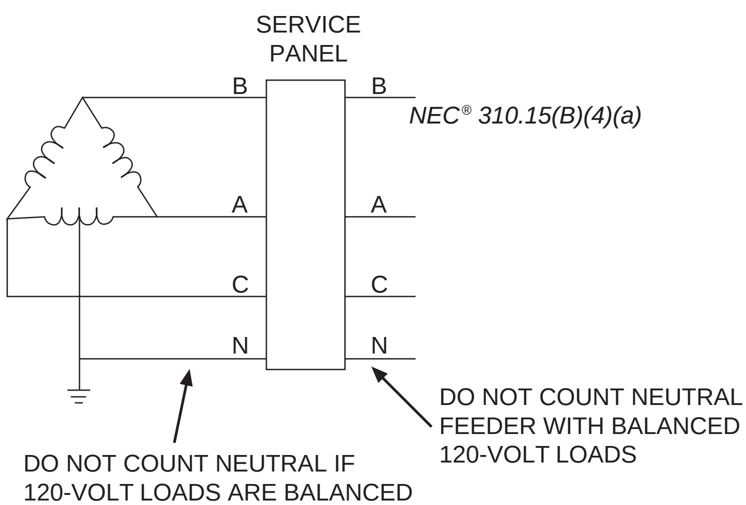


Figure 2.15 The neutral is not counted as a current-carrying conductor for a 4-wire feeder derived from a 240/120-volt delta electrical system with reasonably balanced 120-volt loads.

Sizing Conductors

The Code in *Article 310* requires that the allowable ampacity permitted for a conductor be determined based on the ampacity derating factors for ambient temperatures higher than that for which the ampacity table was developed. When there are more than three current-carrying conductors in cable or raceway, the derating factors of *310.15(B)(2)(a)* shall also apply. A conductor is chosen from the proper ampacity table in the Code by choosing the wire that seems to be adequate, and then multiplying the allowable ampacity in the table by the temperature correction factor if it applies, and by the derating factor from *310.15(B)(2)(a)* if it applies. This derated allowable ampacity value is not permitted to be smaller than the rating of the circuit subject to the provisions of *240.4.* If it is smaller than the circuit rating, then it will be necessary to choose a larger wire and repeat this calculation. The allowable ampacity of a conductor if a temperature derating factor and a derating factor for more than three conductors in a cable or conduit apply can be determined using Equation 2.1.

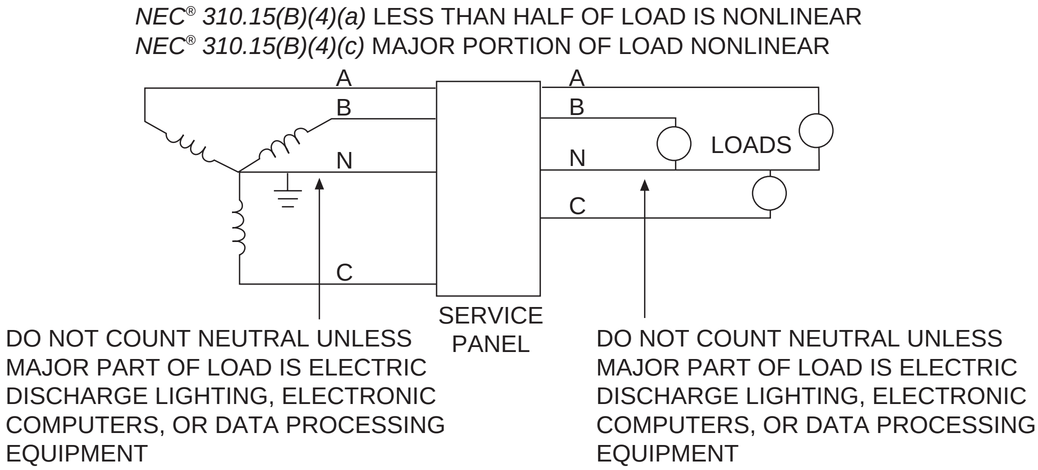


Figure 2.16 The neutral is not counted as a current-carrying conductor for a 4-wire feeder or multiwire branch-circuit unless the major portion of the load is electric discharge lighting, electronic computers, or data-processing equipment.

Adjusted Allowable Ampacity = Table Allowable Ampacity ×
Derating Factor (*310.15(B)(2)(a)*) ×
Temperature Correction Factor **Eq. 2.1**

The rules for sizing conductors for a branch-circuit are in *210.19(A)(1)* and for feeders in *215.2(A)(1)*. These rules are the same, but before they can be applied, first determine the size of overcurrent device protecting the branch-circuit or feeder. The minimum size overcurrent device permitted for a branch-circuit is specified in *210.20(A)* and for feeders in *215.3*. The rules are the same. The minimum overcurrent device rating is to be not less than 1.25 times the continuous load plus any noncontinuous load. Look up the standard ratings of overcurrent devices in *240.6(A)*.

The next step in sizing a conductor for a branch-circuit or a feeder is to determine the minimum permitted conductor size assuming no correction factors or adjustment factors apply. The minimum conductor size is required to have an allowable ampacity not less than 1.25 times the continuous load plus any noncontinuous load. The column of the ampacity table to use depends upon the lowest temperature rating of a component of the circuit. It is necessary to know the temperature rating of splicing devices and terminations of the circuit. It is also necessary to know the insulation temperature rating of the conductors. If no information is known about termination temperature, then the rule in *110.14(C)(1)* will apply. The lowest temperature rating of a component in a circuit will determine the column of *Table 310.16* that will be used to determine the minimum size of the conductor for the circuit or feeder. Assume some terminations in a circuit are rated 60°C and some are rated 75°C. Assume the conductor insulation is THHN with a 90°C rating. For this circuit it will be necessary to look up the minimum conductor size using the 60°C column of *Table 310.16*.

Next, determine if any adjustment or correction factors will apply. Is there a portion of the circuit where there are more than three current-carrying conductors? If the answer is yes, then determine the lowest temperature rating of any component in that portion of the circuit or feeder. For example, assume the conductors being sized have THHN insulation, but other conductors in that same run of raceway have THWN insulation. Then the ampacity to which the adjustment factor will be applied will be from the 75°C column. If all conductors in that portion of the raceway had 90°C rated insulation, then the ampacity to which the adjustment factor will be applied will be from the 90°C column of *Table 310.16*. This is permitted even though in another part of the circuit there are terminations rated at only 60°C. Look up the allowable ampacity in *Table 310.16* and apply any temperature correction factor and adjustment factor from *310.15(B)(2)(a)* that applies to the section of the circuit in question.

NEC® 210.19(A)(1) states in the first sentence that the conductors for a branch-circuit shall have an ampacity not less than the maximum load to be served. The conductor ampacity is the value determined after applying the adjustment and correction factors. That value must not be less than the load. That means 1.0 times the continuous load plus 1.0 times the noncontinuous load. This will determine if the minimum conductor size

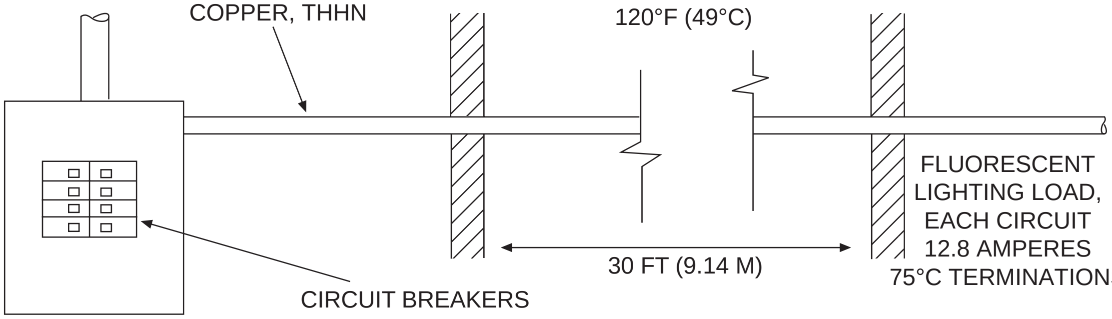


Figure 2.17 Eight circuits of a 120/240-volt, 3-wire electrical system supply fluorescent fixtures using multiwire branch-circuits that run through a room with an ambient temperature of 120°F (49°C).

of the first step is still adequate to handle the load when adjustment and correction factors are applied. The following examples will illustrate the process of conductor size selection.

Example 2.2 The home runs for eight 120-volt lighting circuits supplied from a 120/240-volt, 3-wire, single-phase electrical system are contained in the same conduit, which runs for 30 ft (9.14 m) through an area of a building where the ambient temperature typically runs to 120°F (49°C). There are no fixtures or conductor terminations in the room that may operate up to 120°F (49°C). Each circuit supplies eight fluorescent luminaires (lighting fixtures), each of which draws 1.6 amperes for a total of 12.8 amperes per circuit. Multiwire branch-circuits are used with a common neutral for two ungrounded conductors. The total conductors within the conduit are eight ungrounded conductors and four neutral conductors. This circuit is illustrated in Figure 2.17. All circuits are protected with 20-ampere circuit breakers, and all terminations in the circuits are 75°C rated. Determine the minimum size of Type THHN copper conductors for the circuits.

Answer: The overcurrent device for each circuit has already been selected at 20 amperes. The next step is to determine the minimum size conductor permitted without considering any adjustment or correction factors according to *210.19(A)(1)*. The circuit supplies a continuous load, therefore, the minimum size conductor must have an allowable ampacity of not less than 1.25×12.8 amperes, which is 16 amperes. The 75°C column of *Table 310.16* will be used because of the conductor terminations. It would appear that a size 14 AWG copper conductor is acceptable, but *240.4(D)* only permits a 15-ampere overcurrent device on a size 14 AWG copper wire. These circuits have 20-ampere overcurrent devices, therefore, a size 12 AWG copper wire is required.

Next, apply any adjustment factors to a size 12 AWG copper Type THHN conductor to determine if it is still acceptable. The most severe conditions are in the room with the 120°F (49°C) ambient temperature. The 90°C column of *Table 310.16* can be used in this area to apply the temperature correction and other adjustment factors. For an ambient temperature of 120°F (49°C), the temperature correction factor is 0.82.

Now determine the adjustment factor from *310.15(B)(2)(a)*. First, it is necessary to determine if the neutral conductors are counted as current-carrying conductors. According to *310.15(B)(4)(a),* the neutrals are not counted, therefore, the total number of current carrying conductors for this circuit is eight. From *Table 310.15(B)(2)(a),* the adjustment factor is 0.7. Use Equation 2.1 to determine the adjusted allowable ampacity of THHN copper conductors under these conditions.

$$\text{Adjusted Allowable Ampacity} = 30\text{ A} \times 0.82 \times 0.7 = 17.2\text{ A}$$

Finally, compare the adjusted allowable ampacity of the conductors with the actual load which, in this case, is 12.8 amperes. The adjusted allowable ampacity is greater than the load, but it is less than the rating of the overcurrent device. There is a rule in *240.4(B)* that permits a circuit conductor that does not match a standard rating of an overcurrent device to be protected by the next larger rating of overcurrent device which, in this case, is 20 amperes. The standard ratings of overcurrent devices are listed in *240.6(A)*. The conclusion is that the size 12 AWG copper THHN conductor is adequate for these circuits under these conditions.

Example 2.3 Fluorescent luminaires (lighting fixtures) are installed on 120-volt circuits each of which draws 14.4 amperes. The electrical supply in the building is 3-phase, 4-wire, 208/120-volt service. Six 20-ampere lighting circuits are run in the same raceway to an area of the building where the luminaires (lighting fixtures) are installed. These are multiwire branch-circuits with six ungrounded conductors and two neutrals. The conductors are copper with THWN insulation, and all circuit terminations are 75°C rated. Determine the minimum size conductors for the circuits.

Answer: The overcurrent devices for the circuits have already been selected at 20 amperes, which require a size 12 AWG copper conductor. The load on the circuit is 14.4 amperes which, multiplied by 1.25, gives 18.0 amperes as the minimum conductor allowable ampacity without adjustment factors applied. Fluorescent luminaires (lighting fixtures) are generally considered to be nonlinear loads. In this case, *310.15(B)(4)(c)* requires the neutrals to be counted as current-carrying conductors. For this raceway run, there are eight current-carrying conductors which, according to *Table 310.15(B)(2)(a)*, gives an adjustment factor of 0.7. The 75°C column of *Table 310.16* is used to determine the unadjusted allowable ampacity of the conductors in the raceway. Multiply the 25 amperes by 0.7 to get an adjusted allowable ampacity of 17.5 amperes. The allowable ampacity of the conductor is greater than the load of 14.4 amperes. *NEC® 240.4(B)* permits this 17.5-ampere conductor to be protected with the next larger standard rating of overcurrent device as listed in *240.6(A)*, which is 20 amperes. The conclusion is that a size 12 AWG copper THWN conductor is the minimum size permitted for the circuit.

Example 2.4 Two 3-phase, 3-wire circuits supply a 48-ampere continuous load. The circuit conductors are copper with THHN insulation, and all circuit-conductor terminations are 75°C rated. In route to supplying the load, the circuits run through a room for a distance of 25 ft (7.62 m) that typically has an ambient temperature of 125°F (51.6°C), as shown in Figure 2.18. Determine the minimum size conductors for these circuits.

Answer: First, determine the minimum rating of overcurrent device for the circuits using the rule of *210.20(A)*. The overcurrent device is required to have a rating not less than 1.25 times the continuous load, plus the noncontinuous load. For this circuit, the minimum rating is required to be 60 amperes (1.25×48 A = 60 A). A 60-ampere circuit breaker or set of fuses is the minimum required for this circuit.

Next, determine the minimum size conductor for the circuit assuming adjustment and correction factors do not apply. The rule is found in *210.19(A)*. The minimum conductor allowable ampacity, not considering adjustment or correction factors, is 1.25 times the continuous load plus the noncontinuous load. For this circuit, the minimum conductor size must have an allowable ampacity of 60 amperes

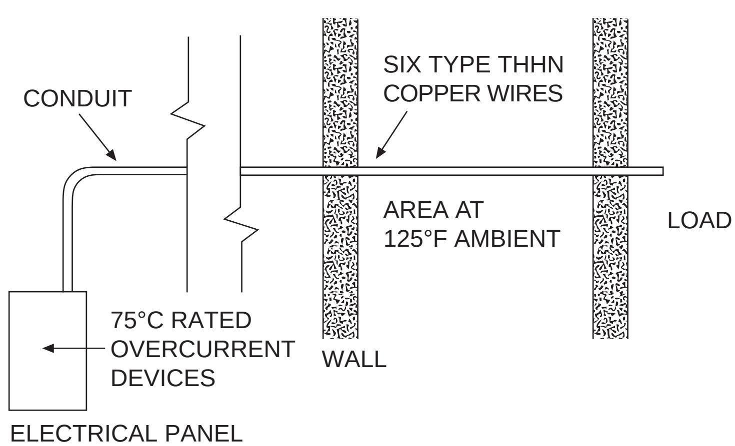


Figure 2.18 A run of conduit passes 25 ft (7.62 m) through a room with a high ambient temperature.

(1.25 × 48 A = 60 A). The termination temperature rating of 75°C determines the column of *Table 310.16* that is used to find the minimum conductor size for this circuit which is size 6 AWG.

Finally, the temperature-correction factor and the adjustment for more than three conductors in the raceway are applied. The conductor insulation is THHN, therefore, it is permitted to use the 90°C column of *Table 310.16* to find the allowable ampacity to which the correction and adjustment factors are applied. Use Equation 2.1 to determine the adjusted allowable ampacity of the conductors. Start with size 6 AWG to see if after adjustment it has an allowable ampacity not less than the 48-ampere load. There are six current-carrying conductors in the raceway.

$$\text{Adjusted Allowable Ampacity} = 75\text{ A} \times 0.8 \times 0.76 = 45.6\text{ A}$$

The adjusted allowable ampacity of the size 6 AWG copper THHN conductors is only 45.6 amperes, which is less than the load of 48 amperes. It will be necessary to try the next larger size conductor. The adjusted allowable ampacity of a size 4 AWG copper THHN conductor is 57.8 amperes (95A × 0.8 × 0.76 = 57.8A). Using the rule of *240.4(B)*, the minimum size conductor permitted for these circuits is size 4 AWG copper Type THHN.

Sizing Conduit and Tubing

If all conductors in the conduit are the same size with the same type of insulation, the minimum trade diameter conduit or tubing permitted can be determined in accordance with *Note 1* of *Chapter 9. Note 1* makes reference to the tables in *Annex C.* There are separate tables for each of twelve types of conduit or tubing. There is one set of tables for conductors with round strands and a separate set of tables for conductors with compact strands. If a type of conduit or tubing is used that is not included in *Annex C,* the maximum number of conductors permitted in the conduit or tubing is determined by using the cross-sectional area provided by the manufacturer and calculating the conductor fill.

When the conductors in a conduit or tubing are of different sizes or types of insulation, the cross-sectional area of the conductors must be determined to calculate the minimum trade diameter of the conduit or tubing to be used. The diameter and cross-sectional area of common types of conductors are given in *Table 5* or *Table 5A* in *Chapter 9.* The total cross-sectional area of all conductors is first determined. Then, the minimum trade diameter conduit or tubing is found in *Table 4* for the type of conduit or tubing to be used. In the case of three or more conductors in conduit or tubing, the 40% fill column is used to determine the minimum trade diameter. Some examples will help illustrate how conduit or tubing is sized for a particular situation.

Example 2.5 Two feeders, each consisting of three size 3/0 AWG, Type THHN conductors, are run in the same Rigid Metal Conduit, as shown in Figure 2.19. Determine the minimum trade diameter Rigid Metal Conduit permitted for the six conductors.

Answer: Look up the minimum permitted Rigid Metal Conduit trade diameter directly in *Annex C, Table C8.* The minimum permitted trade diameter for wire with round strands is trade size 2 1/2 (63). If the wire was of compact strand construction, the minimum permitted trade diameter conduit would be trade size 2 (53) from *Table C8A.*

Example 2.6 Determine the minimum trade diameter, Schedule 40 PVC Rigid Nonmetallic Conduit permitted to contain three size 2/0 AWG, Type THW wires, six size 12 AWG, Type THWN wires, and one bare size 6 AWG copper equipment grounding wire. This conduit is shown in Figure 2.20.

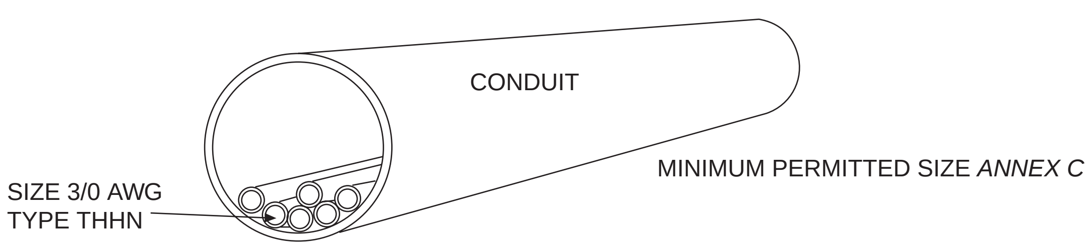


Figure 2.19 Six size 3/0 AWG, Type THHN wires are run in a Rigid Metal Conduit.

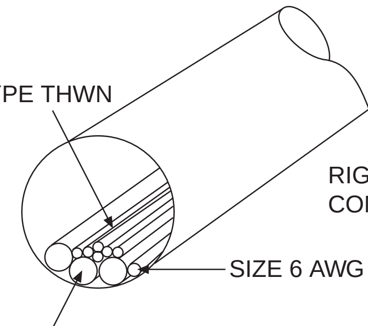


Figure 2.20 Insulated wires and bare copper equipment grounding wires are run in Rigid Nonmetallic Conduit.

Answer: It is necessary to determine the total cross-sectional area of the wires. Wire cross-sectional area is not permitted to exceed 40% of the inside cross-sectional area of the conduit. Minimum trade size 2 (53) is found in *Table 4.*

size 2/0 AWG, Type THW, *Table 5*		
	$3 \times 0.2624 = 0.7872$ in.^{2}	$3 \times 169.3 = 507.9$ mm^2
size 12 AWG, Type THWN, *Table 5*		
	$6 \times 0.0133 = 0.0798$ in.^{2}	$6 \times 8.581 = 51.5$ mm^2
size 6 AWG, bare, *Table 8*		
	$1 \times 0.027 = \underline{0.027}$ in.^{2}	$1 \times 17.09 = \underline{17.1}$ mm^2
	0.8940 in.^{2}	576.5 mm^2

Sizing Conduit and Tubing Nipples

A conduit or tubing nipple is defined in *Note 4* of *Chapter 9* as a length of conduit or tubing that does not exceed 24 in. (600 mm) in length. Figure 2.9 illustrates an application of a nipple. The cross-sectional area of the conductors is not permitted to exceed 60% of the cross-sectional area of the nipple. The nominal inside cross-sectional area of trade diameter conduit and tubing is given in the 100% column of *Table 4, Chapter 9*. For example, the total cross-sectional area of a trade size 2 (53) Rigid Metal Conduit nipple is 3.408 sq. in. (2199 mm^2).

The minimum trade diameter of a conduit or tubing nipple permitted is determined by first finding the total cross-sectional area of all conductors contained within the nipple. This was done for the conductors in Figure 2.20, and the total cross-sectional area of the conductors was determined in Example 2.6 to be 0.8940 sq. in. (576.5 mm^2). Assume the conduit of Example 2.6 is a nipple. Using the cross-sectional area, select a trade size (metric designator) from *Table 4* that is expected to be the correct size, and multiply the total cross-sectional area of that nipple by 0.6 (60%). The resulting area from this calculation is required to be equal to or larger than the cross-sectional area of the conductors. Consider a trade size 1$^1/_4$ (35) Rigid Metal Conduit nipple. The conductor cross-sectional area of the conductors is permitted to be 0.9156 sq. in. (591 mm^2).

$$1.526 \text{ sq. in.} \times 0.6 = 0.9156 \text{ sq. in.}$$

$$(985 \text{ mm}^2 \times 0.6 = 591 \text{ mm}^2)$$

This value is larger than the cross-sectional area of the wire; therefore, trade size 1$^1/_4$ (35) Rigid Metal Conduit nipple is large enough for the conductors. Equation 2.2 can be used to determine the area of a nipple directly that has a cross-sectional area sufficient for the conductors. The total cross-sectional area of the conductors is divided by 0.6 (60%) to determine the minimum nipple cross-sectional area required. Then, just proceed down the 100% column of *Table 4* until an area is found that is equal to or greater than the value calculated. *Table 4* for each type of conduit and tubing now has a 60% fill column. The calculation method used in the past is no longer necessary once the conductor total cross-sectional area has been determined.

For the previous example, look up a conduit or tubing trade size that has a 60% area not less than 0.8940 sq. in. (576.5 mm^2). If the nipple is Rigid Metal Conduit, then trade size 1$^1/_4$ (35) is adequate.

$$\textbf{Actual Inside Area} = \frac{\textbf{Wire Cross-sectional Area}}{\textbf{0.6}} \qquad \textbf{Eq. 2.2}$$

Example 2.7 Assume the conductors form Figure 2.20 with a total cross-sectional area of 0.8940 sq. in. (576.5 mm^2) are to be run through a Schedule 40 PVC Rigid Nonmetallic Conduit nipple between two panels. Determine the minimum trade diameter nipple permitted.

Answer: Now the method is real simple. Find *Table 4* for Schedule 40 PVC Rigid Nonmetallic Conduit and look up a conduit in the 60% area column that is not less than 0.8940 sq. in. (576.5 mm^2). Choose a trade size 1$^1/_2$ (41) nipple.

Wireway Sizing

The total cross-sectional area of the conductors is not permitted to exceed 20% of the cross-sectional area of the wireway, except at splices, *376.22* and *376.56.* The derating rules of *310.15(B)(2)(a)* for more than three conductors in raceway do not apply to metal wireway when there are not more than 30 current-carrying wires in the metal wireway. Wireway is square in cross-section; therefore, the cross-sectional area is determined by squaring the trade dimension of the wireway. For example, a 4-in. by 4-in. (10-cm × 10-cm) wireway has a cross-sectional area of 16 sq. in. (100 cm^2). The interior cross-sectional area of nonmetallic wireway is marked on the wireway by the manufacturer, *378.120.* Equation 2.3 can be used to determine the minimum permitted dimension of wireway for electrical conductors. First determine the total cross-sectional area of the conductors, and then determine the minimum permitted cross-sectional area required with Equation 2.3.

$$\textbf{Actual Inside Area} = \frac{\textbf{Wire Cross-sectional Area}}{\textbf{0.2}} \qquad \textbf{Eq. 2.3}$$

Example 2.8 Determine the minimum wireway dimensions permitted to contain nine size 2/0 AWG, Type THW wires, and twelve size 12 AWG, Type THWN wires. This wireway is shown in Figure 2.21.

Answer: First, determine the total cross-sectional area of the conductors in the wireway. Equation 2.3 can be used to determine the minimum permitted wireway cross-sectional area. A 4-in. by 4-in. (10-cm × 10-cm) wireway has a cross-sectional area of 16.0 sq. in. (100 cm^2). Therefore, a 4-in. (10-cm) square wireway is adequate for the conductors of this example.

Size 2/0 AWG, Type THW, *Table 5*

$9 \times 0.2624 = 2.3616$ in.^{2} $\qquad$ $9 \times 169.3 = 1524$ mm^2

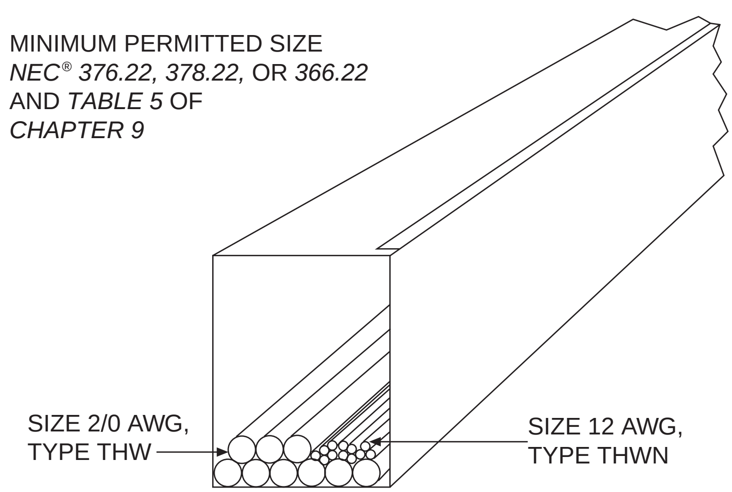


Figure 2.21 Minimum size of Wireway or Auxiliary Gutter based on 20% fill.

Size 12 AWG, Type THWN, *Table 5*

$$12 \times 0.0133 = \underline{0.1596 \text{ in.}^2} \qquad 12 \times 8.581 = \underline{103 \text{ mm}^2}$$

$$\text{Total Wire Area} \qquad 2.5212 \text{ in.}^2 \qquad 1626 \text{ mm}^2$$

$$\text{Actual Inside Area} = \frac{2.5212 \text{ in.}^2}{0.2} = 12.606 \text{ in}^2$$

$$\text{Actual Inside Area} = \frac{1626 \text{ mm}^2}{0.2} = 8130 \text{ mm}^2 = 81.3 \text{ cm}^2$$

Sizing Boxes

The easiest method to size standard boxes is to count the total conductors and conductor equivalents, then look up the size in *Table 314.16(A)*. This can be done only if the wires entering the box are all the same size. If they are not the same size, then the volume of the box must be determined using the volume requirements of *Table 314.16(B)*. The rules for determining the minimum size device or junction box permitted are given in *314.16(B)*. The following steps are used when all wires in the box are the same size:

1. Count each circuit wire entering the box. An unbroken wire only counts as one. (Pigtails do not count.)
2. Where one or more internal cable clamps are used, one conductor equivalent shall be counted based upon the wire size secured by the clamp.
3. Fittings such as fixture studs and hickeys count as one conductor equivalent for each type of fitting.
4. Each device yoke counts as two wire equivalents based upon the wire size terminating at the device.
5. All grounding wires count as one wire equivalent unless the box contains equipment grounding wires for the circuit as well as for an isolated ground receptacle, such as may be used with computer equipment.

If wires of different sizes are in the same box, the equipment grounds are counted as a wire of the largest size. A device in the box is counted as a wire of the largest size connected to that device if more than one size of wire is in the box. Cable clamps are counted as a conductor equivalent to the size secured by the clamp.

Example 2.9 Determine the dimensions of the smallest size metal 3-in. by 2-in. (75-cm × 50-cm) standard device box required for the outlet shown in Figure 2.22. Both Type NM-B cables are size 14 AWG copper, with two insulated wires and a bare equipment grounding wire. There is a single-pole switch in this box with cable clamps.

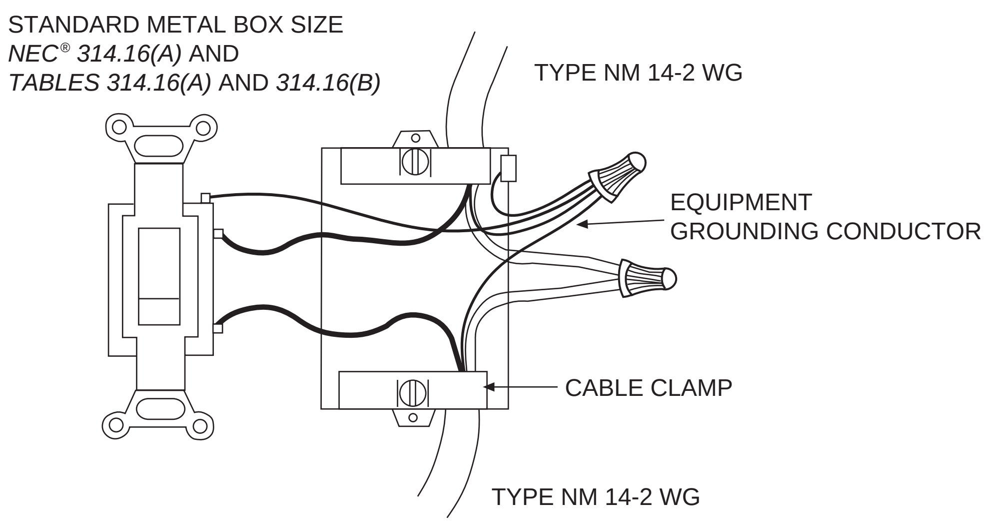


Figure 2.22 A switch is installed in a device box with size 14 AWG electrical cable with an equipment grounding wire.

Answer: Determine the number of conductors in the device box and the conductor equivalents for non-wire parts that take up space in the box. The procedure is described in *314.16(B)*. A 3-in. by 2-in. by $3^1/_2$-in. deep device box (75-cm × 50-cm × 90-cm) is found to be the minimum permitted from *Table 314.16(A)*.

Wires	4
Cable clamps	1
Other fittings	0
Device	2
Grounds	1
Total	8

Example 2.10 Consider another 3-in. by 2-in. device box similar to the one shown in Figure 2.22, except the conductors in the box are of different sizes. Conductors entering the box are a Type NM-B Cable with two size 14 AWG insulated and one bare equipment grounding conductor, and a Type NM-B Cable with two size 12 AWG insulated and one bare equipment grounding conductor. There are cable clamps in the box, and one single-pole switch. Determine the minimum depth standard device box permitted for this application.

Answer: To determine the minimum size box, it will be necessary to determine the volume of the box. First, do a conductor count and determine the number of conductors and conductor equivalents for each wire size based on the rules in *314.16(B)*. The cable clamp, device, and equipment grounds are counted as though they were a conductor of the largest size in the box. In this case, the largest conductor is size 12 AWG. The minimum permitted capacity for the box is computed based upon the number of conductors of different sizes using the values from *Table 314.16(B)*. In this case, the minimum box volume permitted is 17.5 in.^{3} (287 cm^3). The volumes of standard boxes are listed in *Table 314.16(A)*. A 3-in. by 2-in. by $3^1/_2$-in. standard device box is adequate for this application and has a volume of 18 in.^{3} (295 cm^3).

	Size 14 AWG	Size 12 AWG
Wires	2	2
Equipment grounds	0	1
Device	0	2
Cable clamps	0	1
Other fittings	0	0
Totals	2	6

Size 14 AWG	2 × 2.0 in.^{3} = 4.0 in.^{3}	2 × 32.8 cm^3 = 65.6 cm^3
Size 12 AWG	6 × 2.25 in.^{3} = 13.5 in.^{3}	6 × 36.9 cm^3 = 221.4 cm^3
Totals	17.5 in.^{3}	287.0 cm^3

Nonmetallic boxes such as the one shown in Figure 2.23 do not have their volumes listed in *Table 314.16(A)*. The volume of the box is visibly displayed inside the box. Manufacturers can provide catalogs that give the dimensions and volumes of boxes available.

Example 2.11 Type NM-B Cable is installed into a single-gang nonmetallic device box where the cable is fastened such that cable clamps in the box are not necessary. The cable entering and leaving the box has size 14 AWG conductors, two of which are insulated and one is a bare equipment grounding conductor as shown in Figure 2.23. There is also a single-pole switch in the box. Determine the minimum volume required for this box.

Answer: If the nonmetallic box does not contain cable clamps, then the equivalent conductor count is seven, as tabulated on the next page. A nonmetallic device box will be marked with the box volume. Look up the minimum volume requirement for each of the size 14 AWG conductors in *Table 314.16(B)*.

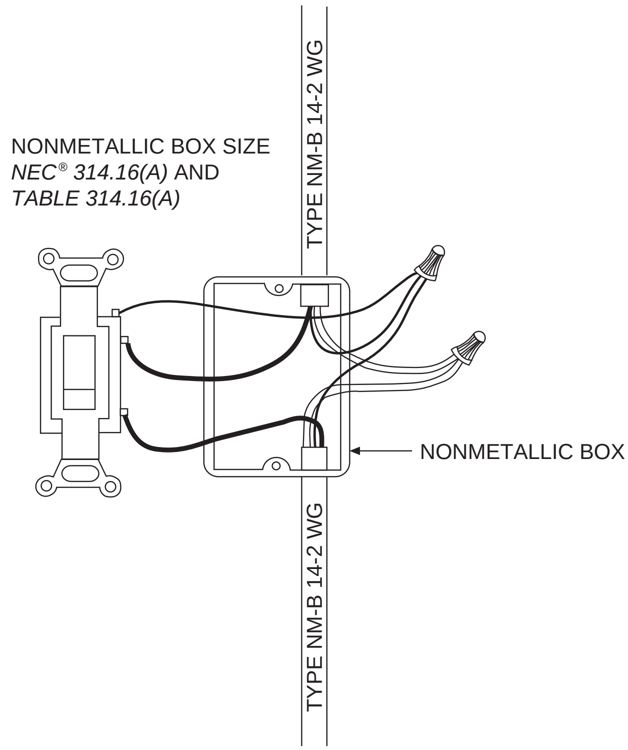


Figure 2.23 A nonmetallic box contains one device and has a Type NM Cable with two size 14 AWG insulated wires and a bare equipment grounding conductor entering the box.

Then multiply the seven conductor count of this device box by 2.0 in.^{3} (32.8 cm^3) for each wire in the box to get the minimum permitted box area of 14 in.^{3} (230 cm^3).

Wires	4
Cable clamps	0
Other fittings	0
Device	2
Grounds	1
Total	7

Size 14 AWG 7×2.0 in.^{3} = 14.0 in^3 7×32.8 cm^3 = 230 cm^3

Fixture wires, up to four including equipment grounding conductors smaller than size 14 AWG, entering a box from a canopy fixture are not counted for the purpose of determining the minimum size box. In some cases, fixture wires smaller than size 14 AWG may be required to be counted, *314.16(B)(1) Exception*. Be sure to count fixture studs and similar fittings, and if a fixture cover does not actually take up space inside a box, it is not counted. Plaster rings and raised covers for devices add volume to a box. Trade literature for device covers will list the amount of volume added for the various types and sizes. The volume of raised covers is usually marked on the cover.

Pull Boxes

Minimum dimensions are required for pull boxes and conduit bodies when the wires are size 4 AWG and larger. There are straight pulls in which the conductors enter one end of the box and leave the opposite end. For a straight pull, the minimum distance between openings is eight times the largest trade size conduit entering the pull box. The rule is found in *314.28(A)(1)*.

Example 2.12 A trade size 2 (53) raceway enters and leaves opposite ends of a pull box as shown in Figure 2.24. The conductors in the raceway are size 2 AWG. Determine the minimum length of pull box permitted.

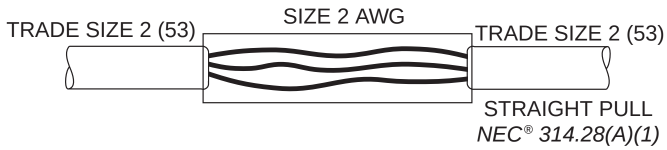


Figure 2.24 A straight pull box in a run of trade size 2 (53) conduit where the conductors are size 4 AWG or larger.

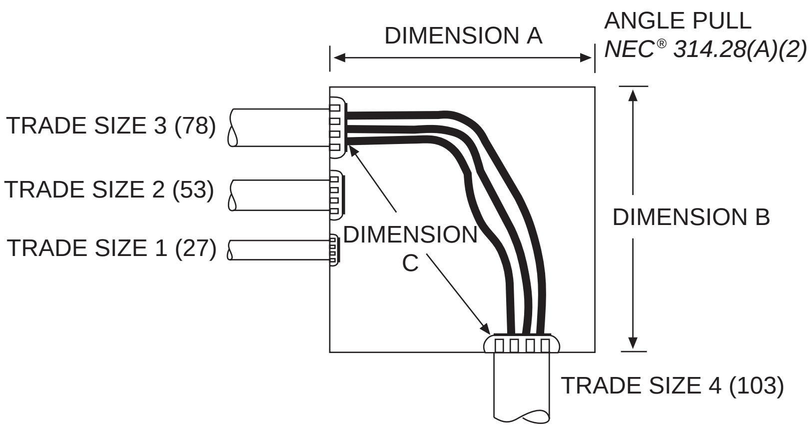


Figure 2.25 A pull box is used to make an angle pull for several conduits where the conductors are size 4 AWG or larger.

Answer: The minimum permitted length of pull box for a straight pull is determined by multiplying the largest trade diameter conduit by eight. The minimum length permitted for this installation is 16 in. (424 mm).

$$8 \times 2 \text{ in.} = 16 \text{ in.} \qquad 8 \times 53 = 424 \text{ mm}$$

For an angle pull, the distance to the opposite wall is not permitted to be less than six times the largest diameter conduit plus the sum of the trade sizes of other conduits or tubing on the same side in the same row. What is being sized is the distance to the opposite wall. This is confusing, and it will be necessary to read *314.28(A)(2)* carefully. An example of an angle pull box is shown in Figure 2.25. These required dimensions apply only when the wire size is 4 AWG and larger. If the wires are size 6 AWG and smaller, there is no minimum dimension requirement. In that case, the box is sized according to *314.16*.

Example 2.13 A pull box has three raceways entering one side, trade sizes 3 (78), 2 (53), and 1 (27), and a trade size 4 (103) raceway entering the adjacent side. Conductors passing from the trade size 4 (103) to the trade size 3 (78) raceways are size 4 AWG or larger. The pull box is shown in Figure 2.25. Determine the minimum dimensions of the pull box.

Answer: Dimension A is determined by multiplying the trade size 3 (78) diameter conduit by six and then adding to it the diameters of the other conduits on that same side in the same row. The minimum permitted length of dimension B is determined by multiplying the 4-in. diameter conduit (103) by six. The pull box is required to have a size not less than 21 in. (548 mm) by 24 in. (618 mm).

Minimum length of dimension B of the pull box:

$$6 \times 4 \text{ in.} = 24 \text{ in.} \qquad 6 \times 103 = 618 \text{ mm}$$

Minimum length of dimension A of the pull box:

$$\begin{array}{rr} 6 \times 3 \text{ in.} = & 18 \text{ in.} \\ + & 2 \text{ in.} \\ + & 1 \text{ in.} \\ \hline & 21 \text{ in.} \end{array} \qquad \begin{array}{rr} 6 \times 78 = & 468 \text{ mm} \\ + & 53 \text{ mm} \\ + & 27 \text{ mm} \\ \hline & 548 \text{ mm} \end{array}$$

The purpose of specifying a minimum size of pull box is to provide an adequate amount of space within the pull box to install conductors size 4 AWG and larger without injuring the insulation on the conductors. In addition to specifying the minimum size of pull box, there is an additional requirement that any conduit entry containing the same conductors must be spaced a minimum distance apart of six times the diameter of the largest raceway involved. Referring to the pull box of Figure 2.25, the conductors pass from a trade size 4 (103) raceway to a trade size 3 (78) raceway. The distance between these two raceways is required to be not less than 24 in. (618 mm).

Dimension C = 6×4 in. = 24 in. = $6 \times 103 = 618$ mm

Conduit Bodies

The rules for determination of the minimum dimensions of pull boxes also apply to conduit bodies with one exception, which is the **LB**-type conduit body. The different situations considered are the straight run and the angle. These minimum dimension requirements apply only when the conduit body contains conductors size 4 AWG and larger.

The rules of *314.28(A)(1)* apply for a straight conduit body, and the length of the conduit body shall not be permitted to be less than eight times the trade diameter of the largest conduit entering the conduit body.

Example 2.14 A conduit body is used for wire pulling access in a straight run of conduit, as shown in Figure 2.26. There are four size 4 AWG, Type THHN wires installed in a trade size 1 (27) conduit. Determine the minimum permitted length (dimension L) for this straight conduit body.

Answer: This is a straight run, and the conduit body shall have a length not less than eight times the trade diameter of the largest conduit entering the conduit body.

8×1 in. = 8 in. $8 \times 27 = 216$ mm

The rule for an angle conduit body is found in *314.28(A)(2)*. The dimension from a conduit entry to the opposite wall of the conduit body shall be required to be not less than six times the trade diameter of the conduit entering the conduit body. There is an exception that may be used for the dimension from the conduit entry to a removable cover. This same exception can be used when a conduit enters the back of a pull box opposite the removable cover. This exception allows the dimension to be determined by the one conductor per terminal column of *Table 312.6(A).*

Example 2.15 A Type LB conduit body is installed in a run of conduit to make a right angle access through a wall, as shown in Figure 2.27. If four size 4 AWG Type THHN wires are run in trade size 1 (27) conduit, determine the minimum dimensions of a Type LB conduit body.

Answer: First, determine the minimum permitted length of dimension L2 that is required to be six times the trade diameter of the conduit to the opposite wall.

Dimension L2: 6×1 in. = 6 in. $6 \times 27 = 162$ mm

Dimension L1 is from the conduit entry to the removable cover. An exception permits this dimension to be determined using the "one conductor per terminal" column of *Table 312.6(A).* Dimension L1 is a minimum of 2 in. (51 mm).

If the wires in the conduit body are size 6 AWG and smaller, then the rules of *314.28* do not apply. The conduit body is then required to have a minimum cross-sectional area of not less than twice the cross-sectional

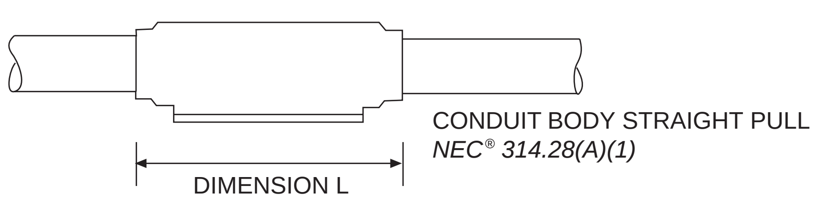


Figure 2.26 A Conduit Body is used to provide access to a conduit to make a straight wire pull.

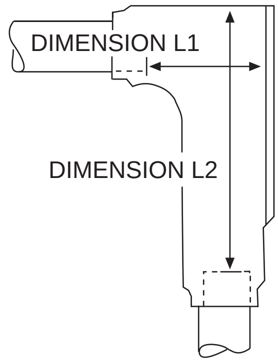


Figure 2.27 Minimum dimensions are required for a Type LB Conduit Body when the wires are size 4 AWG and larger.

area of the largest conduit or tubing entering the conduit body, *314.16(C)*. If a conduit body is to contain splices, taps, or a device, *314.16(C)* requires the volume to be marked in the conduit body, and the fill shall not exceed the requirement of *314.16(B)*.

Sometimes cable assemblies with conductors larger than size 6 AWG join in a box for splicing or terminating. The rules in *314.28(A)* also apply, but there is no conduit or tubing size to use to determine the minimum dimensions of the box. The method to be used is explained in *314.28(A)*. First, determine the minimum size conduit or tubing that would have been needed if the conductors had been run in conduit or tubing. Then use that minimum conduit or tubing size to determine the dimensions of the straight or angle box. The method is explained in Example 2.16.

Example 2.16 A cable assembly containing four conductors size 2 AWG copper with Type THWN insulation enter one side of a box and leave the adjacent side of the box. Determine the minimum size of box required for splicing these conductors.

Answer: Because the conductors are larger than size 6 AWG, this is to be treated as an angle pull and sized according to *314.28(A)(2)*. First determine the minimum trade diameter conduit or tubing that would have been required if the conductors had been run in conduit or tubing rather than as a cable assembly. Look up the cross-sectional area of the size 2 AWG Type THWN conductors in *Table 5* and find the value 0.1158 sq. in. (74.71 mm^2). Multiply this value by 4 conductors to get 0.4632 sq. in. (0.1158 in.^{2} $\times$ 4 = 0.4632 in.^{2}) (74.71 mm^2 $\times$ 4 = 299 mm^2). Then look up the minimum size conduit or tubing from *Table 4* in the 40% column. The minimum is trade size 1$^1/_4$ (35). If two different sizes are found, use whichever is smaller. Now use the rule of *314.28(A)(2)* and multiply by 6 to get the minimum dimension of 7.5 in. (1.25 in. $\times$ 6 = 7.5 in.) (35 mm $\times$ 6 = 210 mm). Another method of finding the minimum trade size conduit or tubing is to look up the size in *Annex C*. Usually, *Table C4* for IMC will give the minimum trade size.

Sizing and Installing Parallel Conductor Sets

In the case of high-ampacity feeders, one conductor per phase may not be practical. Under these circumstances, two or more conductors per phase may be desirable or even necessary. The objective is to keep the resistance of each parallel path equal so the load current will divide equally on each wire of the set. The wires and terminations heat up when they carry current; therefore, the resistance changes when the temperature of the wire and terminations changes. For these reasons, special requirements are necessary when installing parallel sets of wires. The following is a summary of some special installation rules of *310.4* for sets of multiple conductors for each ungrounded conductor and the grounded conductor:

1. Power conductors are permitted to be paralleled only for size 1/0 AWG and larger, except for special applications.
2. All parallel conductors of a phase or neutral set shall be the same length.
3. All conductors of the phase or neutral set shall be of the same material, cross-sectional area, and the same insulation type.

4. All conductors of a phase or neutral set shall be terminated in the same manner.
5. If run in more than one raceway, the raceways shall have the same physical properties, and the same length, and shall be installed in the same manner.
6. If more than one raceway is used, make sure each phase wire and neutral, if present, is placed in each of the raceways to prevent eddy currents, as shown in Figure 2.28. This requirement is found in *300.20(A).*
7. If an equipment grounding wire is present and there is more than one raceway, an equipment grounding wire shall be in each raceway. The size of each equipment grounding conductor is determined according to *250.122(F)*, which means the overcurrent rating of the feeder determines the minimum permitted size of the equipment grounding conductor in each raceway. See also Figure 5.10.

These rules for the installation of parallel sets of conductors apply to conductors of the same phase or neutral. Phase A is not required to be identical to phase B, for example. But all of the wires of phase A are required to be identical, as discussed in the previous points.

Determining the minimum parallel conductor size for a particular application can be confusing. In the case where there is a single main disconnecting means, the minimum permitted conductor size is determined by dividing the rating of the feeder overcurrent device by the number of parallel sets of conductors. If there are more than three current-carrying conductors in a single raceway, then a derating factor according to *310.15(B)(2)(a)* must be applied. Equation 2.4 can be used to determine the minimum permitted wire size for a feeder consisting of parallel sets of conductors. If the feeder rating is not over 800 amperes, then the next wire size smaller may be permitted to be used by *240.4(B).* For some services, calculated load may be used.

$$\textbf{Minimum Parallel Conductor Ampacity} = \frac{\textbf{Feeder Overcurrent Rating}}{\textbf{No. of Sets} \times \textbf{Derate Factor}} \qquad \textbf{Eq. 2.4}$$

Example 2.17 Determine the minimum permitted size of copper Type THWN conductors when three parallel sets are used for a 3-phase, 3-wire feeder with a 500-ampere overcurrent device that is not rated for 100% continuous operation and when the actual load current does not exceed 80% of the rating of the overcurrent device. All nine conductors are run in the same raceway.

Answer: The result of the calculation of Equation 2.4 gives a minimum feeder conductor rating of 238 amperes when there are three parallel sets. The minimum Type THWN copper wire size from *Table 310.16* is 250 kcmil with a rating of 255 amperes. This feeder has a rating of less than 800 amperes; therefore, *240.4(B)* will apply. In this case, a size 4/0 AWG conductor rated at 230 amperes is adequate for the load and will satisfy the requirement of *240.4(B).*

$$\text{Minimum Parallel Conductor Ampacity} = \frac{500\text{ A}}{3 \times 0.7} = 238\text{ A}$$

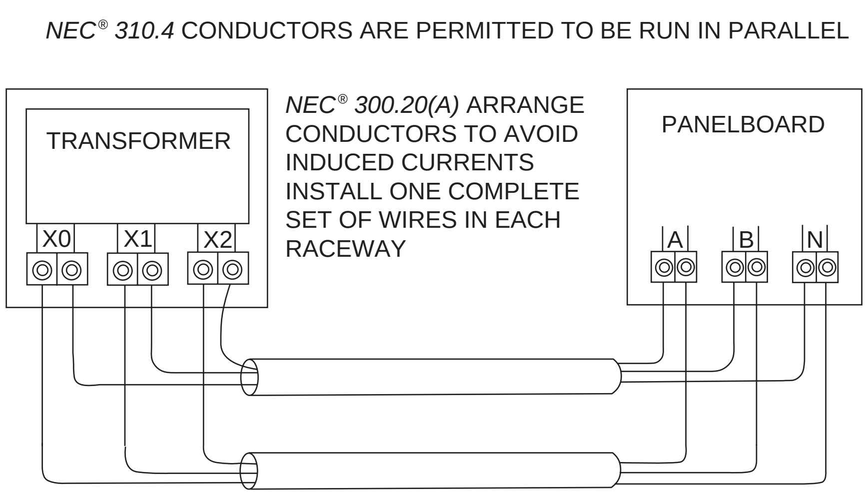


Figure 2.28 Care must be taken when paralleling sets of conductors, particularly when more than one raceway is used.

Size 250-kcmil copper, Type THWN: $255 \text{ A} \times 0.7 \times 3 = 536 \text{ A}$

Size 4/0 AWG copper, Type THWN: $230 \text{ A} \times 0.7 \times 3 = 483 \text{ A}$

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin. Only the articles with significant changes are listed in the following discussion.

Article 314 **Outlet, Device, Pull, and Junction Boxes; Conduit Bodies; Fittings; and Handhole Enclosures**

314.24: This section specifies the minimum depth of boxes used for outlets, devices, and utilization equipment. The previous editions of the Code simply specified the minimum depth to be 1/2 in. (12.7 mm) if the box did not contain any devices or enclosed utilization equipment. The minimum depth was 11/16 in. (23.8 mm) if the box did contain a device or utilization equipment. These remain the minimum depths for boxes with and without devices, but there have been changes in the minimum depth for boxes enclosing utilization equipment. There is also one additional overall rule that applies in all cases, and that is the box shall have sufficient depth to permit proper mounting of the device or utilization equipment that prevents damage to conductors in the box.

When utilization equipment is enclosed in a box, the minimum depth depends upon the size of conductors connecting to the equipment. Extension boxes, plaster rings, and raised covers are permitted to be counted to gain the necessary minimum depth. The minimum depth is 15/16 in. (23.8 mm) when the wires are size 14 AWG and smaller. For wires sizes 12 and 10 AWG, the minimum depth is 1 3/16 in. (30.2 mm) with the additional requirement that for utilization equipment extending more than 1 in. (25 mm) into the box, the minimum depth is the distance the device extends into the box plus an additional 1/4 in. (6 mm). If the wires are sizes 8, 6, or 4 AWG, the minimum box depth is 2 1/16 in. (52.4 mm). Where the wire is larger than size 4 AWG, the box is to be listed for the application. In the case where the utilization equipment extends into the box more than 1 7/8 in. (48 mm), the box is to have a minimum depth of not less than the maximum depth of the utilization equipment plus an additional 1/4 in. (6 mm).

314.27(A): Boxes that are installed in a ceiling at a location intended for a luminaire (lighting fixture) are required to be designed to support luminaires weighing up to 50 lbs. (23 kg). Round and octagon boxes with side brackets are often not designed to support a 50 lb. (23 kg) weight. There is no exception in this section for ceiling outlets such as in closets, stairways, utility rooms, garages, and basements where a light weight luminaire (lighting fixture) or porcelain fixture is commonly used. Another practice is where a fluorescent luminaire is mounted directly to the structure, but over an outlet box. This same paragraph treats wall boxes for luminaires (lighting fixtures) separately and requires the box to be designed for the purpose with the maximum weight that can be supported marked in the box.

314.27(B): This section sets the maximum weight of 50 lbs. (23 kg) that a luminaire (lighting fixture) can weigh and be mounted to the box. The change in this section is that words were added to specify that in order to support a luminaire, the box is required to be designed for the purpose.

314.27(E): This is a new paragraph relating to the support of utilization equipment other than paddle fans. An example of such utilization equipment is a smoke detector. The box is to meet the same requirements as for luminaire mounting as stated in the previous paragraphs (A) and (B). There is an exception that permits utilization equipment weighing not over 6 lbs. (3 kg) to be mounted to a box extension or plaster ring.

314.28(A)(2): In the case where wires are size 4 AWG and larger and where run as cable or as individual wires in raceway, the sizing of a box for pulling purposes is specified in this section. If wires size 4 AWG or larger enter a box, are spliced, and leave the adjacent face of the box, this is also considered to be an angle pull and the provisions of this section for angle pulls shall apply.

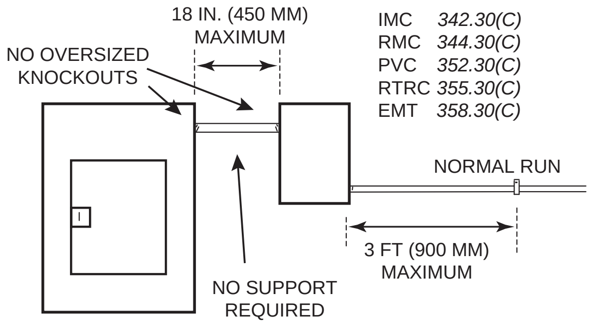


Figure 2.29 An unbroken run of IMC, RMC, PVC, RTRC, or EMT is permitted to connect between two boxes, panels, or enclosures without support other than the terminations, provided the length does not exceed 18 in. (450 mm) and there are no oversized knockouts remaining at either termination.

Article 342 Intermediate Metal Conduit: Type IMC

342.30(C): This is a new paragraph dealing with the case of a short run of IMC between two boxes and or enclosures that are solidly connected to the structure. The question is how short a run of IMC is required before no support is required for the IMC between the boxes or enclosures? If this were a long run of IMC, it would be required to support the raceway within a maximum distance of 3 ft (900 mm) of the termination. Also in *342.30(A)*, the IMC is actually permitted to be supported no closer than 5 ft (1.5 m) from the termination if it is not practical to support it at a closer distance. Now back to the earlier question. In the field, it has been a generally accepted practice to allow a distance of up to 3 ft (900 mm) between enclosures or boxes with no additional support of the IMC other than the terminations to the solidly mounted boxes or enclosures. This new paragraph, however, only permits this practice if the IMC length is not more than 18 in. (450 mm) and there are no oversized knockouts remaining in the box or enclosure. This is illustrated in Figure 2.29. If there are oversized knockouts remaining in one or both of the boxes or enclosures, then a support is required for the IMC. Technically, then, as stated in this paragraph, a support is required between boxes or enclosures, no matter the length of the IMC if oversized knockouts remain in place.

Article 344 Rigid Metal Conduit: Type RMS

344.10(A): This section states the uses permitted for Rigid Metal Conduit (RMC). The change is that now the uses permitted for the different types of RMC are described. In the past, there were questions in the field as to use permitted. Galvanized steel and stainless steel RMC are permitted to be installed in all types of occupancies under any type of condition. The silicon bronze or red brass type of RMC is a special type made for the corrosive conditions that exist in swimming pool areas. This type is permitted for any direct burial application. Aluminum RMC has some limitations and is permitted where judged suitable for the conditions. Supplementary corrosion protection is required where aluminum RMC is installed in contact with the earth.

344.10(B): With respect to elbows, couplings, and fittings for Rigid Metal Conduit in areas where there is a corrosive environment, galvanized steel, stainless steel, and red brass types are permitted. Aluminum RMC elbows, couplings, and fittings are permitted in these areas, but supplementary corrosion protection is required when in direct contact with the earth or encased in concrete.

344.10(C): This paragraph states when Rigid Metal Conduit is permitted to be installed in or under cinder fill. In the previous edition of the Code, the types permitted were not listed. Now it states that galvanized steel, stainless steel, and red brass RMC are permitted for this application. Aluminum RMC is not permitted.

344.30(C): Support for a run of RMC other than the terminations is not required where the run is between two boxes or enclosures as one complete run without couplings or fittings, there are no oversized knockouts remaining at either termination, and the length does not exceed 18 in. (450 mm). If these conditions are not met, support is required to be provided in accordance with *344.30(A)* and *(B)*. See Figure 2.29 and previous discussion under *342.30(C)*.

Article 348 Flexible Metal Conduit: Type FMC

348.12(1): The condition where Flexible Metal Conduit was permitted to be installed in a wet location was deleted. The previous edition of the Code permitted Flexible Metal Conduit to be installed in a wet location if the conductors in the conduit were suitable for the conditions and the FMC was installed in such a manner that water could not enter other raceways or enclosures. Now there are no exceptions; FMC is not permitted to be installed in a wet location.

348.30(A) Exception 1: Flexible Metal Conduit is permitted to be fished into place where the normal support requirements do not apply. The change is that it is made clear that not providing support for the FMC applies only when fished into concealed spaces in finished buildings and in other locations where such support is impractical.

Article 350 Liquidtight Flexible Metal Conduit: Type LFMC

350.30(A) Exception 1: Liquidtight Flexible Metal Conduit is permitted to be fished into place where the normal support requirements do not apply. The change is that it is made clear that not providing support for the LFMC applies only when fished into concealed spaces in finished buildings and in other locations where such support is impractical.

350.30(A) Exception 2: The previous edition of the Code specified that when Liquidtight Flexible Metal Conduit is installed in a location where flexibility is required after installation, the maximum length permitted to be installed supported only by the connectors was 3 ft (900 mm). That is still the rule for LFMC in trade sizes up to $1\frac{1}{4}$ in. (35). For trade sizes $1\frac{1}{2}$ in. (41) up to 2 in. (53), the length supported only by the connectors is permitted to be 4 ft (1.2 m). For trade size $2\frac{1}{2}$ in. (63) and larger, the maximum length supported only by the connectors is 5 ft (1.5 m). This new rule is illustrated in Figure 2.30.

Article 352 Rigid Polyvinyl Chloride Conduit: Type PVC

352.10(F): It is made clear that PVC conduit is permitted to be installed exposed. It now also makes it clear that if PVC conduit is installed in an area where it is exposed to physical damage, the conduit must be identified for physical damage. A new fine print note was added stating that Schedule 80 PVC conduit is identified for installation in areas exposed to physical damage.

352.30(C): Support for a run of PVC Rigid Nonmetallic Conduit other than the terminations is not required where the run is between two boxes or enclosures as one complete run without couplings or fittings, there are no oversized knockouts remaining at either termination, and the length does not exceed 18 in. (450 mm). If these conditions are not met, support is required to be provided in accordance with *352.30(A)* and *(B)*. See Figure 2.29 and previous discussion under *342.30(C)*.

Article 353 High-Density Polyethylene Conduit: Type HDPE

353.10(5): High-Density Polyethylene Conduit (HDPE) is permitted to be installed above ground, provided it is encased in not less than 2 in. (50 mm) of concrete.

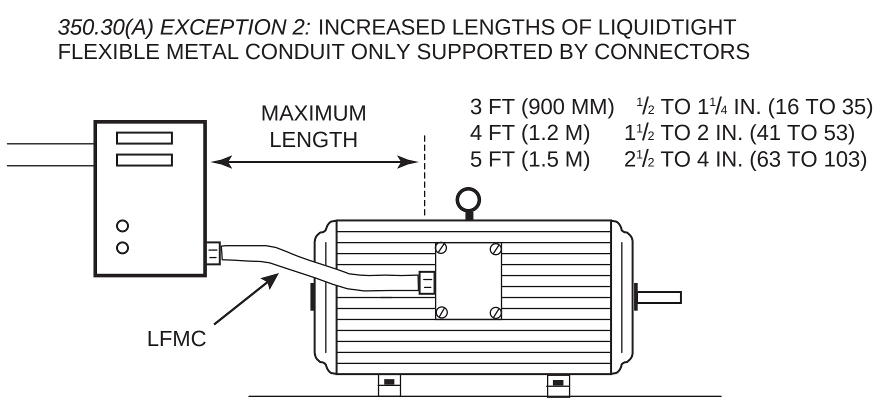


Figure 2.30 The length of Liquidtight Flexible Metal Conduit supported only at the connectors installed where flexibility is needed is permitted to be greater than 3 ft (900 mm) for sizes $1\frac{1}{2}$ in. (38 mm) and larger.

353.20(B): Type HDPE conduit is now permitted in sizes up to trade size 6 in. (155). The maximum size permitted by the previous edition of the Code was trade size 4 in. (103).

Article 354 Nonmetallic Underground Conduit with Conductors: Type NUCC

354.10(5): Nonmetallic Underground Conduit with Conductors (NUCC) is permitted to be installed above ground, provided it is encased in not less than 2 in. (50 mm) of concrete.

Article 355 Reinforced Thermosetting Resin Conduit: Type RTRC

355.2: Reinforced Thermosetting Resin Conduit (RTRC) is classified as Rigid Nonmetallic Conduit, and its use and installation were included in *Article 352* along with PVC in the previous edition of the Code. It is a different material than PVC, yet installation and use are nearly the same as PVC. This material now has its own article. The most noticeable differences with PVC is that RTRC is a stiffer product, and its thermal expansion and contraction are less than half that of PVC.

355.30(C): Support for a run of RTRC Rigid Nonmetallic Conduit other than the terminations is not required where the run is between two boxes or enclosures as one complete run without couplings or fittings, there are no oversized knockouts remaining at either termination, and the length does not exceed 18 in. (450 mm). If these conditions are not met, support is required to be provided in accordance with *355.30(A)* and *(B)*. See Figure 2.29 and previous discussion under *342.30(C)*.

Article 358 Electrical Metallic Tubing: Type EMT

358.30(C): Support for a run of EMT other than the terminations is not required where the run is between two boxes or enclosures as one complete run without couplings or fittings, there are no oversized knockouts remaining at either termination, and the length does not exceed 18 in. (450 mm). If these conditions are not met, support is required to be provided in accordance with *358.30(A)* and *(B)*. See Figure 2.29 and previous discussion under *342.30(C)*.

Article 362 Electrical Nonmetallic Tubing: Type ENT

362.30(A) Exception 3: Electrical Nonmetallic Tubing (ENT) in complete lengths without couplings is now permitted to be fished between outlets in finished buildings or in prefinished wall panels where securing as normally required is impractical. An application in a concealed wall is shown in Figure 2.31.

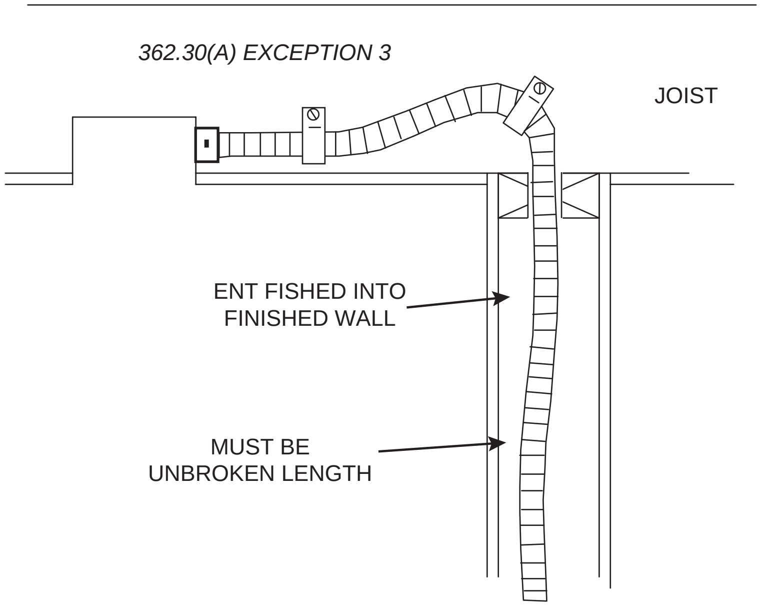


Figure 2.31 It is permitted to fish Electrical Nonmetallic Tubing (ENT) into finished wall spaces of finished buildings where support of the ENT is not practical.

Article 376 Metal Wireways

376.100: New detailed construction specifications that were not in previous editions of the Code are provided for Metal Wireways.

Article 388 Surface Nonmetallic Raceways

388.30: There is now a new requirement that Surface Nonmetallic Raceway be supported in accordance with manufacturer's installation instruction. The previous edition of the Code did not contain any support requirement.

Chapter 9 Tables

Table 1, Note 9: When a multi-conductor cable is run in raceway, this note specified that the cable was to be treated as a single conductor with a diameter equal to the maximum cross-sectional dimension of the cable. There was no such rule for multi-conductor flexible cords. Now flexible cords are covered by this same rule, which states that they are to be treated as a single conductor (53% fill) using the overall diameter of the cable to determine the cord cross-sectional area.

WORKSHEET NO. 2—BEGINNING WIRE, RACEWAY, AND BOX SIZING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A metallic 3 in. by 2 in. (75 mm by 50 mm) device box contains one 3-way switch. The cables entering the box are one Type NM-B size 14 AWG copper 2-conductor with equipment ground, and one Type NM-B size 14 AWG copper 3-conductor with equipment ground, as shown in Figure 2.32. The device box contains cable clamps. The minimum permitted box depth for this installation is:

   A. 2 1/4 in. (57 mm).
   B. 2 1/2 in. (65 mm).
   C. 2 3/4 in. (70 mm).
   D. 3 1/2 in. (90 mm).
   E. 4 in. (100 mm).

   Code reference __________________

2. A single-gang nonmetallic box without cable clamps is used instead of the metallic box shown in Figure 2.32. The cables entering the box are one Type NM-B size 14 AWG copper 2-conductor with equipment ground, and one Type NM-B size 14 AWG copper 3-conductor with equipment ground. There is also a 3-way switch in the box. The minimum box volume permitted is:

   A. 14 in.^{3} (229 cm^3).
   B. 15.75 in.^{3} (258 cm^3).
   C. 16 in.^{3} (262 cm^3).
   D. 18 in.^{3} (295 cm^3).
   E. 20.25 in.^{3} (332 cm^3).

   Code reference __________________

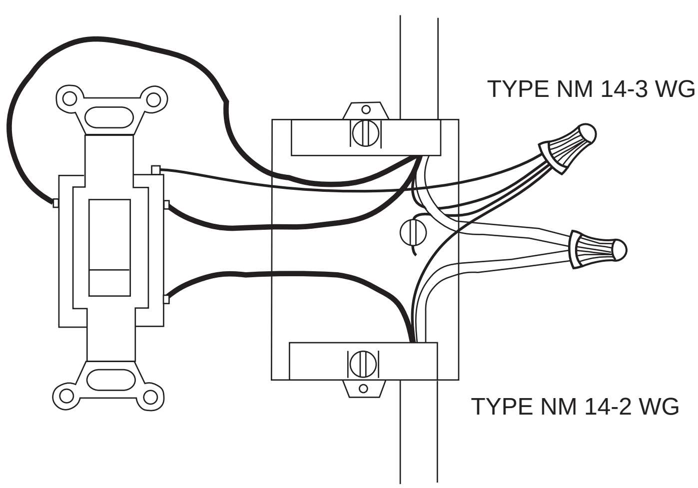


Figure 2.32 A 3-way switch is installed in a metal device box with size 14 AWG Type NM-B Cable entering both ends of the box.

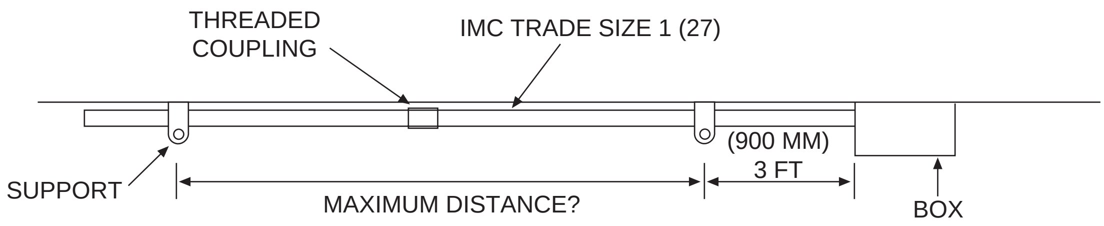


Figure 2.33 Intermediate Metal Conduit is run exposed on the ceiling of a room.

3. A straight run of trade size 1 (27) Intermediate Metal Conduit (IMC) is joined with threaded couplings and is supported within 3 ft (900 mm) of a box, as shown in Figure 2.33. The maximum distance permitted between supports of this straight run of IMC is:
   A. 10 ft (3 m).
   B. 12 ft (3.7 m).
   C. 14 ft (4.3 m).
   D. 16 ft (4.9 m).
   E. 20 ft (6.1 m).

   Code reference ___________________

4. A feeder consists of four size 4/0 AWG copper Type THWN conductors run in *Schedule* 40 PVC Type Rigid Nonmetallic Conduit. The minimum trade size conduit permitted for this feeder is:
   A. trade size 1 (27).
   B. trade size 1$^1/_4$ (35).
   C. trade size 1$^1/_2$ (41).
   D. trade size 2 (53).
   E. trade size 2$^1/_2$ (63).

   Code reference ___________________

5. The conductor cross-sectional area is less than 20% of the cross-sectional area of a metal wireway. The adjustment factors for determining conductor allowable ampacity of *310.15(B)(2)(a)* do not apply to conductors in this wireway if the number of current-carrying conductors in the wireway does not exceed:
   A. thirty.
   B. twelve.
   C. nine.
   D. six.
   E. three.

   Code reference ___________________

6. A nonmetallic single-gang trade size 2 by 3 (50 by 75) box without cable clamps is installed in a wall of a new dwelling. The wiring method is Nonmetallic-Sheathed Cable, Type NM-B with a minimum of $^1/_4$ in. of the cable sheath extending into the box. It is not required to secure the cable to this box if the cable is fastened within a distance from the box measured along the cable of not more than:
   A. 3 in. (75 mm).
   B. 4 in. (100 mm).
   C. 6 in. (150 mm).
   D. 8 in. (200 mm).
   E. 12 in. (300 mm).

   Code reference ___________________

7. Fluorescent lay-in luminaires (lighting fixtures) are mounted in an accessible suspended ceiling and supplied from 20-ampere branch-circuits. Flexible Metal Conduit supported by only a listed connector at a solidly mounted junction box and at the luminaire (lighting fixture) is permitted to be installed to supply a luminaire (fixture) in lengths not to exceed:
   A. 18 in. (450 mm).
   B. 24 in. (600 mm).
   C. 3 ft (900 mm).
   D. 4 ft (1.2 m).
   E. 6 ft (1.8 m).

   Code reference ___________________

8. A pull box is installed with a trade size 4 (103) Electrical Metallic Tubing entering one end and leaving the opposite end. The conductors in the run of raceway are size 500-kcmil copper Type RHW. The minimum length of a pull box permitted for this installation is:
   A. 12 in. (305 mm).
   B. 18 in. (457 mm).
   C. 24 in. (610 mm).
   D. 30 in. (762 mm).
   E. 32 in. (812 mm).

   Code reference ____________________

9. Trade size 1 (27) PVC Type Rigid Nonmetallic Conduit is run as exposed surface wiring in a building and securely fastened within a distance of not more than 3 ft (900 mm) of each box and cabinet. The maximum distance between supports in a run of this RNC is not permitted to be greater than:
   A. 3 ft (900 mm).
   B. 5 ft (1.5 m).
   C. 6 ft (1.8 m).
   D. 8 ft (2.5 m).
   E. 10 ft (3 m).

   Code reference ____________________

10. Size 500-kcmil Type THWN copper conductors are permitted to enter the top of a panelboard and terminate into lugs, as shown in Figure 2.34, provided the distance from the top of the lugs to the top of the panelboard enclosure is not less than:
    A. 6 in. (152 mm).
    B. 10 in. (305 mm).
    C. 11 in. (279 mm).
    D. 14 in. (356 mm).
    E. 15 in. (381 mm).

    Code reference ____________________

11. A 44-ampere continuous load is supplied by a circuit consisting of three copper Type THHN conductors run in Electrical Metallic Tubing as illustrated in Figure 2.35 on the next page. There are no other conductors in the EMT and the circuit is protected with a 60-ampere rated circuit breaker. All conductor terminations in the circuit are rated 75°C. The minimum size conductor permitted for this circuit is:
    A. 8 AWG.
    B. 6 AWG.
    C. 4 AWG.
    D. 3 AWG.
    E. 2 AWG.

    Code reference ____________________

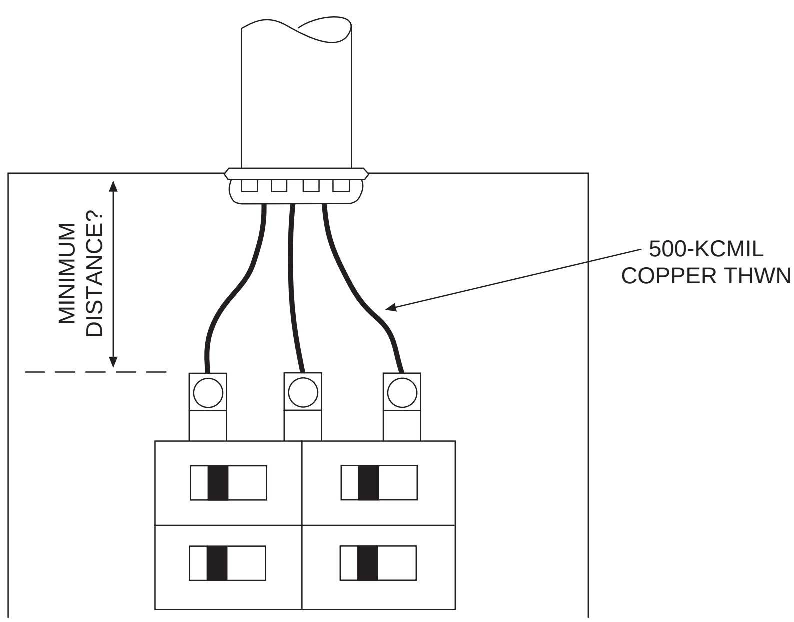


Figure 2.34 A set of size 500-kcmil conductors enter a panelboard and terminate at the supply lugs.

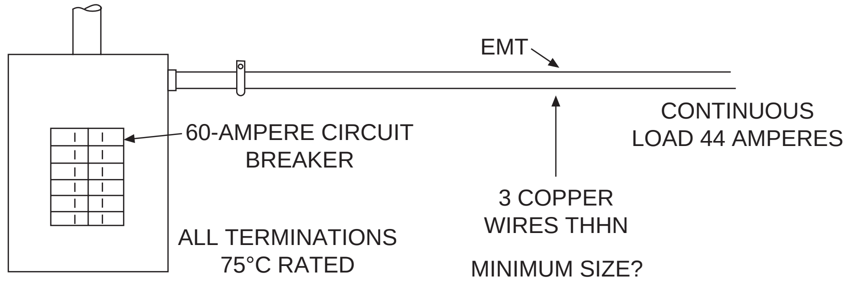


Figure 2.35 Three copper conductors with THHN insulation are run in EMT for a 60-ampere rated circuit to supply a 44-ampere load.

12. A 90° bend made in trade size 2 (53) PVC Rigid Nonmetallic Conduit in the field is not permitted to have a radius measured to the centerline of the conduit of less than:
    A. $9^1/_2$ in. (241 mm).
    B. 10 in. (254 mm).
    C. 12 in. (305 mm).
    D. 14 in. (356 mm).
    E. 15 in. (381 mm).

    Code reference ___________________

13. Conductors are run to an electric motor in raceway with the final connection of Liquidtight Flexible Nonmetallic Conduit, Type LFNC-B, to provide for some flexibility at the motor for adjustments and to prevent transmission of vibration. The installation is shown in Figure 2.36. An equipment bonding jumper is included. The Liquidtight Flexible Nonmetallic Conduit supported only at its terminations is permitted to be installed for this purpose in lengths not exceeding:
    A. 18 in. (450 mm).
    B. 2 ft (600 mm).
    C. 3 ft (900 mm).
    D. 4 ft (1.4 m).
    E. 6 ft (1.8 m).

    Code reference ___________________

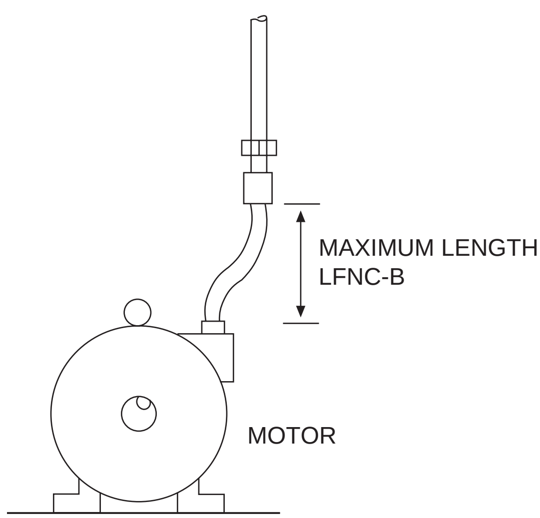


Figure 2.36 The final connection from a conduit to a motor terminal box is with a short length of LFNC-B Liquidtight Flexible Nonmetallic Conduit.

14. A metallic auxiliary gutter is installed at a motor control location for running circuit conductors from a panelboard to the various controllers. The auxiliary gutter is made mechanically and electrically continuous and is required to be supported at intervals not to exceed:
   A. 5 ft (1.5 m).
   B. 6 ft (1.8 m).
   C. 8 ft (2.5 m).
   D. 10 ft (3 m).
   E. 12 ft (3.7 m).

   Code reference ____________________

15. A service in a building has a main overcurrent device rated 1600 amperes. The service-entrance conductors are copper Type THWN run as four parallel sets each in a separate Rigid Metal Conduit, shown in Figure 2.37. All conductor terminations are rated 75°C, and there are only three current-carrying conductors in each service raceway. The minimum size conductors permitted for this service are size:
   A. 500 kcmil.
   B. 600 kcmil.
   C. 700 kcmil.
   D. 750 kcmil.
   E. 800 kcmil.

   Code reference ____________________

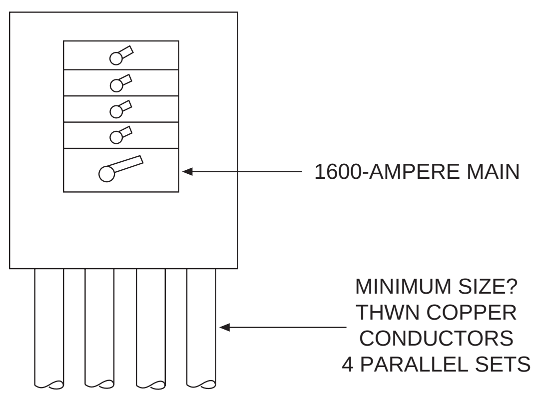


Figure 2.37 A panelboard serving as the main service for a building has a 1600-ampere main overcurrent device and is supplied by four parallel sets of copper THWN conductors.

WORKSHEET NO. 2—ADVANCED WIRE, RACEWAY, AND BOX SIZING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A trade size 1 (27) Electrical Metallic Tubing is run across a ceiling perpendicular to the trusses and attached to the bottom of the trusses as shown in Figure 2.38. The EMT is supported at each luminaire (lighting fixture) and at each truss. The maximum permitted distance from the luminaire (lighting fixture) to the first support is:
   A. 18 in. (450 mm).
   B. 3 ft (900 mm).
   C. 4 ft (1.2 m).
   D. 5 ft (1.5 m).
   E. 10 ft (3 m).

   Code reference ___________________

2. A metal junction box has one size 8 AWG 3-conductor Type NM-B Cable with equipment ground entering and two size 10 AWG 3-conductor Type NM-B Cables with equipment ground entering, as shown in Figure 2.39 on the next page. The junction box is required to have a minimum volume of:
   A. 18 in.^{3} (295 cm^3).
   B. 22.5 in.^{3} (369 cm^3).
   C. 27 in.^{3} (443 cm^3).
   D. 32 in.^{3} (524 cm^3).
   E. 36 in.^{3} (590 cm^3).

   Code reference ___________________

3. A circuit consisting of three copper Type THHN conductors is run in Electrical Metallic Tubing (EMT) serving a continuous load of 44 amperes. There are six other conductors with THHN insulation in the same run of EMT for a total of nine current-

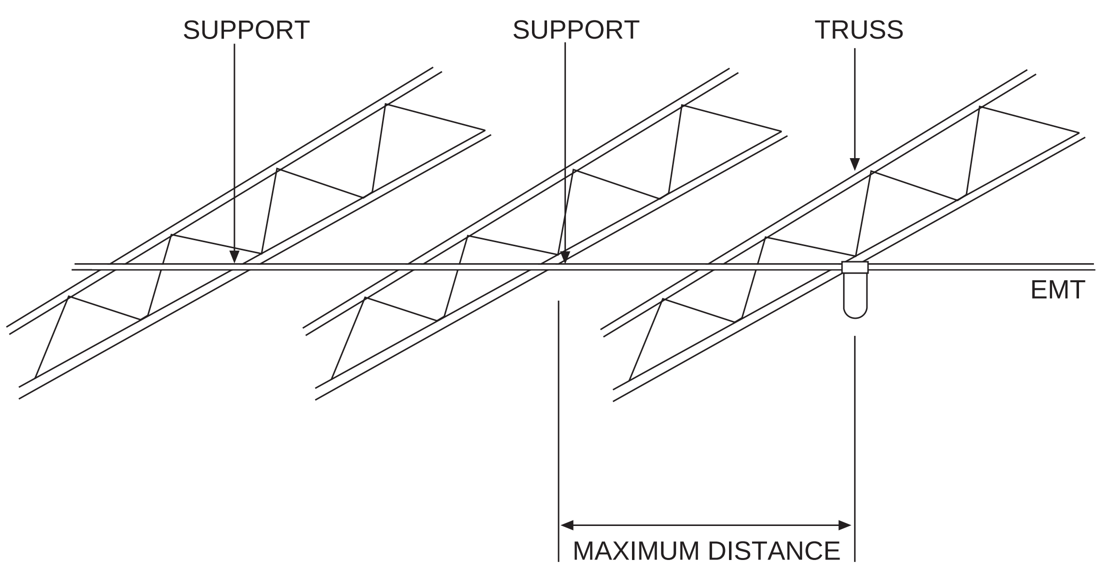


Figure 2.38 Electrical Metallic Tubing of the trade size 1 (27) is attached to the underside of ceiling trusses at the boxes and at the truss between the luminaires (lighting fixtures).

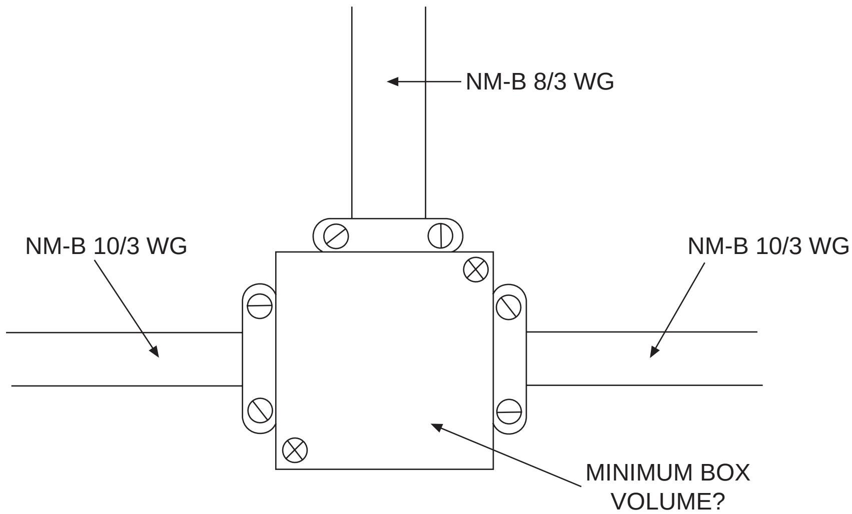


Figure 2.39 A square junction box has two 3-conductor with equipment ground size 10 AWG cables and one 3-conductor with equipment ground size 8 AWG cable entering.

carrying conductors in the raceway, illustrated in Figure 2.40. If a 60-ampere overcurrent device protects the circuit, and all terminations are 75°C rated, the minimum size conductor permitted for the circuit is:

A. 12 AWG.
B. 10 AWG.
C. 8 AWG.
D. 6 AWG.
E. 4 AWG.

Code reference ___________________

4. Several circuits are run in *Schedule* 40 PVC Rigid Nonmetallic Conduit as shown in Figure 2.41 on the next page. There are four conductors size 3/0 AWG copper Type THHN, six conductors size 10 AWG copper Type THHW, and one size 6 AWG bare copper equipment grounding conductor. The minimum trade size PVC conduit permitted for these conductors is:

A. trade size 2 (53).
B. trade size $2^1/_2$ (63).
C. trade size 3 (78).
D. trade size $3^1/_2$ (91).
E. trade size 4 (103).

Code reference ___________________

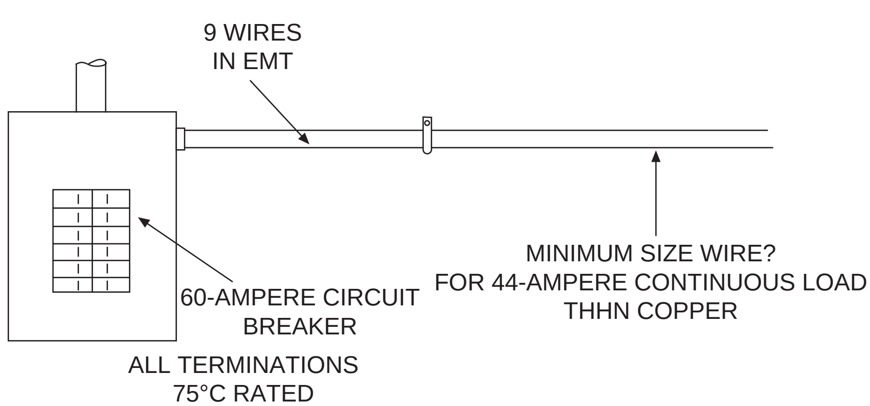


Figure 2.40 A circuit protected at 60 amperes and with a 44-ampere load is run in a raceway with a total of nine current-carrying conductors.

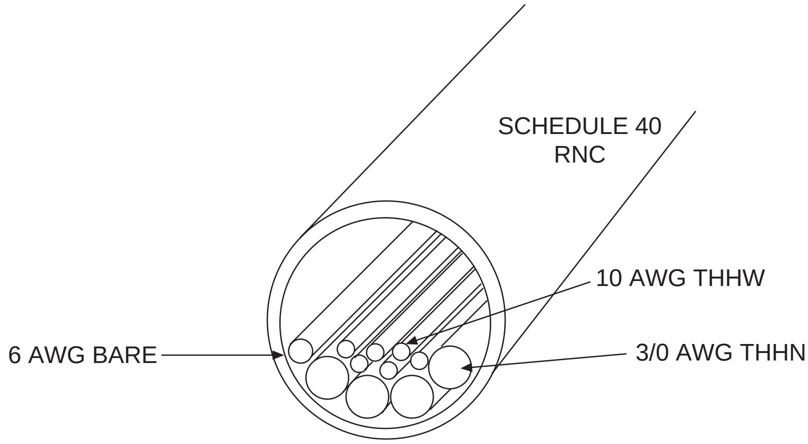


Figure 2.41 A *Schedule* 40 Rigid Nonmetallic Conduit contains one bare size 6 AWG conductor, six size 10 AWG Type THHW conductors, and four size 3/0 AWG Type THHN conductors.

5. Two enclosures are on back-to-back on opposite sides of a solid concrete wall and connected with a Rigid Metal Conduit that is only 14 in. (356 mm) in length. Four size 1 AWG copper Type THWN conductors are run through the conduit which, in this case, is required to have a minimum trade size of:
   A. trade size $^3/_4$ (21).
   B. trade size 1 (27).
   C. trade size $1^1/_4$ (35).
   D. trade size $1^1/_2$ (41).
   E. trade size 2 (53).

   Code reference ___________________

6. The general use 125-volt receptacles in a commercial building are supplied by 20-ampere rated multiwire branch-circuits with three ungrounded conductors and a common neutral from a 208/120-volt, 4-wire, 3-phase electrical system. The conductors for nine circuits are run in a single raceway to an area of the building including nine ungrounded conductors and three neutral conductors. For the purpose of applying adjustment factors to determine the allowable ampacity of the conductors, the number of current-carrying conductors for this set of circuits is:
   A. six.
   B. nine.
   C. ten.
   D. twelve.
   E. sixteen.

   Code reference ___________________

7. Four Type THHN copper current-carrying conductors are run in EMT and supply two 20-ampere incandescent lighting circuits where all conductor terminations are rated 75°C. The load on the circuits is 14.8 amperes. In route to the area where the luminaires (lighting fixtures) are installed, the raceway passes through an area for about 20 ft (6.1 m) where the room temperature is 125°F (52°C). The wiring is illustrated in Figure 2.42. The minimum size conductors permitted for these circuits is:
   A. not possible to determine with the information provided.
   B. 14 AWG.
   C. 12 AWG.
   D. 10 AWG.
   E. 8 AWG.

   Code reference ___________________

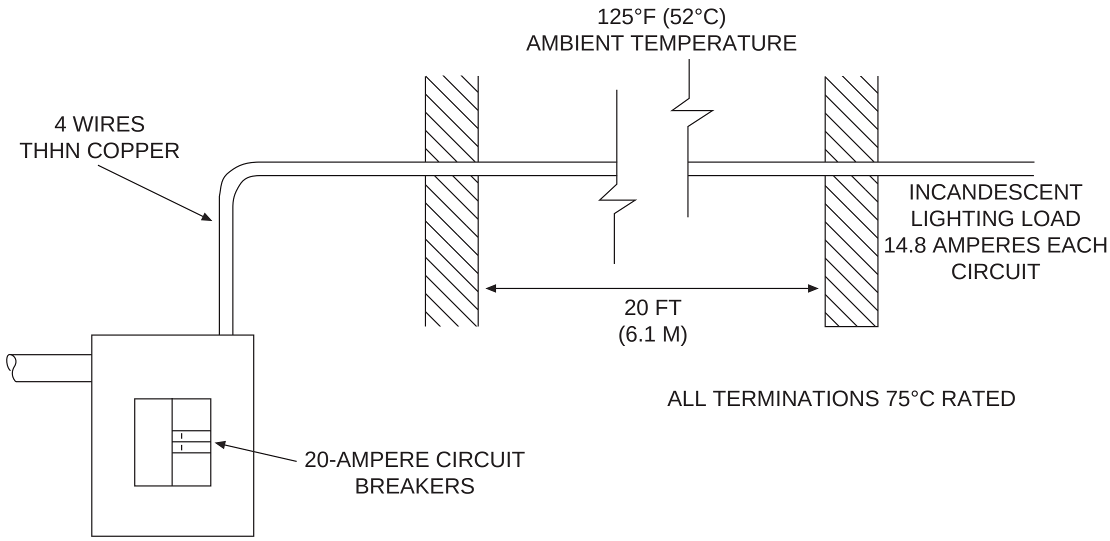


Figure 2.42 Four copper conductors with Type THHN insulation for 20-ampere circuits are run in the same raceway and pass through a room with a 125°F (52°C) ambient temperature.

8. A trade size 2 (53) EMT enters the top of a metal wireway, and out the bottom of the wireway is a trade size 2 (53) Rigid Metal Conduit connecting to a panelboard. Four size 1 AWG copper Type THHN conductors enter the wireway from the EMT and pass directly to the Rigid Metal Conduit as shown in Figure 2.43. The minimum permitted offset distance between the two raceways containing the same conductors is:
   A. not specified in the Code for this application.
   B. 6 in. (152 mm).
   C. 8 in. (203 mm).
   D. 10 in. (254 mm).
   E. 12 in. (318 mm).

   Code reference __________________

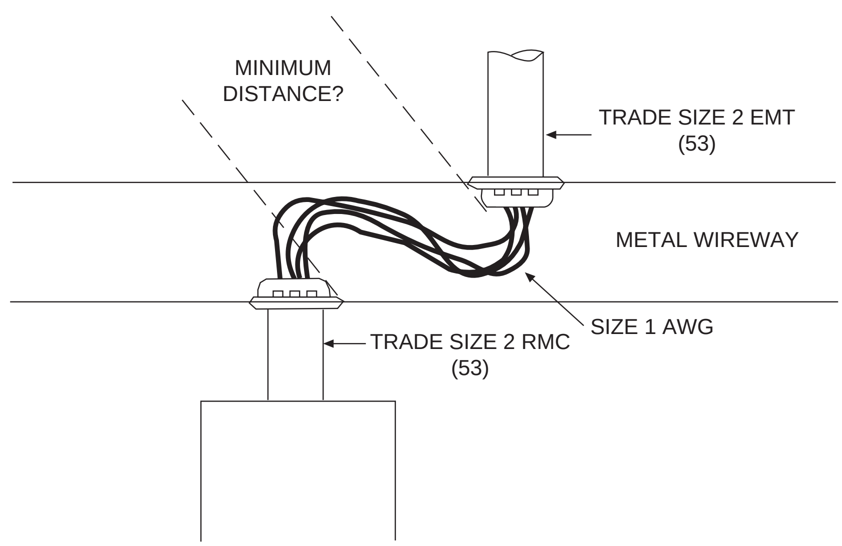


Figure 2.43 Size 1 AWG conductors pass through a metal wireway with a short distance offset.

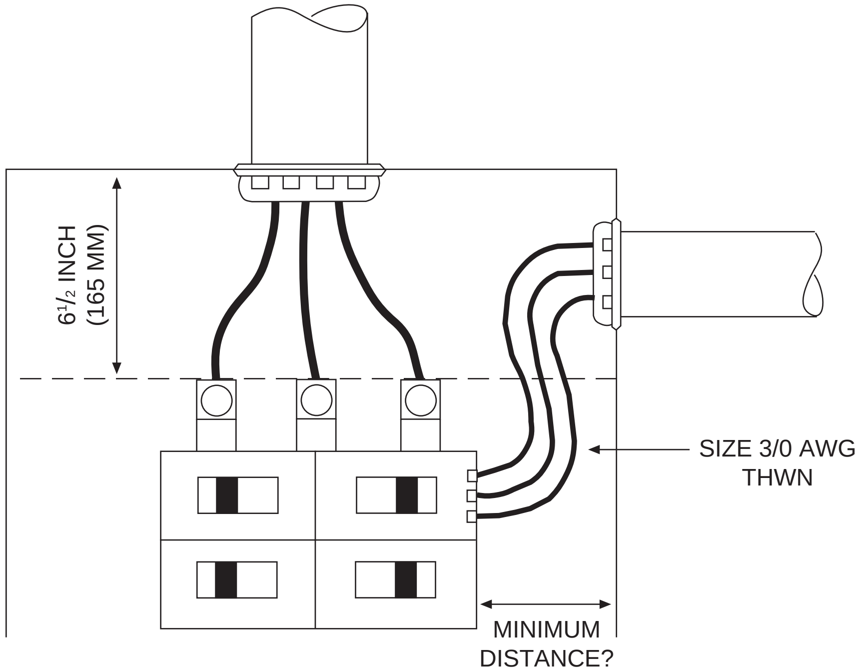


Figure 2.44 Size 3/0 AWG conductors connected to a disconnect make a 90° bend, travel to the top of the panel and then exit the wall opposite the disconnect terminals.

9. Conductors size 3/0 AWG Type THWN copper connected to a disconnect immediately make a 90° bend, travel to the top of the panelboard, then make another 90° bend and leave through the side of the panelboard as shown in Figure 2.44. The gutter space at the top of the panelboard is $6^1/_2$ in. (165 mm) deep. The installation is permitted provided the distance from the disconnect lugs to the side of the panelboard is not less than:
   A. 3 in. (76 mm).
   B. 4 in. (102 mm).
   C. 6 in. (152 mm).
   D. $6^1/_2$ in. (165 mm).
   E. 8 in. (203 mm).

   Code reference ___________________

10. Electrical Nonmetallic Tubing is permitted to be installed:
   A. for exposed work in buildings of any height.
   B. as concealed wiring only if the walls, floors, and ceilings provide a thermal barrier that has at least a 15-minute finish rating.
   C. as concealed wiring in buildings of any height with no requirement that the walls, floors, or ceiling have a fire rating.
   D. as concealed wiring in buildings of not more than three floors unless the walls, floors, and ceilings provide a thermal barrier that has at least a 15-minute finish rating.
   E. as concealed wiring in buildings of not more than three floors unless the walls, floors, and ceilings provide a thermal barrier that has at least a 1-hour finish rating.

   Code reference ___________________

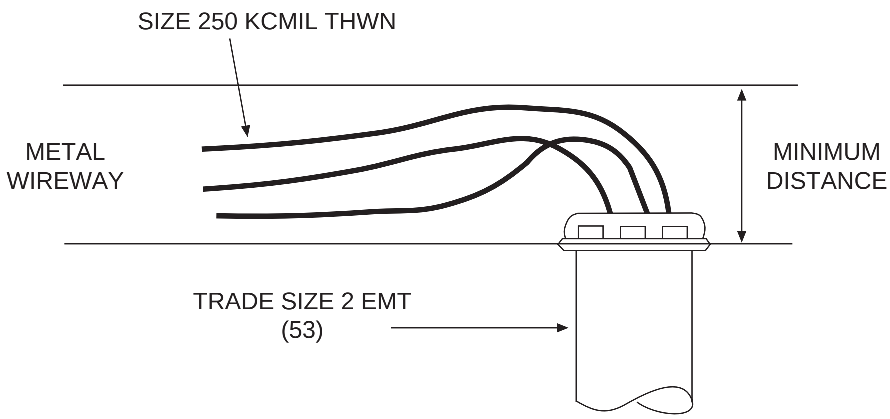


Figure 2.45 Size 250 kcmil conductors enter a metal wireway from a trade size 2 (53) EMT and make a 90° bend.

11. A 140 ft (42.7 m) straight run of trade size 1 (27) PVC Type Rigid Nonmetallic Conduit is installed in an unheated parking structure where the temperature throughout the year is likely to change up to 120°F (66.7°C). The change in length for this run of PVC Conduit over a season will be:
    A. 3.48 in. (88 mm).
    B. 4.87 in. (124 mm).
    C. 5.12 in. (130 mm).
    D. 5.84 in. (148 mm).
    E. 6.82 in. (173 mm).

    Code reference ___________________

12. All conductors run within a metallic auxiliary gutter have insulation rated 75°C. All splices, taps, and terminations of conductors within the auxiliary gutter or elsewhere in the circuits are rated 75°C. A size 8 AWG copper Type THWN conductor runs the entire length of a metallic auxiliary gutter and at one point along the gutter there are a total of 21 current-carrying conductors. The allowable ampacity of the size 8 AWG copper conductor for this application is:
    A. 22.5 amperes.
    B. 25 amperes.
    C. 35 amperes.
    D. 40 amperes.
    E. 50 amperes.

    Code reference ___________________

13. A trade size 2 (53) Electrical Metallic Tubing enters a metal wireway as shown in Figure 2.45, containing three Type THWN copper conductors size 250 kcmil. This metal wireway is required to have a width from the EMT entry to the opposite side of not less than:
    A. 4 1/2 in. (114 mm).
    B. 5 in. (127 mm).
    C. 5 1/2 in. (140 mm).
    D. 7 in. (178 mm).
    E. 9 in. (229 mm).

    Code reference ___________________

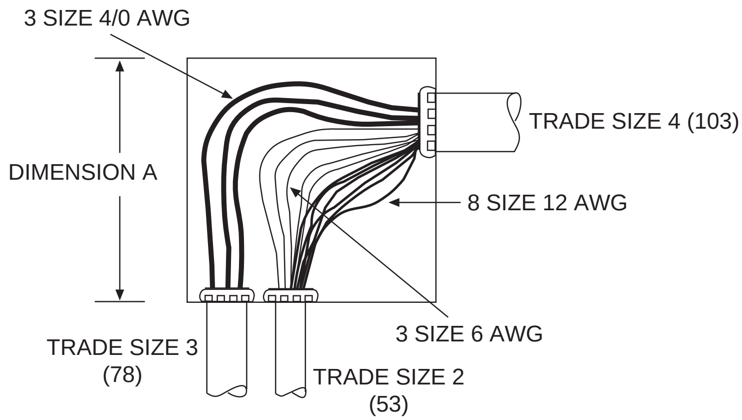


Figure 2.46 A pull box is installed for the purpose of making angle pulls.

14. A pull box has a trade size 4 (103) conduit entering one side and trade sizes 2 (53) and 3 (78) conduit entering the adjacent side as shown in Figure 2.46 on the next page. Three size 4/0 AWG conductors run from the trade size 4 (103) to the trade size 3 (78) conduits. Three size 6 AWG and eight size 12 AWG conductors run from the trade size 4 (103) to the trade size 2 (53) conduits. The minimum distance permitted from the trade size 3 (78) conduit to the opposite wall (dimension A) is:
    A. 20 in. (521 mm).
    B. 22 in. (559 mm).
    C. 24 in. (618 mm).
    D. 26 in. (660 mm).
    E. 30 in. (762 mm).

    Code reference ___________________

15. A 3-phase feeder consists of two parallel sets of Type THHW copper conductors run in a single trade size 6 (155) Rigid Metal Conduit. There is a total of six current-carrying conductors in the conduit. The calculated load for the feeder is 560 amperes and the feeder conductors are protected with a 700-ampere rated overcurrent device. The minimum size conductors permitted for this feeder is:
    A. 400 kcmil.
    B. 500 kcmil.
    C. 600 kcmil.
    D. 700 kcmil.
    E. 750 kcmil.

    Code reference ___________________

UNIT 3

Outlets, Lighting, Appliances, and Heating

OBJECTIVES

After completion of this unit, the student should be able to:

- determine the location of electrical outlets in a dwelling.
- determine the minimum number of general lighting, small appliance, and laundry circuits permitted in a dwelling.
- state the clearance requirements for outside aerial feeders and branch-circuits.
- determine the minimum size flexible cord required for an application.
- state the installation requirements for lighting outlets in clothes closets.
- state the installation requirements for recessed lighting fixtures.
- determine the minimum size conductor for a storage-type electric water heater.
- determine the maximum number of baseboard electric heaters permitted to be installed on a 15- or 20-ampere branch-circuit.
- state if it is permitted to power a room air conditioner from an existing general lighting branch-circuit of a dwelling.
- state the cable type required to be installed for a push button of a door chime.
- answer wiring installation questions relating to *Articles 210, 220, Parts I* and *II, 225, 396, 398, 400, 402, 404, 406, 410, 411, 422, 424, 426, 720,* and *725.*
- state at least five significant changes that occurred from the 2005 to the 2008 Code for *Articles 210, 220, Parts I* and *II, 225, 396, 398, 400, 402, 404, 406, 410, 411, 422, 424, 426, 720,* or *725.*

CODE DISCUSSION

The emphasis of this unit is on circuits and installation of outlets, appliances, and equipment. Methods are covered for determining the minimum number of general illumination, receptacle, and other circuits required for various types of buildings. Outside feeders and branch-circuit installations are also covered. Special circuits such as low-voltage, power-limited-control, and signaling circuit installation are covered in this unit.

Article 210, Part I contains specifications about branch-circuits such as circuit ratings (*210.3*) and voltage limitations for different types of occupancies and types of loads to be served (*210.6*). For example, in a dwelling, the maximum permitted voltage between conductors for luminaires (lighting fixtures) and general-use receptacles is 120 volts nominal. Multiwire branch-circuits are discussed in *210.4.* A multiwire branch-circuit is actually two or more circuits that share a common neutral conductor. In the case of a single-phase, 120/240-volt system, three wires are used to supply two circuits with a common shared neutral and 240 volts between the ungrounded conductors. In the case of a 3-phase 208/120-volt system, three circuits can be supplied with only four conductors. Generally it is assumed that when the loads on the multiwire circuits are the same and all are operating at the same time, the current on the common neutral conductor will be zero or nearly zero. This is not necessarily the case with a multiwire circuit derived from a 3-phase wye electrical system. Sometimes a multiwire branch-circuit will supply multiple devices on the same yoke or strap. A common example is a duplex receptacle where the tab between the ungrounded screw terminal for the two receptacles is removed. Each of the receptacles on the same strap is supplied from a separate circuit and uses a common neutral. See the definition of a multiwire branch-circuit in *Article 100.* It is required by *210.4(B)* that multiwire branch-circuits originate from an overcurrent device that will de-energize all circuits at the same time. This can be accomplished using a 2-pole or 3-pole circuit breaker or single-pole circuit breaker with a handle tie.

Ground-fault circuit-interrupter requirements for receptacles are covered in *210.8.* There are several general requirements that apply to any type of facility. All 15- and 20-ampere, 125-volt receptacles in bathrooms, kitchens, within 6 ft (1.8 m) of a sink, outdoor locations and on rooftops of any type of facility are required to be GFCI protected. This can be accomplished with a ground-fault detecting receptacle, or a ground-fault detecting circuit breaker. Both the ungrounded conductor and the neutral pass through a current-sensing coil. If the current measured in those two wires is different by more than 0.006 amperes (6 milliamperes), the interrupter will trip. This means the current is finding a return path other than the neutral wire, which possibly could be a person. The dwelling GFCI requirements for protection of 125-volt, 15- and 20-ampere receptacles are summarized below:

- Receptacles serving *kitchen countertop* surfaces
- *Bathroom* receptacles
- *Outside* receptacles (see exception for snow-melting equipment)
- *Crawlspace* receptacles
- *Garage* receptacles
- Receptacles in *accessory buildings* at or below grade used for storage or work areas (See Figure 3.1)
- Receptacles in *unfinished basement* or unfinished portion of a basement (see exception for fire alarm)
- Receptacles serving countertop and within 6 ft (1.8 m) of a *wet bar,* laundry, or utility sink
- Receptacles in a *boat house* or for a boat hoist

The minimum number of branch-circuits required for a building are specified in *210.11.* Calculating the minimum number of branch-circuits is covered later under *Sample Calculation.* Four 20-ampere branch-circuits are required as a minimum in a dwelling. Two 20-ampere branch-circuits are required to supply the receptacles in the kitchen, dining room, and similar rooms. One 20-ampere branch-circuit is required to supply laundry equipment such as an electric washer and possibly a gas dryer. Another 20-ampere branch-circuit is required to supply the receptacle outlets in the bathroom or bathrooms of the dwelling. The minimum

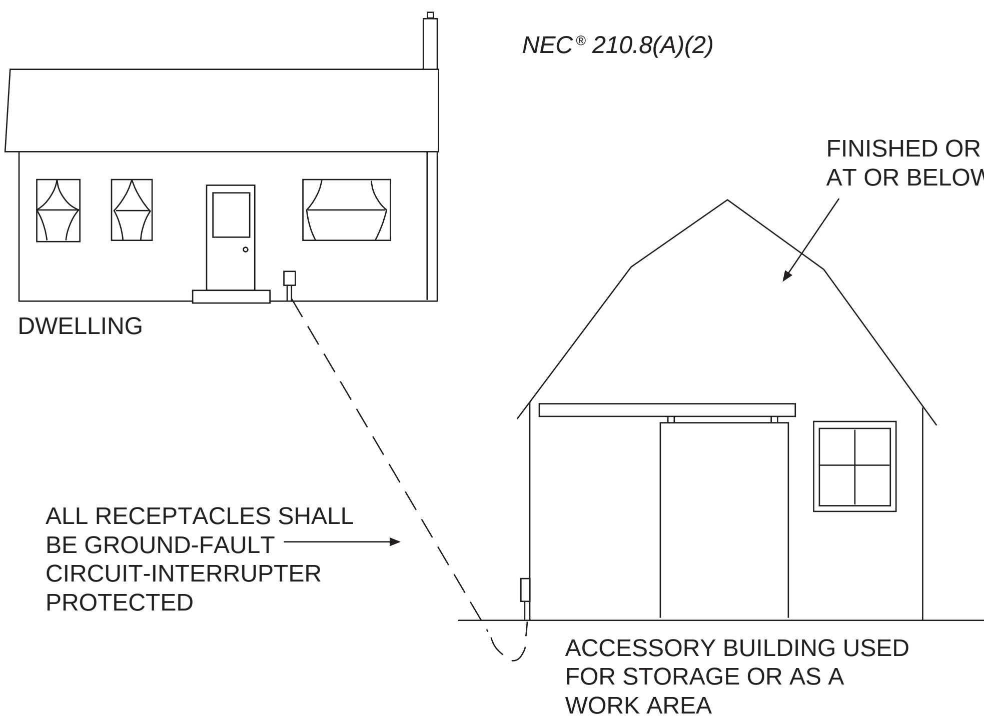


Figure 3.1 Receptacles in accessory buildings of dwellings, whether finished or unfinished, at or below grade, if used for storage or as work areas, are required to be GFCI protected for personnel.

number of remaining general purpose 15- and 20-ampere circuits is calculated according to the method of *210.11(A)* and *220.12.*

Arcing faults can occur particularly when Nonmetallic-Sheathed Cable run concealed in walls, floors, and ceilings is damaged such as being penetrated by a nail or screw. In this case, current flows intermittently between conductors, or between a circuit conductor and the equipment grounding conductor or some other grounded structural member. This is known as a parallel arcing fault. An example of a series-arcing fault is when a loose connection occurs in either the ungrounded- or grounded-circuit conductor such as a loose screw at a switch or receptacle. Overcurrent devices such as circuit breakers and fuses require a specified amount of energy to open depending upon their rating. An arcing fault can create enough heat at the fault location to start a fire without drawing enough energy at the overcurrent device to cause it to open the circuit. It has been reported that dwelling fires caused by arcing faults have become prevalent enough to justify action to be taken to require a device on dwelling circuits that can detect an arcing fault in a circuit and disconnect power to the circuit. The device that is capable of detecting an arcing condition in a circuit is called an Arc-Fault Circuit-Interrupter (AFCI) and is defined in *210.12(A).* The purpose of an AFCI is to detect a potentially fire-producing arcing condition anywhere in the circuit wiring of the dwelling or in equipment attached to the circuit such as a damaged cord to a floor lamp. An Arc-Fault Circuit-Interrupter is required to be installed in the circuit-panel in place of the circuit breaker, or away from the circuit panel under certain conditions. There is more discussion of circuit-arcing conditions in *Unit 6,* and there is a diagram of an AFCI that replaces a normal circuit breaker in Figure 6.6.

Arc-Fault Circuit-Interrupters (AFCI) are required by *210.12(B)* for the protection of all branch-circuits that supply 120-volt, 15- and 20-ampere outlets in dwelling bedrooms, living room, dining room, sitting room, family room, den, library, recreation room, closets, and hallways. The definition of dwelling unit is in *Article 100* and includes one-family, two-family, and multifamily living units. Mobile homes and manufactured homes that also meet this definition are included.

Arc-Fault Circuit-Interrupters (AFCI) are intended to be installed in a circuit panel to protect the entire circuit. There are two types of AFCIs available, the branch/feeder type and the combination type. The combination type is a relatively new development that is better at detecting series arcing conditions than the older branch/feeder type. The Code now requires the combination type to be used on all new circuit installations where an AFCI is required. Arc-Fault Circuit-Interrupters are also available as a receptacle device that protects any appliance or equipment plugged into the receptacle as well as any part of the down-line circuit.

Arc-Fault Circuit-Interrupters are intended for protection of the entire circuit, including the wiring and equipment supplied by the circuit. It has been determined that wiring run in Rigid Metal Conduit (RMC), Intermediate Metal Conduit (IMC), Electrical Metallic Tubing (EMT), and steel Type AC cable listed as meeting the grounding requirements of *250.118* is not easily damaged after installation, and if so, any arcing that may occur does not pose a fire hazard. As a result, an exception is permitted for installing the AFCI at the service panel. If the wiring is run with RMC, IMC, EMT, or approved Type AC cable, and the box supplied is metal, the AFCI is permitted to be installed at the first outlet of the circuit. An AFCI receptacle looks similar to a GFCI receptacle.

Article 210, Part II covers the ratings of branch-circuits, including those in dwellings. *NEC® 210.19(A)* states that the branch-circuit conductors shall have an ampacity of not less than the maximum load to be served. The rating of a branch-circuit is the rating of the overcurrent device protecting the circuit. The actual rating of any one branch-circuit is determined by the method in *210.20(A).* The overcurrent device protecting a circuit is required to have a rating not less than 1.25 times any continuous load served plus 1.0 times any noncontinuous load served.

The minimum circuit rating of 40 amperes for a dwelling electric range is given in *210.19(A)(3).* The neutral conductor of the range circuit is permitted to be of a smaller size than the ungrounded conductors, but it is not permitted to have an ampacity less than 70% of the branch-circuit rating, and it shall be no smaller than size 10 AWG copper (*210.19(A)(3) Exception 2*).

A tap is a conductor that connects to a branch-circuit or feeder conductor to serve a specific load. The tap conductor shall be of sufficient ampacity to supply the load. The tap conductor is permitted to be smaller than the branch-circuit or feeder conductor, but the Code sets a minimum size based on the rating of the branch-circuit or feeder. Additional discussion of taps is in *Units 6, 7,* and *8. Exception 1* to *210.19(A)(3)* permits a tap with sufficient ampacity to serve the load but not less than 20 amperes for an electric wall-mounted oven or counter-mounted cooking unit in a dwelling when the circuit is protected at not more than 50 amperes. This is illustrated in Figure 3.2. There is another tap rule in this article. *NEC® 210.19(A)(4) Exception 1* permits taps to branch-circuits provided the tap conductor is to individual lampholders or luminaires (lighting fixtures) and is not more than 18 in. (450 mm) in length. For a branch-circuit rated up to 30 amperes, the tap shall have an ampere rating

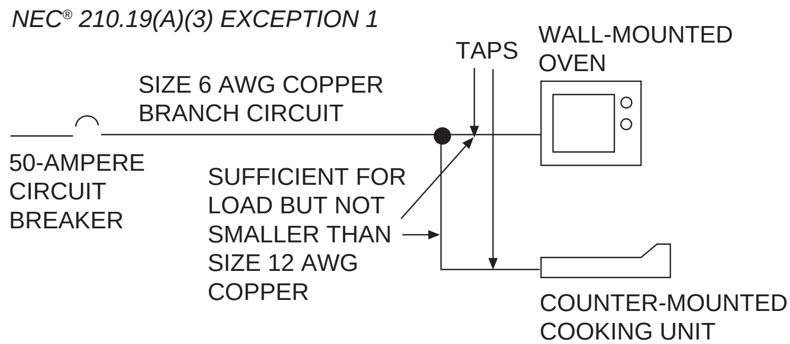


Figure 3.2 Taps in a dwelling range circuit shall have sufficient ampacity for the load, and shall not be less than 20 amperes.

sufficient for the load, and not less than 15 amperes. For a branch-circuit rated up to 50 amperes, the tap shall have an ampere rating sufficient for the load, and not less than 20 amperes.

FPN 4 to *210.19(A)* recommends a maximum of 3% voltage drop be permitted on branch-circuits. There is a complete discussion of voltage drop in *Unit 6* with examples to show how to size a conductor to maintain voltage drop within the desired level. *NEC® 210.21(B)(1)* states that when a single receptacle is installed on a branch-circuit, the receptacle is not permitted to have a rating less than that of the branch-circuit rating. A single receptacle is defined in *Article 100*. It has provisions for the connection of only one cord-connected device. A duplex receptacle outlet is considered two receptacles. Therefore, if a single receptacle on a yoke is installed on a 20-ampere circuit, the minimum receptacle rating permitted is 20 amperes. If a duplex receptacle outlet is installed on a 20-ampere branch-circuit, the receptacle rating is permitted to be either 15 or 20 amperes. *NEC® 210.23* covers the permissible loads on branch-circuits of various ratings. For example, *210.23(A)* permits 15- and 20-ampere branch-circuits to supply typical residential and commercial lighting outlets. It is necessary to read the remainder of this section to determine the restrictions on the type of outlets and equipment permitted to be supplied from branch-circuits of various ratings.

The minimum requirements for providing outlets for lighting and receptacles are given in *Article 210, Part III*. The maximum permitted spacing of receptacle outlets in dwellings is given in *210.52*. A receptacle outlet shall be installed in listed rooms of a dwelling such that any point measured along the wall is not greater than 6 ft (1.8 m) from the outlet. Wall spaces 2 ft (600 mm) wide or wider shall have a receptacle outlet. These rules are illustrated in Figure 3.3. A minimum of two 125-volt, 20-ampere small appliance branch-circuits are required in a dwelling to serve the kitchen, dining room and similar rooms, *210.11(C)(1)*. Not fewer than two small-appliance branch-circuits are required to supply the receptacles serving the kitchen counters, *210.52(B)(3)*. All of the receptacles in the kitchen, dining room, and similar rooms are required to be supplied by small-appliance branch-circuits. It is permitted to have a wall switch-controlled receptacle in the dining room, but not the kitchen, for the purpose of supplying lighting served by a general-purpose branch-circuit, *210.70(A)(1) Exception 1*. Generally, the small appliance branch-circuits are only permitted to serve the receptacles in the kitchen, dining room, and similar rooms, *210.52(B)(2)*. The refrigerator is

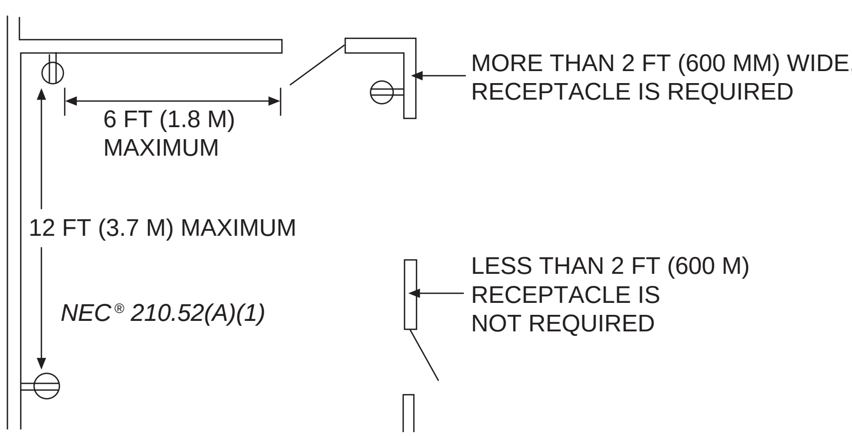


Figure 3.3 Required maximum spacing of receptacle outlets in a dwelling.

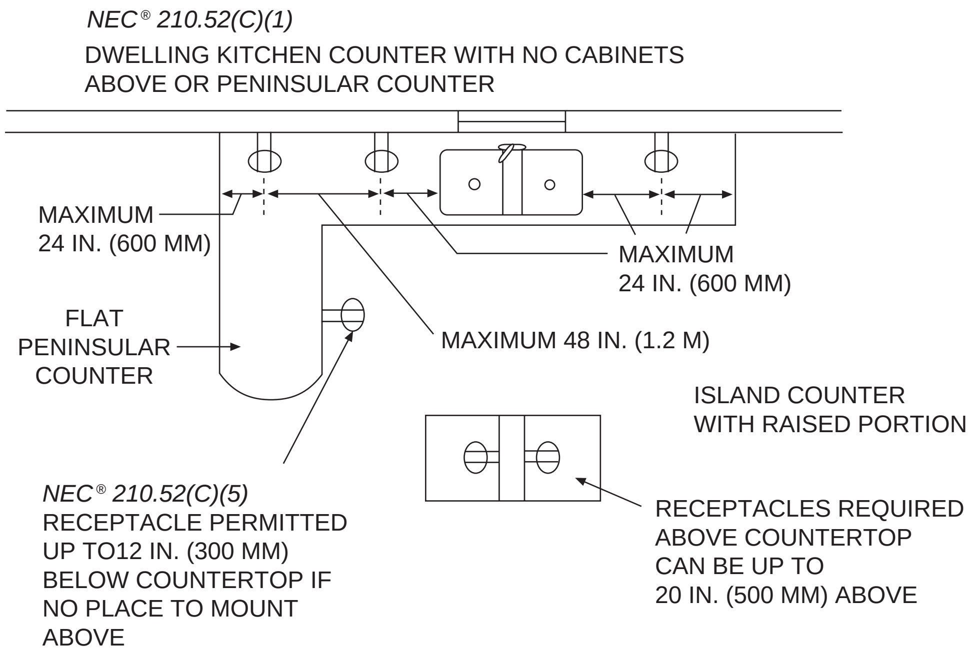


Figure 3.4 When a dwelling kitchen countertop is flat with no raised portions, and there is no other practical means to mount the receptacles within 18 in. (450 mm) above the surface, the receptacles are then permitted to be mounted no less than 12 in. (300 mm) below the countertop surface.

permitted to be supplied by a small-appliance branch-circuit, however, it is permitted to provide a dedicated 15-ampere rated branch-circuit for the refrigerator, *210.52(B)(1) Exception 2*. Receptacle outlets of the small appliance branch-circuits serving kitchen counters along a wall are required to be spaced such that no point along the wall line is more than 24 in. (600 mm) from a receptacle outlet, *210.52(C)(1)*. This is illustrated in Figure 3.4. A receptacle outlet is required to serve a peninsular counter that extends out into the room a distance from the connecting edge of at least 12 in. (300 mm) if at least 24 in. wide (600 mm), or a distance of 24 in. (600 mm) if less than 24 in. (600 mm) wide as shown in Figure 3.5. A receptacle is not required to be installed on a wall behind a range or sink unless the sink is set out from the wall more than 12 in. (300 mm) or out from a corner more than 18 in. (450 mm).

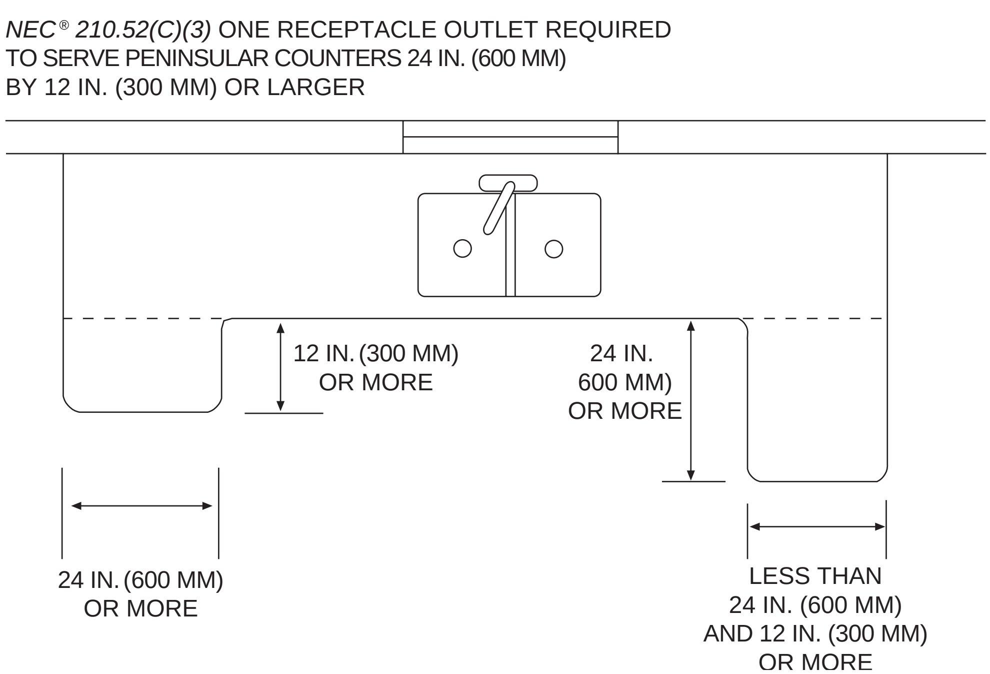


Figure 3.5 One receptacle outlet is required to serve a peninsular counter with minimum dimensions of 12 in. (300 mm) by 24 in. (600 mm) or greater.

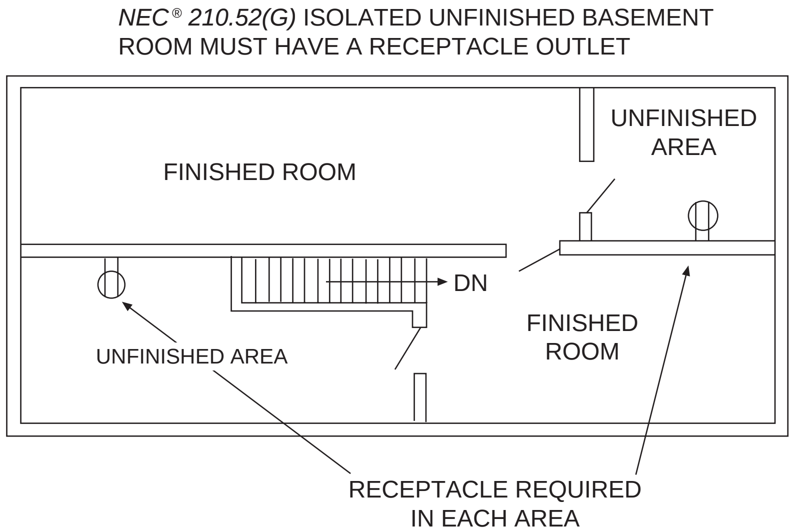


Figure 3.6 Unfinished areas of a basement in a dwelling that are isolated from each other by a finished area are each required to have a receptacle outlet.

At least one receptacle is required to be installed at the front and one at the back of a one-family dwelling or at each unit of a two-family dwelling. It is stated in *210.52(E)* that this receptacle is to be accessible at grade level and not more than 6½ ft (2 m) above grade level. When there is a deck attached to the dwelling, sometimes a receptacle installed to serve the deck is not considered to be accessible to grade level. In some areas, another receptacle accessible at grade level may be required to be installed. A similar problem can arise with respect to a receptacle available for service of a central air-conditioning unit. In *210.63*, a receptacle on a 125-volt, single-phase, 15- or 20-ampere circuit is required to be located not more than 25 ft (7.5 m) from an air-conditioning unit. In the case of an air-conditioning unit located on the outside of a dwelling, this is another consideration when placing the required outside receptacle.

It is not uncommon for a dwelling basement to have unfinished portions separated by finished portions. It is made clear in *210.52(G)* that a receptacle is required to be installed in each unfinished portion of a dwelling basement if the unfinished portions are not adjoining such as shown in Figure 3.6.

NEC® 210.70(A) requires that every habitable room of a dwelling, including other listed areas, shall have a lighting outlet that is wall switch-controlled. A switched receptacle outlet may be used in place of an actual luminaire (lighting fixture) in some rooms, as shown in Figure 3.7. A lighting outlet is also required to be installed in hallways, stairways, attached garages, and detached garages with power. In the case of interior stairways, a switch controlling the lighting is required at each level when there are six steps or more. At least one lighting outlet containing a switch, or that is wall switch-controlled, is required for attics, underfloor spaces, basements, and utility rooms used for storage or containing equipment requiring servicing. The switch is required at the normal point of entry to the space, and the lighting outlet is required to be located at any

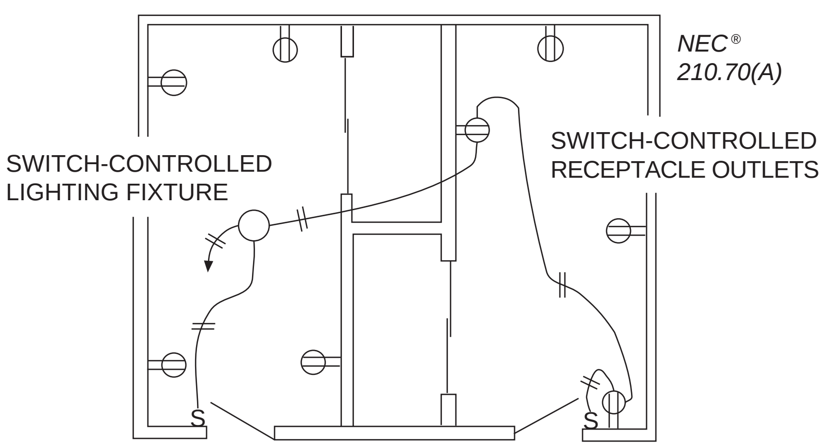


Figure 3.7 Wall switch-controlled lighting is required in every habitable room of a dwelling.

equipment requiring servicing. Automatic control of lighting is permitted for hallways, stairways, and outdoor entrances.

Article 220, Parts I and *II* provides requirements for the determination of the number of outlets of various types permitted on a branch-circuit. *NEC® 220.12* provides important information for the determination of the number of branch-circuits required for receptacles and general lighting in buildings. *Table 220.12* gives the minimum unit load in VA/ft^2 or VA/m^2 of building area considered in determining the minimum number of branch-circuits for lighting and for determining the minimum lighting load for feeder calculation purposes. If the actual lighting load is known to be of a greater value, that load shall be considered the general lighting load.

NEC® 220.14(J) permits the general use receptacles in a dwelling to be included in the general illumination calculation. Small appliance receptacle loads and laundry receptacle load are specified elsewhere in the Code and are not a part of this general illumination load calculation. This means that the 3 volt-amperes per square ft (33 VA/m^2) from *Table 220.12* is used for a dwelling to determine the minimum number of general illumination branch-circuits that will supply the receptacle outlets and lighting fixtures. The significance of this is that the 180-volt-amperes requirement of *220.14(J)* does not apply to dwelling general-use receptacles. The number of outlets permitted on a circuit depends upon the loads to be served, and according to *220.18*, the total load is not permitted to exceed the rating of the circuit. In the case of general illumination in a dwelling, the load is determined based on the method described in *220.12,* which is the area of the dwelling times 3 volt-amperes per square ft (33 VA/m^2). This is converted into the number of circuits according to the method of *210.11(A)* where the total load in volt-amperes is divided by 120 volts and then divided into 15- or 20-ampere circuits.

Article 225 gives the requirements for the installation of branch-circuit and feeder conductors outside. Minimum size of conductors for overhead spans, protection of conductors, and overhead conductor clearances is specified in this article. Clearances above ground of aerial conductors are covered in *225.18.* Similar requirements for service conductors are covered in *230.24.* The conductor clearance over areas accessible only to pedestrians is a minimum of 10 ft (3.0 m). For a residential driveway and other driveways not subject to truck traffic, the minimum clearance is 12 ft (3.7 m), provided the conductors do not exceed 300 volts-to-ground. This clearance is increased to 15 ft (4.5 m) for conductors operating at more than 300 volts-to-ground. An 18-ft minimum conductor clearance is required when the driveway or road is subject to truck traffic. Branch-circuit and feeder conductor clearances above roofs are covered in *225.19.* The minimum overhead conductor clearances for roofs accessible to only pedestrians are summarized in Figure 3.8, and covered in *Exception 1 to 225.19.*

Part II of *Article 225* gives the rules for supplying power from a building or structure on the property to another building or structure on the same property. *NEC® 250.32* deals with the neutral conductor and equipment grounding when supplying power to another building or structure on the same property. These rules deal with the disconnecting means for power to a building supplied by feeders or in some cases branch-circuits. In the case where qualified personnel are on duty at all times to facilitate safe disconnecting procedures, it is permitted for the disconnecting means to be located at a remote location

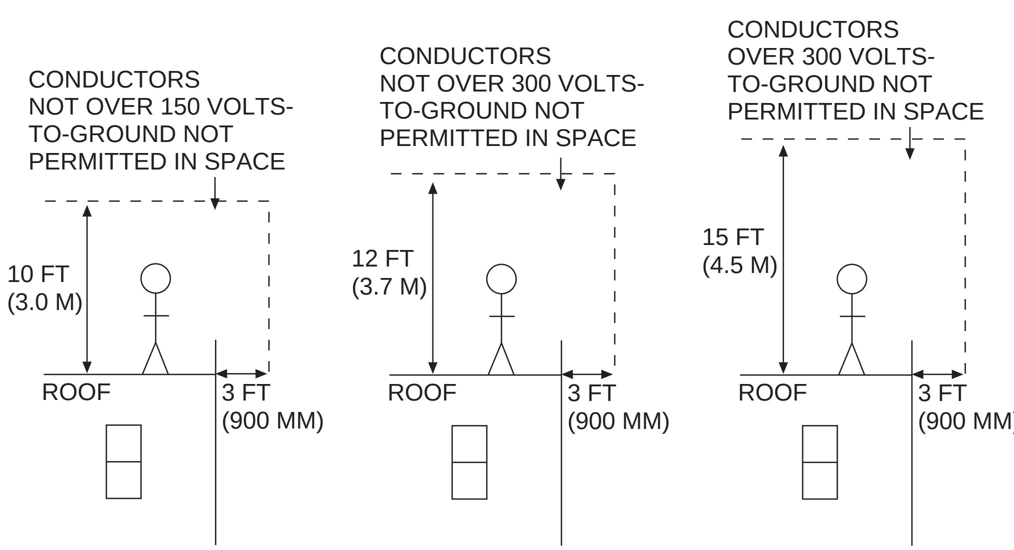


Figure 3.8 Minimum overhead conductor clearances for roofs accessible only to pedestrians.

on the property, *225.32 Exception 1*. The disconnecting means in general is located either inside or outside the building, *225.32*. Whether located inside or outside the disconnect is required to be at the closest practical location to the point where the conductors enter the building. Up to six disconnecting means are permitted as covered in *225.33*. These rules are summarized in Figure 3.9. The disconnecting means is required to be rated as suitable for use as service equipment.

Article 396 deals with Messenger-Supported Wiring, such as aerial triplex or quadruplex cable where a bare conductor supports the insulated conductors. It is permitted to field construct a support messenger and suitably attach the conductors to the messenger. There are no minimum conductor size requirements for overhead spans using Messenger-Supported Wiring. The ampacity of messenger-supported conductors is to be determined using the methods of *310.15,* which basically means the ampacity is determined in most cases using *Table 310.16* or *Table 310.20.*

Article 398 covers the situation in which conductors are run within a building or on the outside of a building where the individual conductors are supported by open wires on insulating devices. The wiring covered by this article is required to be exposed except where passing through a wall or floor. Open Wiring on Insulators is not permitted to be concealed except where passing through structural barriers such as walls. This wiring method is only permitted for industrial or agricultural installations.

Article 400 provides information and requirements on the use of flexible cords and cables. *Table 400.4* gives information about the various types of cords and cables and states the uses permitted. *Table 400.5* gives the allowable ampacity and ampacity derating factors applicable when more than three current-carrying conductors are in the cable of flexible cord. Refer to *Unit 2* for examples of how to determine the minimum size wire permitted when more than three current-carrying conductors are in flexible cord or cable. Markings on the flexible cord or cable with uses permitted and installation requirements are covered in this article. Temperature adjustment factors are also required to be applied to flexible-cord ampacity when the cord will be used in an area where the ambient temperature is above 30°C (86°F). Maximum temperature ratings are printed on some flexible cords. The temperature rating is likely different depending upon whether the cord is to be used in a dry or wet location. Temperature correction factors for flexible cords, as stated in *400.5,* are found at the bottom of *Table 310.16.*

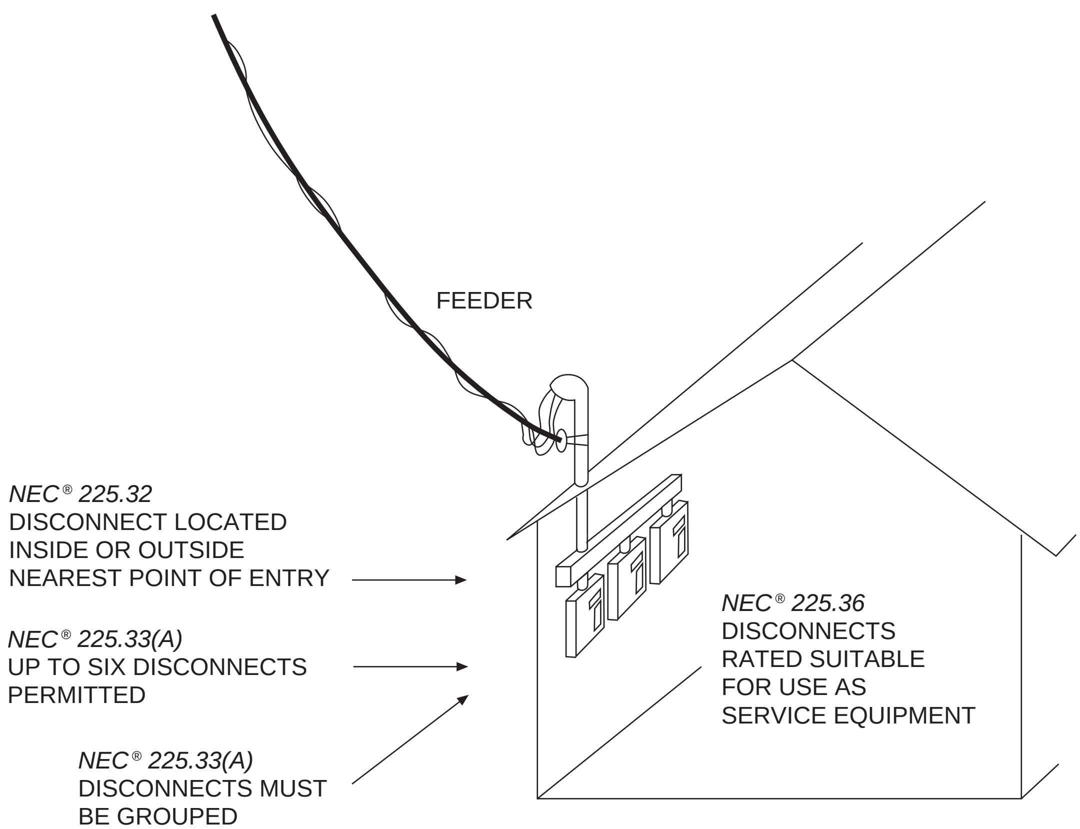


Figure 3.9 When one building is supplied power from another building or structure on the same property, the requirements for the disconnecting means for the building are generally the same as for installing a service in the building.

Article 402 lists the markings on fixture wires, the types available and their uses, and general installation requirements. *Table 402.5* gives the permitted ampacity of the fixture wires of sizes 18 to 10 AWG.

Article 404 covers the installation, rating, and use of switches of various types, including knife switches and circuit breakers used as switches. All switches and circuit breakers used as switches are not permitted to be installed such that the center of the handle is more than 6 ft 7 in. (2 m) above the floor when in the "on" position, as stated in *404.8(A). NEC® 240.83(D)* specifies that when a circuit breaker is used as a switch for 120- and 277-volt fluorescent lighting, the circuit breaker shall be marked "SWD" or "HID." A circuit breaker used as a switch for high-intensity discharge lighting is required to be marked "HID." The "SWD" marking may be on the side of the circuit breaker, or it may be on the small label next to the circuit-conductor terminal screw. If a circuit breaker is approved for use as a switch for high-intensity discharge lighting, the "HID" label is usually on the side of the circuit breaker.

Article 406 covers the ratings, types, and installation of receptacles, cord connectors, and attachment plugs. *NEC® 406.2(C)* deals with the situation in which aluminum conductors are attached directly to a receptacle outlet. The receptacle outlet is required to be marked CO/ALR if it is suitable for use with aluminum terminations. Do not confuse this marking with the usual marking of cu/al, which is frequently used for other types of terminations suitable for both copper and aluminum conductors. *NEC® 406.2(D)* covers receptacles with the equipment grounding terminal isolated from the yoke. Other rules on installation of isolated ground receptacles are found in *250.96(B)* and *250.146(D)*. These receptacle types are permitted to supply electronic equipment where electrical noise may be a problem. These receptacles are identified by an orange triangle. Permitted means of identification of receptacles with isolated grounds are illustrated in Figure 3.10. When receptacles are installed outside exposed to weather, or in damp locations, a cover must be installed that will guard against the entrance of water under the typical operating conditions. *NEC® 406.8* specifies the means of protecting receptacles from the entrance of water by using a weather-proof enclosure. Any 15- or 20-ampere, 125- or 250-volt receptacle in a wet location is required to be provided with a cover that will prevent the entrance of water with or without the plug inserted into the receptacle as shown in Figure 3.11.

There is an additional requirement that receptacles installed outside either in damp or wet locations are required to be listed as weather-resistant. This is a new type of receptacle that is resistant to the entrance of water if the actual receptacle becomes exposed to the weather, such as when a weather-proof cover is damaged *NEC® 406.10* specifies the different means of grounding a receptacle. The main rule requires a bonding jumper

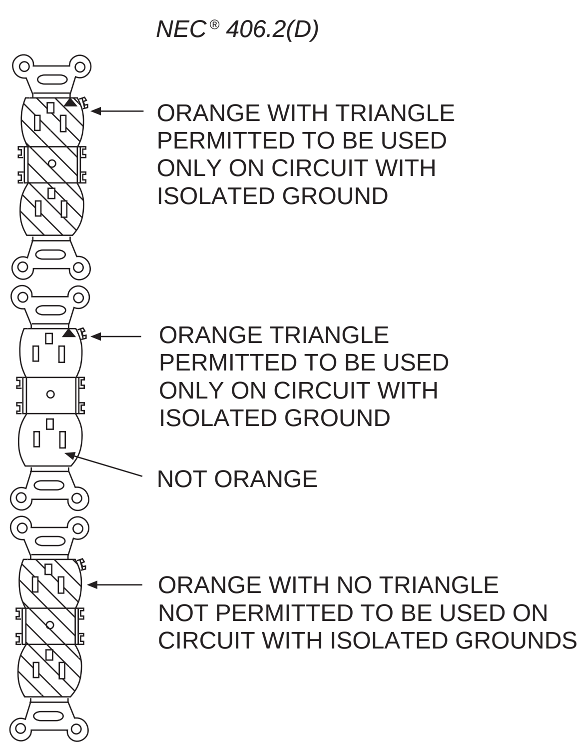


Figure 3.10 Receptacles installed on a circuit with the equipment grounding terminals isolated from the other circuit equipment grounds, as permitted in *NEC® 250.146(D)*, shall be identified with an orange triangle on the face of the receptacle.

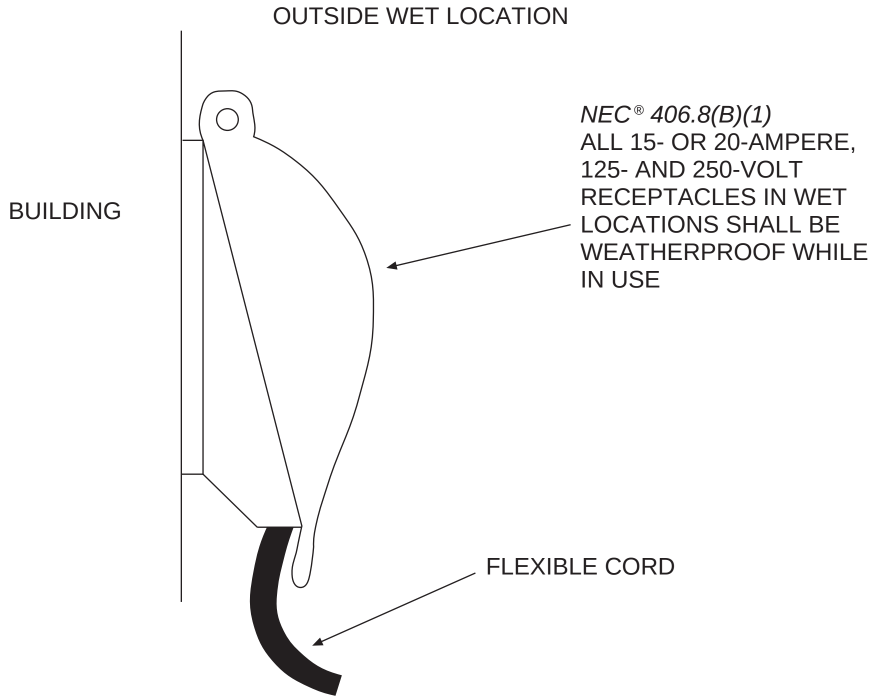


Figure 3.11 Receptacles rated 15- or 20-amperes, 125 volts installed in wet locations are required to have covers that are weatherproof regardless of the intended use of the receptacle.

to be connected between the receptacle grounding terminal and a grounded metal box or equipment grounding wire if a nonmetallic box is used. Alternatives are direct metal-to-metal contact between a metal receptacle yoke and a metal box when the box is surface mounted. Fastening to a raised cover is not considered to be an acceptable means of grounding the receptacle unless the raised cover is listed for grounding. In the case of a flush-mounted metal box, a self-grounding receptacle with a contact device on the mounting screw to maintain electrical contact between the mounting screw and the receptacle yoke is considered an acceptable means of grounding the receptacle.

Receptacles installed in dwellings are required to be of a tamper-resistant type according to *406.11*. There are receptacle covers that are listed as temper-resistant, but the tamper-resistant receptacles are different. The openings to the receptacle are closed when no plug is inserted. Pushing a pointed object into one of the slots will not open the slot. It is necessary to insert an actual plug in order for the slots to open and allow insertion of the plug. These tamper-resistant receptacles are required when receptacles are installed on 125 volt, 15- and 20-ampere circuits in a dwelling.

Article 410 gives requirements on the installation, location, grounding, support, and wiring of luminaires (lighting fixtures) and associated auxiliary equipment. *NEC® 410.2* gives a definition of storage space in clothes closets. This is important because a luminaire (lighting fixture) is required to be installed such that a minimum clearance is maintained between the luminaire (lighting fixture) and the storage space. *Figure 410.2* gives the dimensions of the storage space in a clothes closet. *NEC® 410.16(B)* states that incandescent luminaires (lighting fixtures) with exposed or partially-exposed lamps are not permitted to be installed in a clothes closet. This means porcelain lamp receptacles with bare lamps are not permitted to be installed in clothes closets.

Fire is a danger if excessive heat is produced by improper installation or use of luminaires (lighting fixtures). Incandescent luminaires (fixtures) require a higher wattage to obtain the same amount of light as electric discharge luminaires (fixtures). Therefore, the heat produced by incandescent lamps is usually greater than for electric discharge luminaires (fixtures). Electric discharge luminaires (fixtures) usually have a ballast that is a source of heat in addition to the lamp. Ballasts for most fluorescent luminaires (fixtures) are required by *410.130(E)* to be thermally protected, and ballasts for recessed high-intensity discharge luminaires (fixtures) are required by *410.130(F)* to be thermally protected or inherently protected.

Recessed luminaires (lighting fixtures), if not installed properly, can create a fire hazard. *Part XI* of *Article 410* provides installation requirements for recessed luminaires (fixtures). For most applications, recessed incandescent luminaires (fixtures) are required to be thermally protected. Overheating of the luminaires (fixtures) will interrupt electrical power to the lamps. The lamps generally will light again when the luminaire (fixture) cools.

Article 411 provides specifications for lighting systems that operate at 30 volts or less. One example of such a system is low-voltage landscape lighting for gardens, walkways, decks, patios, and other building accent illumination. Lighting systems are required to be listed for the purpose. The low-voltage secondary circuit is required to be insulated from the supply branch-circuit by an isolating transformer. Each secondary lighting circuit is not permitted to operate at more than 25 amperes. The lighting system isolating transformer is not permitted to be supplied from a branch-circuit with a rating more than 20 amperes.

Article 422 provides information and requirements for electrical appliances in any type of occupancy. Branch-circuit requirements, control of appliances, and disconnects are covered. Storage-type electric water heater wiring is covered in *422.13*. When the capacity of the electric storage-type water heater is not more than 120 gallons (450 L), the branch-circuit conductor shall be sized at not less than 1.25 times the nameplate rating of the water heater. If the water heater rating is given in watts, then a calculation must be done to determine the ampere rating of the water heater. An electric water heater with a rating of 3500 watts at 240 volts will have an ampere rating of 14.6 amperes. This is determined by dividing 3500 watts by 240 volts. The minimum branch-circuit conductor rating permitted is 1.25 times the 14.6 amperes or 18.3 amperes. The minimum circuit conductor size would be 12 AWG copper protected with a 20-ampere overcurrent device.

Article 424 on fixed electric space-heating equipment is covered including space heating cables. Branch-circuit requirements, control, disconnection, grounding, location, and wiring are covered. The first part of the article gives general wiring requirements, while the later parts of the article relate to specific types of electric heating equipment or installations.

An individual branch-circuit is permitted to supply any size space-heating load, although within an electric heating unit, the resistance loads may be subdivided. *NEC® 424.22(B)* only permits an individual resistance heating element to draw up to 48 amperes and be protected at not more than 60 amperes. If a heating branch-circuit supplies two or more fixed heating units, the branch-circuit is not permitted to have a rating of more than 30 amperes, according to *424.3(A)*. The overcurrent device protecting an electric heating circuit, as well as the conductors, is not permitted to be less than 1.25 times the load to be served. The heating units are most likely rated in watts, therefore, the wattage must be divided by the circuit operating voltage to determine the full-load current of the circuit. If a room has two 1500-watt, 240-volt resistance baseboard heating units, the total load served will be 12.5 amperes (3000 W / 240 V = 12.5 A). The overcurrent device and the conductor are required to have a rating not less than 15.6 amperes ($12.5 \times 1.25 = 15.6$ A). The overcurrent device will be rated 20 amperes, and the conductor will be size 12 AWG copper.

Disconnecting means for electric heating equipment is covered in *Part III* of *Article 424*. Of particular importance is *424.20*, which specifies the conditions that must be met in order for a thermostat to serve as the disconnecting means for an electric heating unit. All ungrounded conductors must be opened, the thermostat must have a marked off position, and a change of temperature is not capable of energizing the circuit conductors.

Article 426 deals with the installation and use of outdoor electric de-icing and snow-melting equipment, such as heating cable embedded in concrete. Definitions of different methods of using electricity for the production of heat are covered in *426.2*. The minimum size of conductor permitted for branch-circuits for electric outdoor snow-melting and de-icing equipment is covered in *426.4* and shall be not less than 1.25 times the total load on the circuit.

Outdoor snow-melting and de-icing equipment is required by *426.28* to be provided with equipment ground-fault protection. This protection is required for the equipment, not the circuit, and the purpose is fire prevention not personnel protection. Ground-fault equipment protection (GFPE) is permitted to be provided as an integral part of the equipment, or it can be provided as part of a GFPE circuit breaker. These devices commonly are rated to detect leakage current of 30 milliamperes or 50 milliamperes. The range over which they are intended to protect is between 6 and 50 milliamperes.

Article 720 deals with electrical circuit installation, either alternating current or direct current, that operates at less than 50 volts. Minimum wire size and receptacle rating are covered. Some installation types are listed that are covered elsewhere in the Code. It is important to note that even though the voltage is low, it is electrical current flow that causes heating and can result in fire. There are specific requirements for installations operating at less than 50 volts in other articles.

Article 725 covers the installation of remote-control, signaling, and power-limited circuits that are not an integral part of a device or appliance. These circuit types are divided into Class 1, Class 2, and Class 3 circuits. Line voltage control circuits for motors and other equipment are Class 1 circuits. Thermostat circuits operating at 24 volts for furnace control, and door chime and similar circuits are considered Class 2 because they have

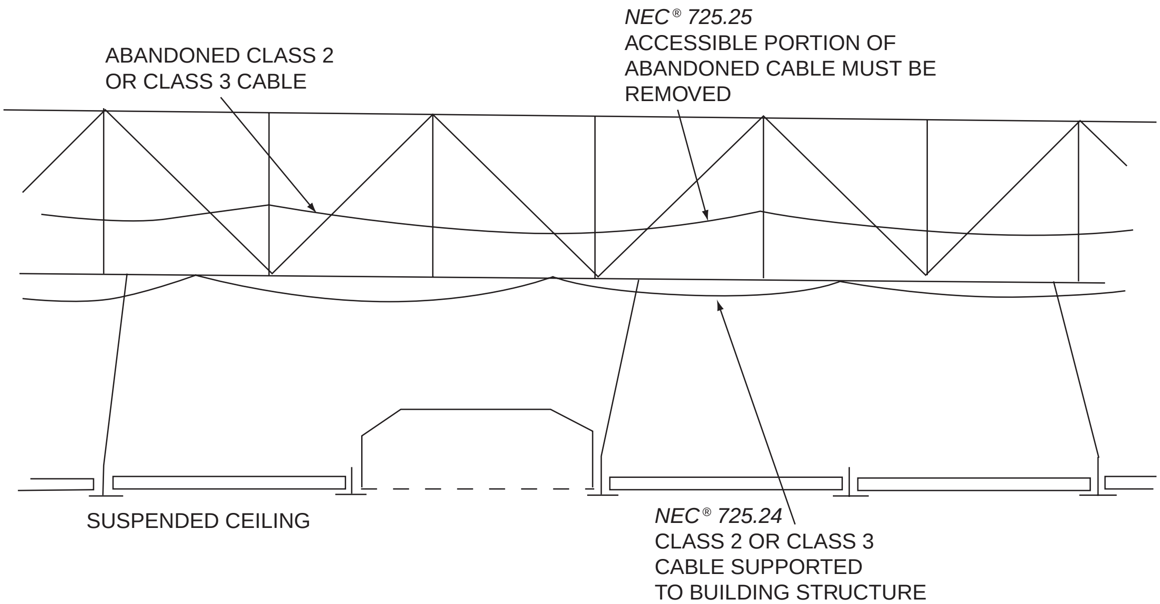


Figure 3.12 Class 2 and Class 3 cables are required to be supported by the structure of the building and all accessible portions of abandoned cable are required to be removed.

supply transformers limiting the maximum current that can flow if the wires become shorted. Wiring methods for Class 1 circuits are covered in *725.46.* The wiring methods of *Chapter 3* of the Code shall be permitted. If the conductors are of sizes 18 and 16 AWG, the insulation type is specified in *725.49.* Wiring methods and materials for Class 2 and Class 3 wiring are specified in *725.130.*

Class 2, Class 3, and PLTC cables are defined as abandoned in *725.2* if not being terminated at equipment or tagged for future use. Accessible portions of abandoned Class 2, Class 3, and PLTC cables as stated in *725.25*, are required to be removed. Cables that are installed exposed, as stated in *725.24*, are required to be supported by the structure of the building in such a manner that they will not be damaged in normal use of the area in which they are installed. When installed through building materials such as bored holes in wood framing members, the same rules in *300.4(D)* must be followed as normal power circuit cables. When installed above a suspended ceiling, the rules of *300.11* must be followed, and cables are required to be supported by the structure of the building in some manner such as shown in Figure 3.12, or supported by tie wires installed specifically for the purpose of electrical wiring. Cables are not permitted to be installed above a suspended ceiling in such a manner that access to the space above is prevented by the installation of the cables according to *725.21.* Installation of Class 2 and Class 3 cables is covered in *725.139* through *725.143.* In *725.143* it is stated that Class 2 and Class 3 cables are not permitted to be attached to the exterior of conduits and raceways.

SAMPLE CALCULATIONS

Information found in *Articles 210* and *220* of the Code is used to determine the minimum number of circuits required in a dwelling or other building. The following are examples of how these calculations are used to determine the number of circuits required. The same information is used to determine the maximum number of outlets permitted on a particular circuit. An important issue is whether the loads are considered continuous loads. In many situations, it is a matter of judgment as to the use of the loads on a circuit. In the case of receptacles outlets, it would depend on the particular application. If the load is considered to be continuous, then the overcurrent device protecting the circuit is not permitted to be loaded to more than 80% of its rating. The exception is when the overcurrent device and the enclosure into which it is installed are rated for operation at 100%, *210.19(A)(1)*.

Circuit and Outlet Requirements

The minimum number of circuits for general illumination is based on the actual load when the load is known; however, the minimum permitted demand load for general illumination is specified in Code

Table 220.12. The demand load for receptacle outlets shall be considered a load of 180 volt-amperes (VA) per strap or yoke at an outlet. In the case of a dwelling, the receptacle outlets are considered loads for general illumination, and the load is determined based on the 3 volt-amperes per square ft (33 VA/m^2) from *Table 220.12* and not from the 180-volt-amperes per outlet as stated in *220.14(I)*. This information on loads has three basic purposes: (1) it is used to determine the minimum number of branch-circuits in a building or an area of a building; (2) it is used to determine the minimum number of outlets on a particular branch-circuit; and (3) it is used to determine the demand load of a building or an area of a building for the purpose of sizing a feeder or electrical service or distribution panel. This latter function of feeders and panels will be the subject of *Unit 4*.

The minimum number of circuits for general illumination for a dwelling, which includes receptacle outlets and lighting outlets, is determined by multiplying the area of the building by the unit load found in *Table 220.12*. This process is described in *210.11(A)* and *220.12*. Once the total general illumination load in volt-amperes is determined, divide by 120 volts to get the current. Assuming the circuits are made up of fixed luminaires (lighting fixtures) and receptacle outlets, the minimum number of circuits can be determined by dividing the general illumination current by the rating of the circuits. If this number of circuits is not adequate to supply the specific load, then the number of circuits must be increased. That decision cannot be made without some knowledge of the loads to be served. The following example shows how to determine the minimum number of circuits required in a dwelling for general illumination.

Example 3.1 A dwelling has 2100 square ft (195 m^2) of living area. The area does not include the unfinished basement. Determine the minimum number of general illumination branch-circuits required in this dwelling assuming circuits rated 15 amperes.

Answer: First look up the minimum unit load for dwelling general illumination in *Table 220.12* and find 3 VA/ft^2 (33 VA/m^2). Next multiply this unit load by the living area of the dwelling to get 6300 VA (6435 VA based on metric calculation). Four 15-ampere rated general illumination circuits are required for this dwelling.

$$2100\ \text{ft}^2 \times 3\ \text{VA/ft}^2 = 6300\ \text{VA} \qquad 195\ \text{m}^2 \times 33\ \text{VA/m}^2 = 6435\ \text{VA}$$

$$\frac{6300\ \text{VA}}{120\ \text{V}} = 53\ \text{amperes} \qquad \frac{6435\ \text{VA}}{120\ \text{V}} = 54\ \text{amperes}$$

$$\frac{53\ \text{A}}{15\ \text{A/circuit}} = 3.5\ \text{circuits} \qquad \frac{54\ \text{A}}{15\ \text{A/circuit}} = 3.6\ \text{circuits}$$

There is seldom justification to consider dwelling loads for general illumination to be continuous loads. There are both lighting loads and receptacle outlets on the circuits, and generally this type of load combination will not apply a heavy load to the circuit on a continuous basis.

Buildings other than dwellings have the general illumination load generally limited to fixed lighting. If the actual ampere rating of the luminaires (lighting fixtures) is known, then this load is required to be used if it is greater than the load determined using the unit load required from *Table 220.12*. The following example shows how to determine the minimum number of general illumination circuits that are required for an office building:

Example 3.2 An area of a building devoted to offices has an area of 8200 sq. ft (762 m^2). Determine the minimum number of 20-ampere, 120-volt rated general illumination branch-circuits required for the office space of the building.

Answer: This is a building space listed in general illumination *Table 220.12*. The unit load for office space is 3.5 VA/ft^2 (39 VA/m^2). Multiply the unit general illumination load by the area of the office space to get the volt-ampere for general illumination. This is a continuous load, therefore, multiply the load by 1.25. Then divide by 20 ampere per circuit to determine the minimum number of circuits required which is 15.0 (15.5 using metric factors). Even though one calculation arrives at 15 circuits and the other arrives at 16 circuits, either is considered to be in compliance according to *90.9(D)*.

$$8200\text{ ft}^2 \times 3.5\text{ VA/ft}^2 = 28{,}700\text{ VA} \qquad 762\text{ m}^2 \times 39\text{ VA/m}^2 = 29{,}718\text{ VA}$$

$$1.25 \times 28{,}700\text{ VA} = 35{,}875\text{ VA} \qquad 1.25 \times 29{,}718\text{ VA} = 37{,}148\text{ VA}$$

$$\frac{35{,}875\text{ VA}}{120\text{ V}} = 299\text{ amperes} \qquad \frac{37{,}148\text{ VA}}{120\text{ V}} = 310\text{ amperes}$$

$$\frac{299\text{ A}}{20\text{ A/circuit}} = 15.0\text{ circuits} \qquad \frac{310\text{ A}}{20\text{ A/circuit}} = 15.5\text{ circuits}$$

To determine the actual number of luminaires (lighting fixtures) on the circuit, these lighting loads usually are considered to be continuous loads. Continuous load means the branch-circuit is not permitted to be loaded more than 80% of the circuit rating. For a 20-ampere lighting circuit, the maximum permitted continuous load on the circuit would be 16 amperes. If the current drawn by the luminaires (lighting fixtures) is known, the number of luminaires (fixtures) on a branch-circuit can be determined. The method is shown in the following example.

Example 3.3 Electric discharge luminaires (lighting fixtures) to be installed in a building each are rated at 1.9 amperes at 120 volts. Determine the maximum number of these luminaires (fixtures) permitted to be installed on a 20-ampere branch-circuit in a commercial building.

Answer: The 20-ampere branch-circuit is only permitted to be loaded to 80% of the circuit rating, which is 16 amperes. Divide the 16 amperes by the rated current of each luminaire (fixture) to determine the maximum number of luminaires (fixtures) permitted to be installed on the circuit. It is necessary to round a fraction down to the next integer or the circuit will carry more than 16 amperes. The maximum number of luminaires (fixtures) permitted to be installed on the circuit is eight.

$$\frac{16\text{ A/circuit}}{1.9\text{ A/luminaire (lighting fixture)}} = 8.4\text{ luminaires (lighting fixtures)}$$

When to consider loads to be continuous is frequently a matter of judgment. In a commercial building, for example, receptacle loads may be operated with a great amount of diversity. Therefore, the times will be infrequent when the circuit would be operated near the circuit rating, especially for three hours or longer. In this case, the receptacle circuit is not to be considered a continuous load. In another case, the receptacle circuit could be considered a continuous load.

In *Annex D* of the Code, several examples illustrate how to determine the minimum number of branch-circuits for different building types. *Example D1(a)* is an example for a single-family dwelling, and *Example D4(a)* shows how to determine the minimum number of branch-circuits for each dwelling unit of a multifamily dwelling. *Example D3* shows how to determine the minimum number of branch-circuits for a store building.

Electric Range for a Dwelling

An electric range for a dwelling seldom operates at full nameplate rating, and when it does, the load is on only for a short time. Damage to conductors requires heat-producing current over a time period. If the time period is known to be limited, the wires will not be damaged. The range circuit rating is permitted by *220.18(C)* to be based on a range demand load. The minimum rating circuit permitted for a household electric range is 40 amperes for ranges rated more than $8\frac{3}{4}$ kW, as specified in *210.19(A)(3)*. The range demand load is found in *Table 220.55*. Column C of *Table 220.55* gives the demand load of an electric range or ranges that have a rating of not more than 12 kW. For example, one 12-kW electric range can be taken at a demand load of 8 kW for the purpose of sizing the branch-circuit overcurrent device and minimum conductor size. The following example explains the process.

Example 3.4 A 10-kW electric range in a dwelling operates from a 120/240-volt circuit. Determine the minimum ampere rating of the circuit permitted to supply this electric range.

Answer: The demand load for a 10-kW electric range is considered to be 8 kVA from column C of *Table 220.55*. Multiply the 8 kVA by 1000 to convert to VA and then divide by 240 volts to get the current, which is 33.3 amperes. A 35-ampere overcurrent device (*240.6*) is sufficient for the load, but the minimum permitted is 40 amperes *210.19(A)(3)*.

The minimum circuit rating for a household electric range is 40 amperes according to *210.19(A)(3)*. The circuit conductor is not permitted to have an allowable ampacity less than the rating of the range circuit, and the minimum conductor size is found in *Table 310.16*. For the previous example, where the circuit has a 40-ampere rating, the minimum copper conductor size permitted is 8 AWG. If the circuit is wired using Nonmetallic-Sheathed Cable, Type NM-B, according to *334.80*, the allowable ampacity of the conductors is found in the 60°C column of *Table 310.16*. If the circuit is wired using service-entrance cable Type SE, the installation of the cable is required to be the same as for Type NM-B, according to *338.10(B)(4)*. This means that even though the conductor insulation and terminations are rated 75°C, the 60°C column of *Table 310.16* is required because *334.80* applies to Type SE cable when it is installed as an inside branch-circuit or feeder. If the circuit is wired as individual conductors in raceway, then the column of *Table 310.16* that is used to size the conductors depends upon the insulation rating of the conductors and the conductor terminations. Be aware of any conductor insulation minimum ratings that may be marked on an appliance terminal box.

New electric range branch-circuits are required to have the grounded-circuit conductor (neutral) separated from the equipment grounding conductor. A 4-wire circuit and a 4-wire cord are required to supply an electric range, counter-mounted cooking unit, or wall-mounted oven. If the range is cord- and plug-connected, the receptacle is required to be of the 4-wire type with the neutral terminal separate from the equipment grounding terminal. The minimum ampere rating of the receptacle is permitted to be determined in the same manner as the circuit overcurrent device, according to *210.21(B)(4)*. In the case of an existing electric range circuit, the neutral conductor is permitted by *Exception 1* of *250.140* and *250.142(B)* to also serve as the equipment grounding conductor. The conditions that must be satisfied for the neutral to also serve as the equipment grounding conductor are covered in *250.140*.

The minimum branch-circuit rating for a household electric range is permitted to be determined using the rules in *220.55* according to *422.10(A)*. *NEC® 422.11(B)* sets the maximum branch-circuit demand load at 60 amperes. If the appliance has a demand load higher than 60 amperes, then the load of the appliance is required to be subdivided so it will not exceed 50 amperes. Column C of *Table 220.55* applies to an electric range rated not over 12 kW. *Note 1* of *Table 220.55* permits the use of Column C for ranges rated more than 12 kW by increasing the value in column C by 5% for each kW in access of 12 kW. If the range is rated 14 kW, then the value in column C is increased by 5% twice. The demand load of an electric range with a rating greater than 12 kW can be calculated according to the rule of *Note 1* of *Table 220.55* using Equation 3.1. Don't be confused by the units kW and kVA. For the purpose of these branch-circuit calculations these units are considered interchangeable.

$$\textbf{Range Demand Load} = \textbf{[(Value in column C)} \times \textbf{0.05} \times \textbf{(Range kW – 12 kW)]} + \textbf{(Value in column C)} \qquad \textbf{Eq. 3.1}$$

$$= [(8\text{ kW}) \times 0.05 \times (14\text{ kW} - 12\text{ kW})] + 8\text{ kVA}$$

$$= (8\text{ kW} \times 0.05 \times 2) + 8\text{ kVA}$$

$$= 0.8\text{ kVA} + 8\text{ kVA} = 8.8\text{ kVA}$$

If the rating of the electric range is a fraction, such as 14.5 kW, the number is rounded to the nearest whole number before doing the calculation. *Note 1* of *Table 220.55* requires the value in column C to be increased by 5% for every kW the range rating is greater than 12 kW, and by 5% for any major fraction of a kW. A major fraction is 0.5 or greater. This means that for a 14.5-kW electric range you must use 15 in the calculation. Do not use 14.5 kW. If an electric range has a rating of 16.4 kW, round down and use 16 kW in the calculation. The following example will illustrate how to determine the minimum range demand load when the nameplate rating of the range is a fraction.

Example 3.5 A 17.4-kW electric range is installed in a dwelling. Determine the minimum circuit rating and copper conductor size if the circuit is wired using Type NM-B Nonmetallic-Sheathed Cable.

Answer: The demand load can be determined using Equation 3.1, which is the rule in *Note 1* of *Table 220.55*. The range rating is greater than $8\frac{3}{4}$ kW, therefore, look up the demand for one range rated 12 kW in column C of *Table 220.55* and find 8 kVA. The nameplate rating of the range is a fraction, so round the 17.4 kW off to 17 kW. Now use Equation 3.1 to determine the range demand load.

$$\text{Demand load} = [(8\text{ kW}) \times 0.05 \times (17\text{ kW} - 12\text{ kW})] + 8\text{ kVA}$$

$$= (8\text{ kW} \times 0.05 \times 5) + 8\text{ kVA} = 10\text{ kVA}$$

$$\text{Demand load current} = \frac{10\text{ kVA} \times 1000}{240\text{ V}} = 41.7\text{ amperes}$$

The minimum circuit rating is 45 amperes, however, it is more likely a 50-ampere overcurrent device would be used. The circuit is wired with Type NM-B Cable, therefore, the 60°C column of *Table 310.16* will be used to determine the minimum size conductor. The rating of the circuit determines the size of conductor, therefore, the minimum size permitted is 6 AWG.

An oven and cooking unit can be separate units and built into the kitchen, as shown in Figure 3.13. The range conductor is permitted to extend from the supply panel to a junction box, and then taps connect to the counter-mounted cooking unit and to the wall-mounted oven. This is permitted by *Exception 1* to *210.19(A)(3)*. The rules for determining the minimum size of conductors for a wall-mounted oven and a counter-mounted cooking unit supplied from the same branch-circuit are found in *Note 4* to *Table 220.55*. The minimum conductor size for the counter-mounted cooking unit and the wall-mounted oven is determined based on the nameplate rating of each unit. It is permitted to add together the nameplate ratings of one counter-mounted cooking unit and up to two wall-mounted ovens for a dwelling to determine the rating of the circuit. The combined nameplate ratings are treated as one range for the purpose of determining the demand load. The following example is for a counter-mounted cooking unit and a wall-mounted oven supplied by the same branch-circuit with a tap to each unit.

Example 3.6 A dwelling electric range consists of a wall-mounted oven with a nameplate rating of 6.6 kW and a counter-mounted cooking unit with a rating of 8 kW, shown in Figure 3.13. Determine the minimum rating for the range circuit, and the minimum size Type NM-B copper cable required for the circuit and for the tap to each cooking unit.

Answer: Add the 8-kW rating of the counter-mounted cooking unit to the 6.6-kW rating of the wall-mounted oven to get a combined rating of 14.6 kW. Next determine the demand load for the range using Equation 3.1.

$$\text{Demand load} = [(8\text{ kW}) \times 0.05 \times (15\text{ kW} - 12\text{ kW})] + 8\text{ kVA}$$

$$= (8\text{ kW} \times 0.05 \times 3) + 8\text{ kVA} = 9.2\text{ kVA}$$

$$\text{Demand load current} = \frac{9.2\text{ kVA} \times 1000}{240\text{ V}} = 38.3\text{ amperes}$$

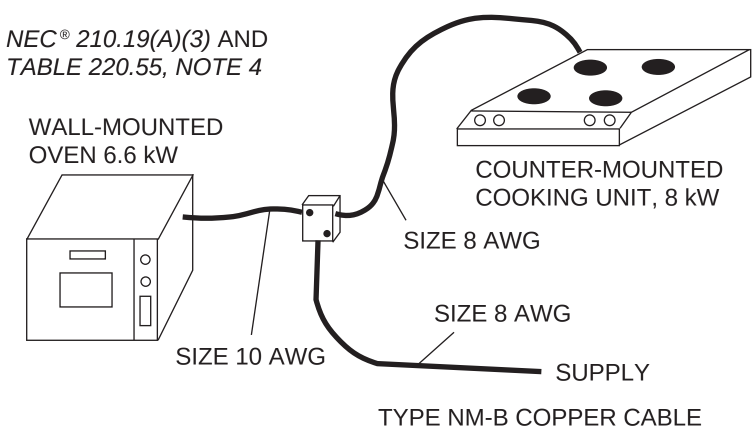


Figure 3.13 A wall-mounted oven and a counter-mounted cooking unit are installed on a single branch-circuit.

The minimum rating permitted for this branch-circuit serving both the counter-mounted cooking unit and the wall-mounted oven is 40 amperes. Now determine the full-load current for each cooking unit.

$$\text{Wall-mounted oven current} = \frac{6.6 \text{ kVA} \times 1000}{240 \text{ V}} = 28 \text{ amperes}$$

$$\text{Counter-mounted cooking unit current} = \frac{8 \text{ kVA} \times 1000}{240 \text{ V}} = 33 \text{ amperes}$$

Nonmetallic-Sheathed Cable is used for the circuit, therefore, the 60°C column of *Table 310.16* is used to determine the minimum conductor size. The branch-circuit conductor is size 8 AWG, the tap to the counter-mounted cooking unit is size 8 AWG, and the tap to the wall-mounted oven is 10 AWG.

A disconnecting means is required to be provided for the electric range that will disconnect all ungrounded conductors. The rule is found in *422.31*. If the branch-circuit overcurrent device is located within sight from the appliance, or is capable of being locked in the open position, *422.31(B)* will permit the overcurrent device to act as the disconnecting means. The plug and receptacle is permitted to act as the disconnecting means if it is accessible or if it can be reached by removal of a range storage drawer, as stated in *422.33(B)*. *NEC® 422.16(B)(3)* permits a plug and receptacle or a plug and connector to be used to make the power connection to a wall-mounted oven or a counter-mounted cooking unit, but it does not permit these connections to serve as the disconnecting means for the cooking unit.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC®* that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 210 Branch-Circuits

210.4(B): This paragraph requires the simultaneous disconnecting of all ungrounded conductors of a multiwire branch-circuit. The simultaneous disconnecting requirement in the previous edition of the Code only applied when the multiwire branch-circuit supplied more than one device on the same yoke, such as the case with a split duplex receptacle. Now there is no reference to multiple devices on the same yoke. All multiwire branch-circuits in all types of occupancies are required to have all ungrounded conductors simultaneously disconnected. Listed handle ties on single-pole circuit breakers are acceptable, but now the rule applies to circuits such as lighting circuits where individual rows of luminaires (lighting fixtures) are controlled by individual switches, but share a common neutral, such as shown in Figure 3.14.

210.4(D): All conductors of a multiwire branch-circuit at some point in the originating equipment or panelboard are required to be held together as a group by tape, ties, or some similar means to indicate they are associated with the same circuit, unless the grouping is obvious.

210.8(A)(2): This paragraph requires that 125 volt, 15- and 20-ampere receptacles installed in a garage or at grade level in an accessory building be GFCI protected. There were two exceptions that provided for non-GFCI protected receptacles for cord and plug connection of equipment in dedicated space such as a refrigerator or freezer in a garage. Another receptacle affected by this deletion of the exceptions is that a receptacle installed in the ceiling of a garage for supply of a garage-door opener is now required to be GFCI protected, such as illustrated in Figure 3.15. Those exceptions were deleted and now all receptacles in these spaces of a dwelling are required to be GFCI protected.

210.8(A)(5): This paragraph requires all 125 volt, 15- and 20-ampere receptacles installed in a dwelling basement to be GFCI protected. Exceptions were deleted that permitted equipment installed in dedicated space to be cord and plug connected without GFCI protection. This exception covered appliances and equipment such as sump pumps, washers, and gas dryers. These exceptions are gone, and now

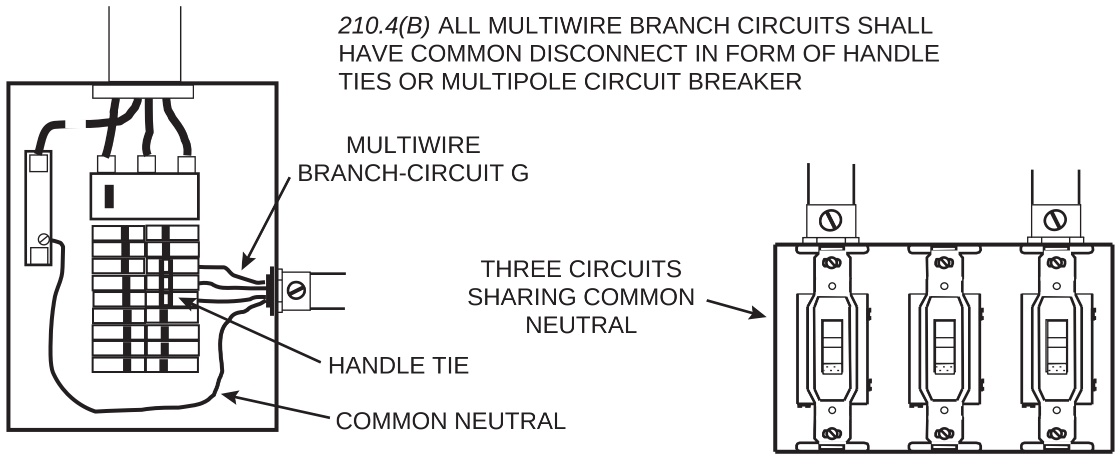


Figure 3.14 Multiwire branch-circuits in all occupancies are now required to have a common disconnect such as a multipole circuit breaker, or handle ties that will disconnect all ungrounded wires of the circuit simultaneously.

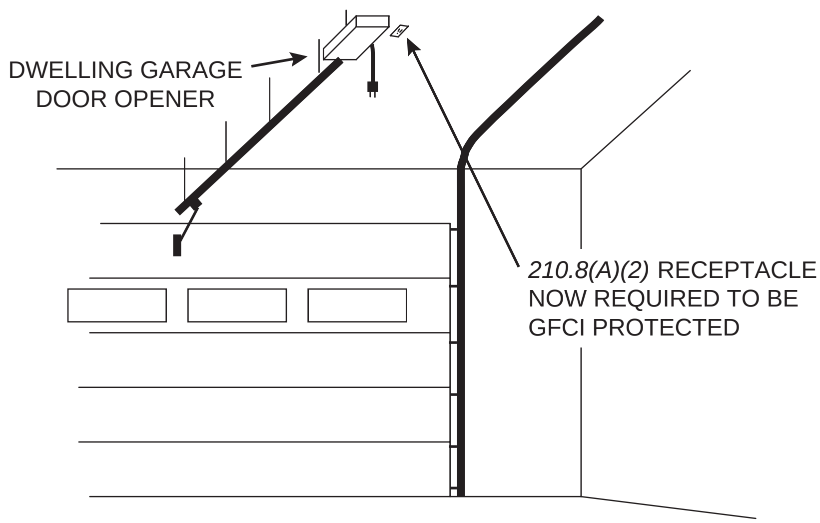


Figure 3.15 All dwelling 125-volt, 15- and 20-ampere receptacles in the garage and outside are required to be GFCI protected.

appliances and equipment such as these are required to be supplied from GFCI-protected receptacles or circuits as illustrated in Figure 3.16.

210.8(B)(4): The previous edition of the Code required that receptacles installed outdoors accessible to the public on 125 volt, 15- and 20-ampere circuits be GFCI protected for non-dwelling occupancies such as commercial, industrial, and farm. The change is that the reference “accessible to the public” was deleted. Now all outside receptacles on 125 volt, 15- and 20-ampere circuits for non-dwelling occupancies are required to be GFCI protected. There is an exception that applies for industrial only where the receptacles are accessible only to qualified personnel and there is an assured equipment grounding program under *590.6(B)(2)*.

210.8(B)(5): Receptacles supplied by 125-volt, 15- and 20-ampere circuits and located within 6 ft (1.8 m) of a sink in all non-dwelling occupancies are now required to be GFCI protected, illustrated in Figure 3.17. There is an exception for laboratories in industrial facilities where loss of power would pose a greater hazard; the GFCI protection for the receptacle is permitted to be omitted. There is a second exception for patient care areas of health care facilities where a receptacle located within 6 ft (1.8 m) of a sink is not necessarily required to be GFCI protected.

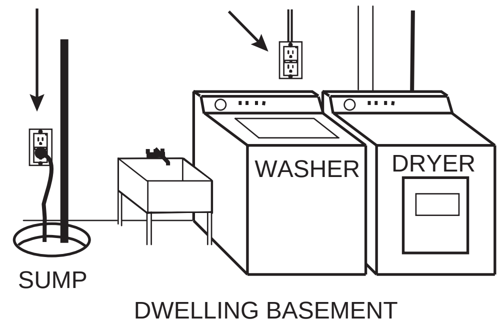


Figure 3.16 All dwelling 125-volt, 15- and 20-ampere receptacles in the unfinished portion of a basement are now required to be GFCI protected.

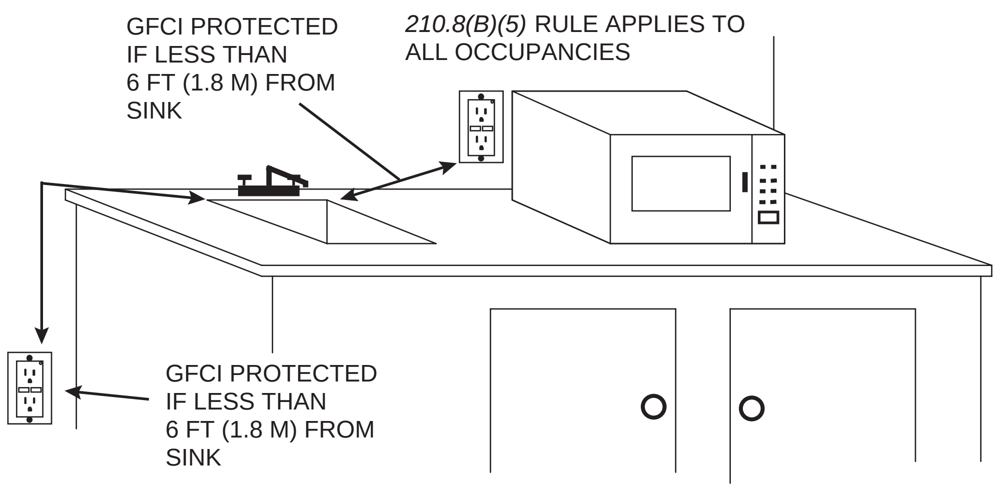


Figure 3.17 Receptacles rated 125-volt, 15- and 20-ampere installed within 6 ft (1.8 m) of the edge of a sink in all occupancies are required to be GFCI protected. There are very few exceptions.

210.8(C): The previous edition of the Code required outlets for a dwelling boat lift supplied by 125-volt, 15- and 20-ampere circuits to be GFCI protected. Now circuit ampere rating is not specified, and the rule also applies to boat lift outlets on circuits rated up to 240 volts.

210.12(B): There is a change in the arc-fault circuit interrupter requirements for dwellings. A new version of the AFCI will be required called the “combination-type.” The type presently used is called the branch/feeder type and no longer will be acceptable as meeting the Code requirement. The area within a dwelling where an outlet is required to be AFCI protected has increased. The previous edition of the Code only required AFCI protection for 120-volt, 15- and 20-ampere circuits supplying outlets in dwelling bedrooms. In addition to outlets on 120-volt, 15- and 20-ampere circuits in bedrooms, the list of rooms where AFCI protection is required has expanded to include the family room, diningroom, livingroom, parlor, library, den, sunroom, recreation room, all closets with outlets, hallways, and similar areas or rooms. Typical area of a dwelling covered and not covered are shown in Figure 3.18. The kitchen, laundry room, utility room, bathrooms, garage, unfinished basement areas, attic, and outside outlets are excluded from the requirement. AFCI protection for those circuits is optional. None of the areas where AFCI protection is required are areas where GFCI protection is required, unless an outlet is located within 6 ft (1.8 m) of a sink. The AFCI is required to be at the source of the circuit; therefore, it is required to be installed in the service panel of the dwelling, but there is an exception.

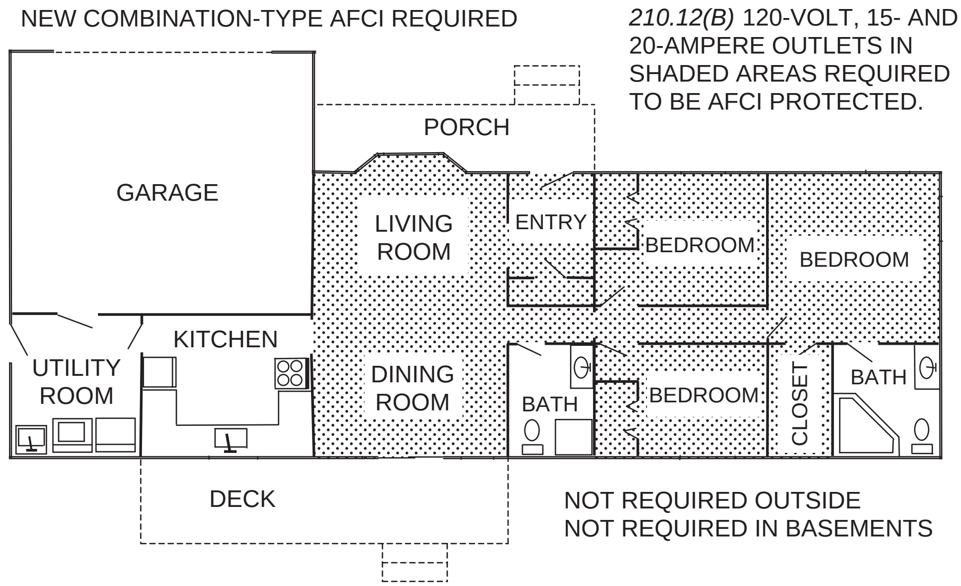


Figure 3.18 The new combination-type AFCI is required for protection of all 120-volt, 15- and 20-ampere branch-circuits in a dwelling livingroom, dining room, family room, den, recreation room, library, hallway, closets, and bedrooms.

210.12(B) Exception: This exception permits an arc-fault circuit interrupter (AFCI) required for dwelling applications to be installed at the first outlet on the circuit instead of at the service panel, provided installation requirements are followed. For the AFCI to be located at the first outlet on the circuit, the wiring between the service panel and the first outlet is required to be run in Rigid Metal Conduit, Intermediate Metal Conduit, Electrical Metallic Tubing, or steel Armored Cable, Type AC, meeting the grounding requirements of *250.118*. Testing has shown that when run as steel Type AC cable, or as RMC, IMC, or ENT, a fire hazard due to an arcing condition is highly unlikely; therefore, as long as these materials are used as the wiring method from the service panel to the first outlet, the AFCI is permitted to be installed at the first outlet, most likely in the form of a receptacle type AFCI. There is an additional requirement that the first outlet must be a metal box. A typical installation is shown in Figure 3.19. After the first box, other wiring methods acceptable for dwelling applications are permitted.

210.52(E)(3): At least one receptacle is required to be installed at each balcony, deck, or porch that is attached to the structure and accessible from inside the dwelling. There is an exception that where the useable space is less than 20 sq ft (1.86 sq. m) a receptacle accessible from the balcony, porch, or deck is not required.

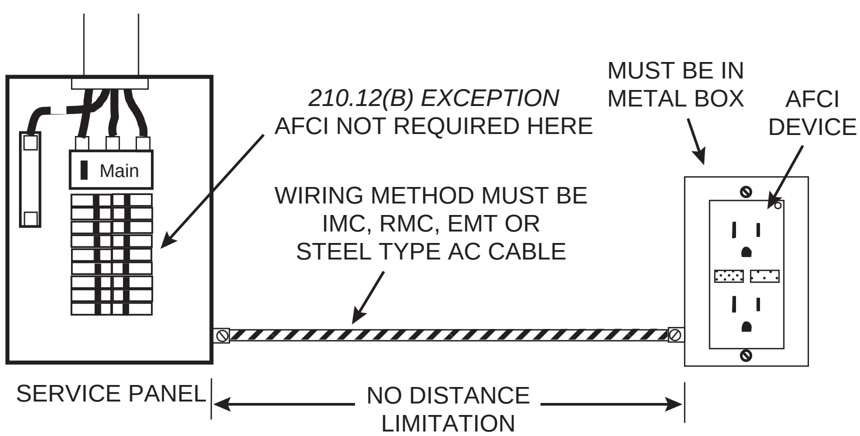


Figure 3.19 An AFCI is permitted to be located at the first outlet on a 120-volt, 15- and 20-ampere circuit if the outlet box is metal, and the wiring between the service panel and the outlet box is RMC, IMC, EMT, or steel Type AC cable suitable for grounding.

210.60(A): This section specifies receptacle outlet placement for guest rooms and suites in hotels and motels and similar occupancies. The word "dormitories" was added to make it clear they are to be treated in the same manner as guest rooms.

Article 225 Outside Branch-Circuits and Feeders

225.10: Types of wiring methods permitted to be installed on the outside of buildings are listed in this section. Type UF cable which is suitable to be installed in wet locations was left out and is now listed as an acceptable wiring method.

225.22: This section states requirements for installation of raceway on the exterior of buildings. An exception was deleted that made reference to flexible metal conduit, which is no longer permitted to be installed on the exterior of a building if the location is considered to be a wet location.

Article 396 Messenger Supported Wiring

Table 396.10(A): Medium voltage cable, Type MV, is now permitted to be installed as messenger supported wiring with specifications provided in *328.10(3) Exception*.

396.30: This section now contains all requirements for a messenger as a means of support and as a neutral conductor or as an equipment grounding conductor. There is actually no change in this section, but it now states specifically when and how a messenger is permitted to serve as a grounded conductor (neutral) or an equipment grounding conductor.

Article 404 Switches

404.4: This section provides specifications on the installation of switches and circuit breakers used as switches in damp and wet locations. The section was too general, thus placing unnecessary restrictions on some installations. There is no longer a reference to installations outside a building. Just because the switch is located outside a building does not necessarily mean it is in a damp or wet location. The section also distinguishes between a surface-mounted switch and a flush-mounted switch. For surface mounting, a weatherproof enclosure is required in a damp or wet location. In the case of a flush-mounted switch in a damp or wet location, only a weather-proof cover is required.

404.9(B)(1): This section specifies methods of grounding a switch. The change is that it specifically states that a switch is considered grounded if it is connected using metal screws to a metal cover that is considered grounded. The previous edition of the Code only made reference to use of metal screws to ground a switch to a grounded metal box.

Article 406 Receptacles, Cord Connectors, and Attachment Plugs

406.4(G): If two receptacles or a receptacle and a switch are installed in the same box and there is more than 300 volts between terminals of the separate devices, then a metal barrier is required to be installed between the devices. This rule has been in effect for switches where multiple switches are connected to different phases of a 480/277 volt, 4-wire wye electrical system. In this case, there will be 480 volts between terminals of adjacent switches. It is not common to find two receptacles in the same box with more than 300 volts between the two separate receptacles. Generally, special use receptacles of this voltage are installed in a dedicated box.

406.8(A): All nonlocking receptacles rated 15- and 20-ampere, 125 volt and 250 volt that are installed outdoors in a weather-protected area are considered to be in a damp location. The cover is required to be one that is weatherproof when there is no plug in the receptacle. The change is that now there is an additional requirement that the receptacle be one that is listed as weather-resistant.

406.8(B): All nonlocking receptacles rated 15- and 20-ampere, 125 volt and 250 volt that are installed in a wet location shall have an enclosure that is weather-proof both with a plug inserted and without a plug inserted. The change is that now there is an additional requirement that the receptacle be one that is listed as weather-resistant. There is an exception dealing with the case where plugs are removed and the area is power-washed. The receptacle must still be listed as weather-resistant, but the cover is permitted to be of a type that is weather-proof only when the plug is removed.

406.11: All 15- and 20-ampere 125-volt and 250-volt receptacles installed in a dwelling are required to be of the tamper resistant type. The receptacle slot openings are closed until a plug is inserted; see Figure 3.20. Simply pushing an object into one of the slots will not open the receptacle. An actual plug of the correct

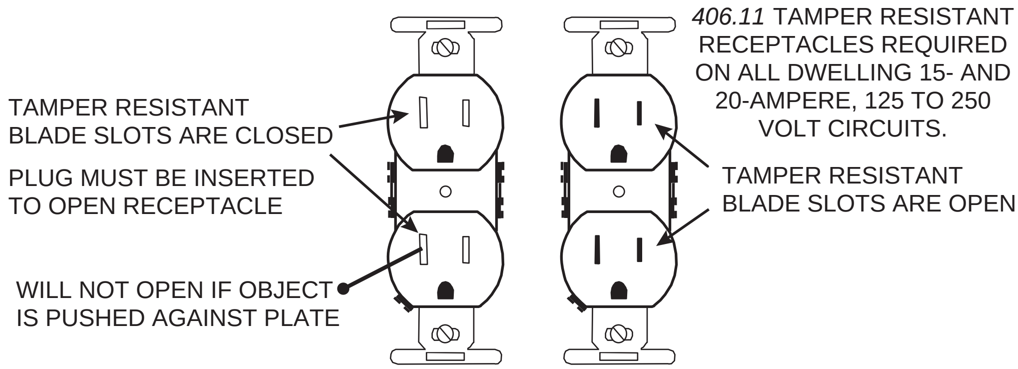


Figure 3.20 All 15- and 20-ampere, 125-volt and 250-volt straight blade receptacles installed in a dwelling are required to be of the tamper-resistant type.

configuration must be inserted in order to open the receptacle. It does not matter where the receptacle is installed; there are no exceptions.

Article 410 Luminaires, Lampholders, and Lamps

There was some reorganization of the material in this article, and many of the sections were renumbered. Some of the section and paragraph titles were also changed to better describe the subjects covered.

410.16: This section provides rules on the types of luminaires (lighting fixtures) that are permitted to be installed in clothes closets. As shown in Figure 3.21, light emitting diode (LED) lumiaires are permitted to be installed in a clothes closet if identified for use in storage areas.

410.130(G): Double-ended fluorescent luminaires (lighting fixtures) installed indoors for all locations other than dwellings and associated dwelling structures shall have a means of disconnecting live power to the ballast. The disconnect is permitted to be internal to the luminaire, like the one shown in Figure 3.22, or it can be a single device attached to the luminaire. A disconnecting means is permitted to be located away from the luminaire, but must be within sight of the luminaire. In the case of a multi-wire branch-circuit, all of the ungrounded wires and the neutral are required to be simultaneously disconnected.

410.151(B) FPN: This section specifies the maximum load that is permitted to be connected to a lighting track, which is simply the maximum rating of the track. When making a feeder or service calculation, however, it is required to add a load to the calculation that is equal to 150 volt-amperes for each 2 ft (600 mm) of lighting track to be installed. The new fine print note points out that this calculation is for feeder or service load determination only and has nothing to do with the length of track that can be installed on a circuit or the number of luminaires that can be supplied by a track. Since track lighting

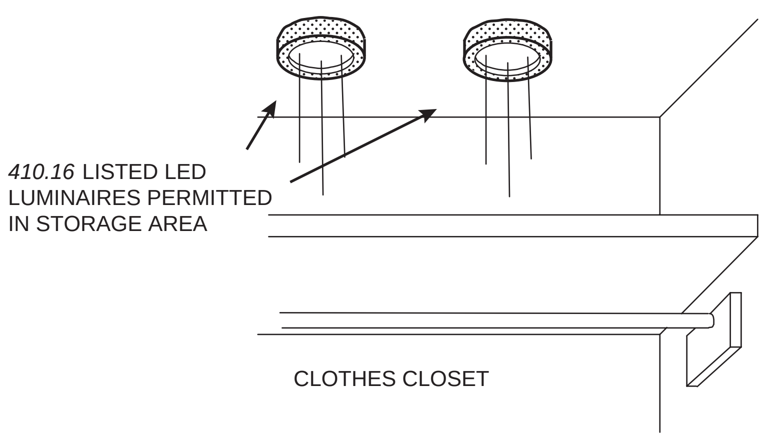


Figure 3.21 LED luminaires (lighting fixtures) listed for use in closet storage areas are permitted to be installed in a dwelling clothes closet.

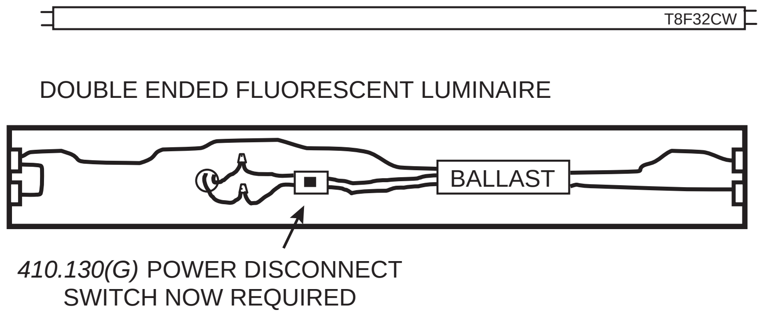


Figure 3.22 Double-ended fluorescent luminaires are now required to be equipped with a device that will disconnect power to the ballast. There are a few exceptions.

is a continuous load, the maximum load that can be supplied by any lighting track is not permitted to exceed 80% of the rating of the overcurrent device protecting the circuit.

Article 411 Lighting Systems Operating at 30 Volts or Less

411.3: New more specific listing requirements are provided for lighting systems that operate at not more than 30 volts. A complete lighting system can be listed as a unit, or a lighting system can be installed as an assembly of listed components. There was some confusion in the field in the past as to whether a low-voltage lighting system could be an assembly of individual listed components.

411.5(D): Insulated secondary conductors of a low-voltage lighting system can carry enough current to cause a fire, and now there are some specific rules about their installation. If supplied by a Class 2 supply, the wires are to be installed in accordance with the rules of *Part I* and *Part III* of *Article 725*. Other wiring is to be installed a minimum of 7 ft (2.1 m) above the floor or installed using one of the methods used for normal circuits unless for mounting at a lower height.

Article 422 Appliances

422.13: This section specifies that a storage-type electric water heater is to be considered a continuous load for the purpose of sizing the branch-circuit. The words “for the purpose of sizing the branch-circuit” were added. A feeder or service calculation includes a storage-type water heater at 100% of the rating, and sometimes a demand factor is applied that reduces that value. For the purpose determining the minimum branch-circuit rating and the minimum wire size, 125% of the load is used in the calculation.

422.51: Vending machines are required to be manufactured with integral GFCI protection. Older vending machines without integral GFCI protection are required to be connected to a circuit that is GFCI protected. This rule went into effect with the previous edition of the Code. What is new is a definition of a vending machine. A key point in the definition is that it dispenses a product or merchandise, as compared to a coin-operated washer or dryer that provides a service.

422.52: This is a new section that requires drinking fountains that are electrically powered to be GFCI protected, illustrated in Figure 3.23. This applies to both plug and cord connected and hard-wired drinking fountains.

Article 424 Fixed Electric Space-Heating Equipment

424.19: This section requires the simultaneous disconnection of all ungrounded conductors to fixed electric space-heating equipment. There was never a specification as to the rating of the disconnect, considering that some of the equipment consists of electric heating elements as well as motors. The disconnecting means is now required to have an ampere rating not less than 125% of the total load of motors and heaters.

424.19: The provisions for locking the disconnecting means for fixed electric space-heating equipment were not specified in the previous edition of the Code. It now specifies that there must be a permanent means of locking the disconnecting means in the open position. In the case of a circuit breaker, the locking kit must be of a type that remains in place even when the lock is not present.

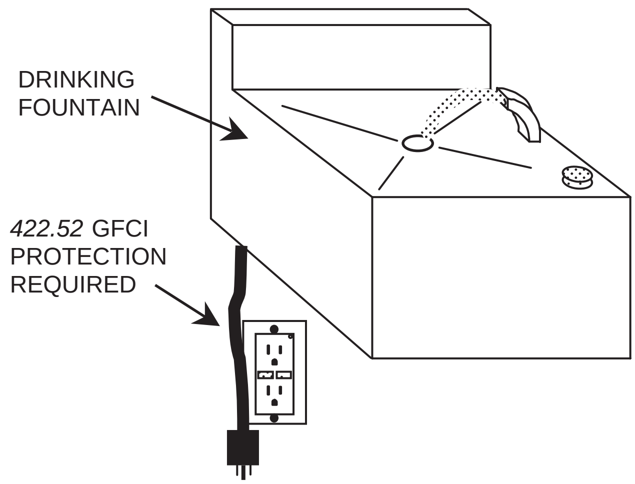


Figure 3.23 Electrically powered drinking fountains are now required to be GFCI protected.

Article 725 Class 1, Class 2, and Class 3 Remote-Control, Signaling, and Power-Limited Circuits

This article dealing with Class 1, Class 2, and Class 3 wiring installations was reorganized slightly, but it was almost completely renumbered. The new section numbers compared to the previous edition section numbers are as follows:

Part I General				
	2005 Code	725.1	through	725.15
	2008 Code	725.1	through	725.35
Part II Class 1 Circuits				
	2005 Code	725.21	through	725.29
	2008 Code	725.41	through	725.52
Part III Class 2 and Class 3 Circuits				
	2005 Code	725.41	through	725.61
	2008 Code	725.121	through	725.154
Part IV Listing Requirements				
	2005 Code	725.82		
	2008 Code	725.179		

725.24: Class 1, Class 2, and Class 3 cables are to be installed in a neat manner, and supported by straps, staples, hangers, cable ties, and similar fittings. The change is that cable ties are a frequent method used to support these cables, but is was not specifically mentioned in the list.

725.25: Abandoned cables not marked in a durable manner for future use are required to be removed in accessible locations. This is not a new requirement, but it is considered such an important requirement that it now is in a separate section.

725.130(B) Exception 3: Some security systems use bare Class 2 cables, and now that technique is permitted if the cable is installed as a part of a listed system.

725.154(D)(4)(2): This paragraph deals with the installation of Power-Limited Tray Cable (PLTC) in an industrial classified hazardous location. Cable Type PLTC-ER that does not have a metallic jacket is permitted to be run outside a cable tray to make transitions from one cable tray to another, or to adjacent equipment. There are support and protection requirements that must be met. The real significance of this change is the **-ER** in the cable type designation. Cables that carry this designation are rated as “Exposed Routing,” which means they are permitted to be installed exposed outside a cable tray or raceway.

725.179(E): Nonmetallic-Sheathed, Power-Limited Tray Cable, Type PLTC when installed in a wet location is required to be listed to be suitable for use in a wet location or have a moisture-impervious metal sheath.

WORKSHEET NO. 3—BEGINNING OUTLETS, LIGHTING, APPLIANCES, AND HEATING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A two-family dwelling has both living units with grade level access both from the front and the back yard. The minimum number of 125-volt, 15- or 20-ampere receptacle outlets required on the outside of this building is:
   A. not specified in the Code.
   B. one.
   C. two.
   D. three.
   E. four.

   Code reference___________________

2. A living area in a dwelling has a wall that is 4 ft (1.22 m) long, then makes a 90° corner and continues for another 20 ft (6.10 m), and makes another corner and continues for 7 ft (2.13 m) as shown in Figure 3.24. The minimum number of receptacle outlets permitted to be installed on this 31 ft (9.45 m) wall section is:
   A. two.
   B. three.
   C. four.
   D. five.
   E. six.

   Code reference___________________

3. A thermostat circuit in a single-family dwelling is rated as Class 2 power-limited operating at 24 volts. A listed cable less than $^1/_4$ in. (6 mm) in diameter permitted for this application but not permitted to be installed in a commercial building without raceway protection is Type:
   A. CL2.
   B. CL3.
   C. CL2P-CI.
   D. CL2R.
   E. CL2X.

   Code reference___________________

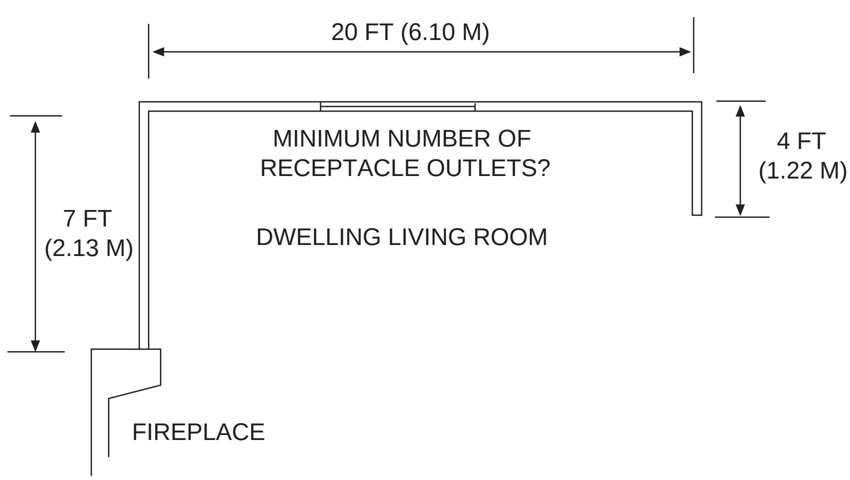


Figure 3.24 Determine the minimum number of receptacle outlets permitted to be installed on this length of unbroken wall in the living room of a dwelling.

4. Receptacle outlets are installed along the walls of living areas of a single-family dwelling where a specific load is not anticipated. These receptacle outlets are not in the kitchen, bath, or dining room. Assume also that receptacle outlets intended for an entertainment center are not included. The maximum number of receptacle outlets permitted to be installed on a 15-ampere, 125-volt branch-circuit is:
   A. not limited as long as the circuit is not overloaded.
   B. six.
   C. seven.
   D. eight.
   E. ten.

   Code reference ___________________

5. An overhead 120/240-volt, 3-wire set of feeder conductors supplies power from a dwelling to an outbuilding on a property considered to be strictly residential with no intended truck traffic as shown in Figure 3.25. If the conductors pass over a driveway, the minimum clearance from ground to an open conductor is to be not less than:
   A. 10 ft (3.0 m).
   B. 12 ft (3.7 m).
   C. 15 ft (4.5 m).
   D. 18 ft (5.5 m).
   E. 22 ft (6.7 m).

   Code reference ___________________

6. A single-family dwelling has three bathrooms. The minimum number of 20-ampere 125-volt branch-circuits required for the dwelling is:
   A. not specified in the Code.
   B. three.
   C. four.
   D. five.
   E. six.

   Code reference ___________________

7. A 12-kW electric range is to be installed in a single-family dwelling. The minimum rating 120/240-volt, 3-wire circuit permitted for the range is:
   A. 30 amperes.
   B. 35 amperes.
   C. 40 amperes.
   D. 50 amperes.
   E. 60 amperes.

   Code reference ___________________

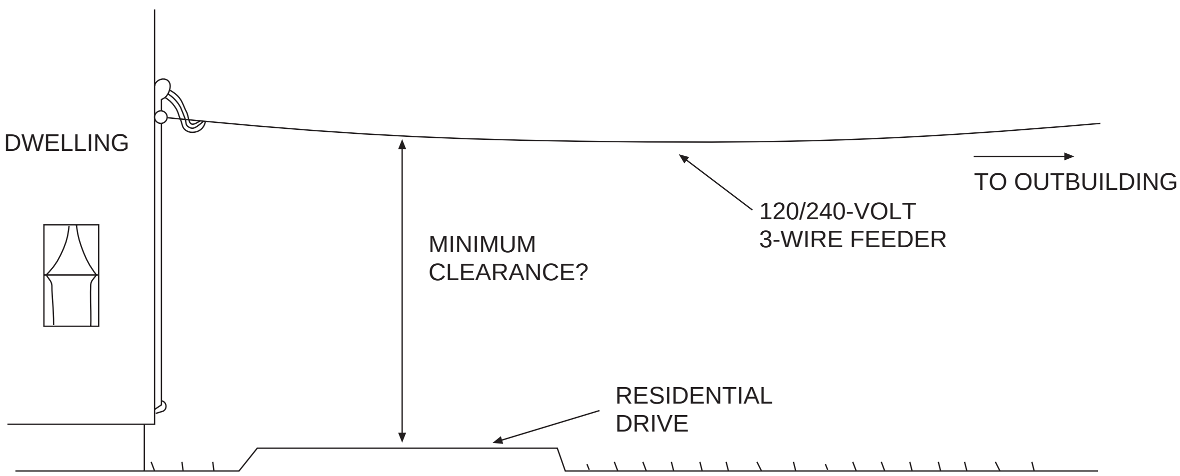


Figure 3.25 Determine the minimum clearance of overhead conductors operating at 120/240 volts and running over a residential drive.

8. A 15-ampere rated duplex receptacle on a 20-ampere, 125-volt circuit and mounted on the outside of a building and exposed to the weather is:
   A. only required to have an enclosure that is weatherproof when the receptacle is not in use.
   B. permitted to have an enclosure that is weatherproof only when the receptacle is not in use provided the intended use is only when personnel are present.
   C. not required to have a weather-proof cover if the receptacle is GFCI protected for personnel and weather-resistant rated.
   D. required to have an enclosure that is weather-proof, whether the receptacle is in use or not in use and the receptacle is weather-resistant rated.
   E. is permitted to be exposed if weather-resistant rated.

Code reference ___________________

9. Fluorescent luminaires (lighting fixtures) in a commercial building are designed to be connected end-to-end. The luminaires (fixtures) are installed in rows in a room connected end-to-end, and supplied power for the entire row with one outlet at the first luminaire (fixture) as shown in Figure 3.26. The maximum number of 20-ampere 2-wire branch-circuits permitted to supply any one row of luminaires (fixtures) is:
   A. none, because fluorescent luminaires (lighting fixtures) are required to be individually supplied with power.
   B. one.
   C. two.
   D. three.
   E. four.

Code reference ___________________

10. The allowable ampacity of a size 18 AWG copper 2-wire Type SPT-1 flexible extension cord is:
    A. 7 amperes.
    B. 10 amperes.
    C. 12 amperes.
    D. 13 amperes.
    E. 15 amperes.

Code reference ___________________

11. A receptacle outlet is located on a wall of a dwelling living room 6 in. (0.15 m) from a corner. After turning the corner, a wall section is 10 ft (3.05 m) in length. The wall then makes another corner and comes to another receptacle within 6 in. (0.15 m) as shown in Figure 3.27. The minimum number of receptacle outlets required to be installed on the 10-ft (3.05 m) wall section is:
    A. none.
    B. one.
    C. two.
    D. three.
    E. four.

Code reference ___________________

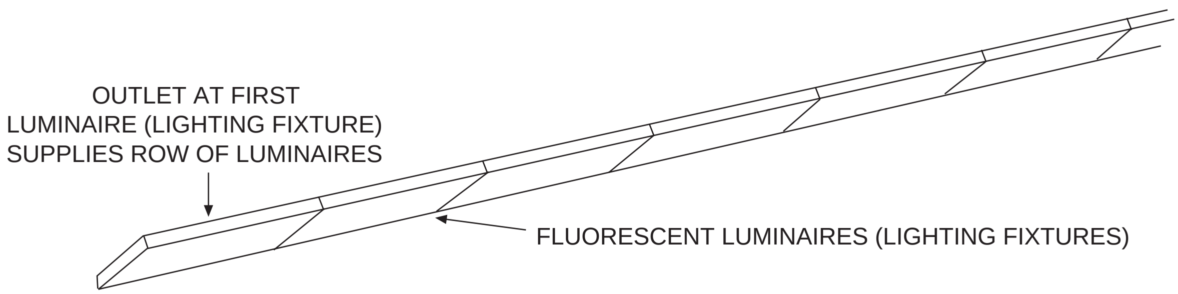


Figure 3.26 Determine the maximum number of 2-wire circuits that are permitted to supply luminaires (lighting fixtures) mounted end-to-end in a continuous row.

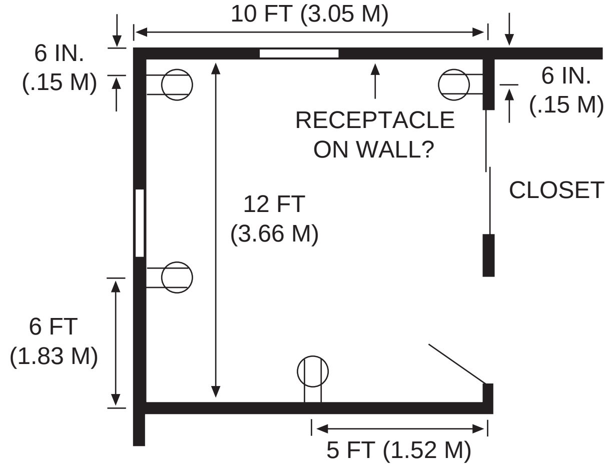


Figure 3.27 Determine the minimum number of receptacle outlets required to be installed on the 10 ft (3.05 m) section of wall in the dwelling.

12. An electric range in a single-family dwelling has a rating of 15 kW. The minimum demand load permitted to be used to determine the minimum circuit rating for the range is:
    A. 8 kVA.
    B. 8.4 kVA.
    C. 9.2 kVA.
    D. 12 kVA.
    E. 15 kVA.

    Code reference ___________________

13. A single-pole snap switch on a 15-ampere circuit in a dwelling fails and during replacement it is discovered the wire connected to the switch is aluminum size 12 AWG. If the aluminum wire is to be connected directly to the terminal screw of the replacement switch, the switch must be marked:
    A. cu/al.
    B. approved for aluminum wire.
    C. al-only.
    D. cu/al and 90° rated.
    E. CO/ALR.

    Code reference ___________________

14. A recessed incandescent luminaire (lighting fixture) is marked as thermally protected but it is not rated for direct contact with insulation (non-Type IC). Not counting the mounting points, the minimum distance required between the luminaire (fixture) and the wood joist, as shown in Figure 3.28, is:
    A. 1/2 in. (13 mm).
    B. 3/4 in. (19 mm).
    C. 1 in. (25 mm).
    D. 2 in. (51 mm).
    E. 3 in. (76 mm).

    Code reference ___________________

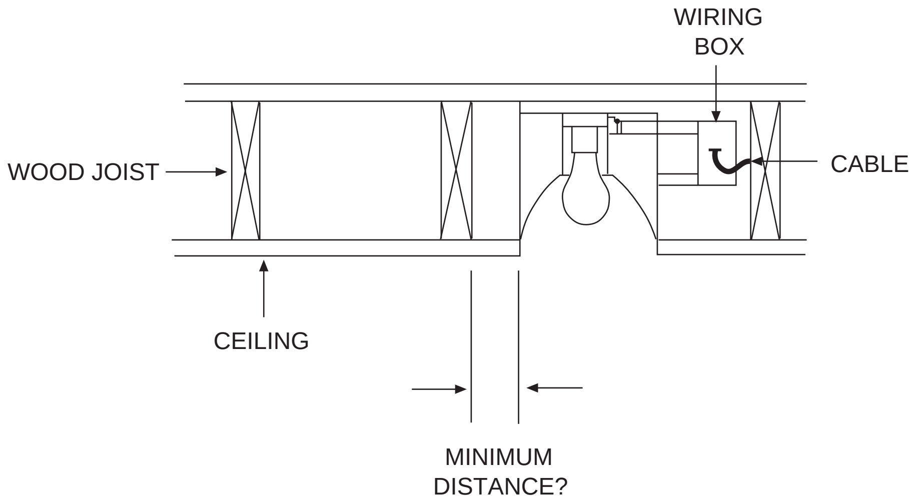


Figure 3.28 A recessed incandescent lunminaire (lighting fixture) is marked as thermally protected but not rated for installation in direct contact with insulation. Determine the minimum spacing required between the side of the luminaire (lighting fixture) and the adjacent wood joist.

15. A Type CL2 cable for a Class 2 circuit is run from a furnace to a thermostat location in another part of a new building under construction. The cable is required to be attached to structural components of the building at intervals not to exceed:
    A. any distance because support distances are not specified for a Class 2 circuit.
    B. $4^{1}/2$ ft (1.37 m).
    C. 5 ft (1.52 m).
    D. 6 ft (1.83 m).
    E. 8 ft (2.44 m).

Code reference ___________________

WORKSHEET NO. 3—ADVANCED OUTLETS, LIGHTING, APPLIANCES, AND HEATING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A single-family dwelling has a living area of 2600 sq. ft (241.5 m^2). All circuits for general illumination, in addition to those for small appliances, laundry and bathroom receptacles are rated at 15 amperes. The minimum number of general illumination branch-circuits permitted for this dwelling is:
   A. three.
   B. four.
   C. five.
   D. six.
   E. seven.

   Code reference ____________________

2. A 4500-watt, single-phase, 240-volt electric, 80-gallon (300 L) storage-type water heater is provided power with a copper Type NM-B Cable. The minimum size copper conductor permitted for this circuit is:
   A. 18 AWG.
   B. 16 AWG.
   C. 14 AWG.
   D. 12 AWG.
   E. 10 AWG.

   Code reference ____________________

3. Electric discharge luminaires (lighting fixtures) with mogul-base screw-shell lampholders supplied by a 30-ampere branch-circuit are cord- and plug-connected to receptacles located directly above the luminaires. Each luminaire (fixture) draws 3.8 amperes. The minimum rating receptacle permitted for each luminaire (fixture) is:
   A. 5 amperes.
   B. 10 amperes.
   C. 15 amperes.
   D. 20 amperes.
   E. 30 amperes.

   Code reference ____________________

4. A peninsular type dwelling kitchen counter has a cupboard mounted above with a receptacle intended to serve the peninsular counter mounted to the underside of the cupboard as shown in Figure 3.29. The maximum distance from the surface of the counter to the receptacle outlet is not permitted to be more than:
   A. 18 in. (450 mm).
   B. 20 in. (500 mm).
   C. 24 in. (600 mm).
   D. 30 in. (750 mm).
   E. 36 in. (900 mm).

   Code reference ____________________

5. An electric range rated 16.4 kW is installed in a single-family dwelling. The minimum demand load permitted to be used to determine the rating of the circuit is:
   A. 9.6 kVA.
   B. 9.76 kVA.
   C. 10 kVA.
   D. 16 kVA.
   E. 16.4 kVA.

   Code reference ____________________

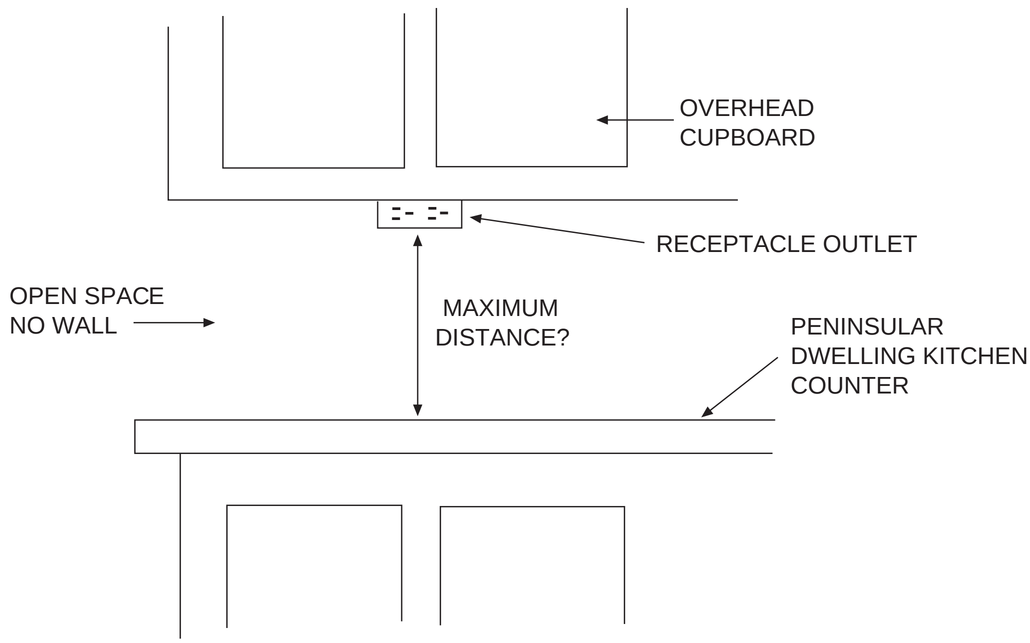


Figure 3.29 A cupboard is mounted above a swelling peninsular kitchen counter with a receptacle outlet mounted to the bottom of the cupboard. Determine the minimum distance from the counter to the receptacle.

6. A particular piece of 3-phase, 240-volt portable equipment is connected to a permanent wiring system with extra hard service Type SOW copper flexible cord. The minimum conductor ampacity required for the equipment is 14 amperes. The minimum size flexible cord permitted to supply this equipment is:
   A. 16 AWG.
   B. 14 AWG.
   C. 12 AWG.
   D. 10 AWG.
   E. 8 AWG.

   Code reference ___________________

7. Class 2 circuit conductors installed in an elevator hoistway as a riser in lengths greater than 6 ft (1.8 m) are *not* permitted to be run in:
   A. Rigid Metal Conduit.
   B. Rigid Nonmetallic Conduit.
   C. Liquidtight Flexible Nonmetallic Conduit.
   D. Liquidtight Flexible Metal Conduit.
   E. Electrical Metallic Tubing.

   Code reference ___________________

8. Three separate electric baseboard space-heating units are installed in a room of a dwelling on a single 240-volt branch-circuit. The maximum rating branch-circuit permitted for these baseboard heating units is:
   A. 15 amperes.
   B. 20 amperes.
   C. 30 amperes.
   D. 40 amperes.
   E. not limited.

   Code reference ___________________

9. A dwelling has three bathrooms, and the fan and luminaires (lighting fixtures) in each bathroom are installed on the same circuit with the receptacle in the same bathroom. The minimum number of 20-ampere, 125-volt branch-circuits required for this dwelling to serve the bathrooms is:
   A. only dependent upon the load to be served.
   B. one.
   C. two.
   D. three.
   E. four.

   Code reference ___________________

10. The outlets in a dwelling that are required to be Arc-Fault Circuit-Interrupter (AFCI) protected are:
    A. only receptacles in bedrooms.
    B. all bedroom outlets on 120-volt, 15- and 20-ampere circuits.
    C. all outlets on 120-volt, 15- and 20-ampere circuits in the entire dwelling.
    D. all outlets on 120-volt, 15- and 20-ampere circuits serving the family room, dining room, livingroom, parlor, library, den, bedrooms, sunroom, recreation room, closets, hallways, and similar rooms and areas.
    E. all outlets on circuits not run in metal raceway or metal-sheathed cable.

    Code reference ___________________

11. One building is supplied power from another building on the same property. The feeder to the second building is protected by a 200-ampere overcurrent device at the first building, and terminates immediately at a 200-ampere fusible switch upon entry to the second building as shown in Figure 3.30. This fusible switch is required to be rated as suitable for use as service equipment:
    A. only if the feeder contains a grounded circuit conductor that is also grounded at the second building and bonded to the disconnect enclosure.
    B. only if the feeder conductors are installed overhead and exposed to lightning.
    C. no matter what voltage or type of feeder supplies the second building.
    D. in all cases except where a grounded circuit conductor in the feeder is run separate from an equipment grounding conductor, and the grounded conductor is not grounded at the second building.
    E. only if the feeder has an ungrounded conductor operating at more than 250 volts-to-ground.

    Code reference ___________________

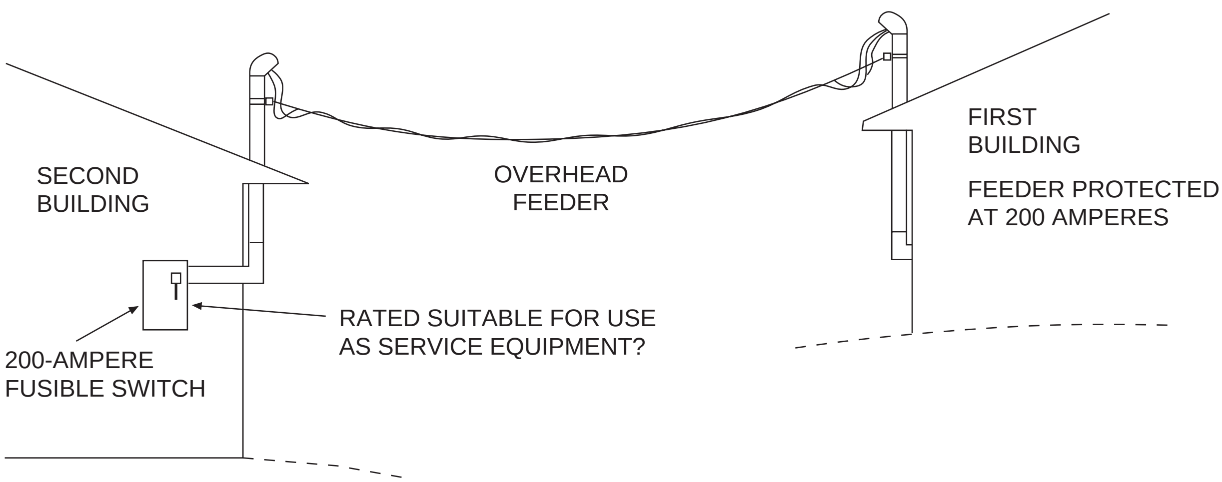


Figure 3.30 The second building receives the power from the first building. Determine the conditions under which the disconnect in the second building is required to be rated as suitable for use as service equipment.

12. A dimmer switch is *not* permitted to control:
    A. a receptacle that is intended to supply an incandescent floor or table luminaire (lighting fixture).
    B. more than one incandescent luminaire (fixture) on the same circuit in a dwelling.
    C. loads greater than 300 watts except in commercial or industrial buildings.
    D. luminaires (lighting fixtures) in a dwelling with exposed conductive parts unless protected with a GFCI for personnel.
    E. a single incandescent luminaire (fixture).

Code reference ___________________

13. A complex of buildings is supplied power from a substation on the property with overhead lines to each building operating as a 4-wire grounded wye feeder at 8300/4800 volts. The conductors pass over open lands subject to vehicular traffic, pedestrian areas, and roadways suitable for truck traffic. The clearance from the roadway to the conductors, as shown in Figure 3.31, is not permitted to be less than:
    A. 15 ft (4.5 m).
    B. 18½ ft (5.6 m).
    C. 20 ft (6 m).
    D. 22 ft (6.7 m).
    E. 30 ft (9 m).

Code reference ___________________

14. A 208/120-volt, 4-wire feeder supplies power from one building to a separate building on the same property. The feeder is protected by a 100-ampere overcurrent device in the first building. The property management does not have a qualified electrician on site at all times. The disconnecting means for the second building is:
    A. permitted to be located inside the first building.
    B. required to be located on the outside of the second building or inside and in either location near the point of entry of the conductors to the building.
    C. required to be located inside the building at the nearest practical point where the conductors enter the building.
    D. required to be located at the first building.
    E. permitted to be located outside the second building, not necessarily on the building, but within 50 ft (15 m) of the building.

Code reference ___________________

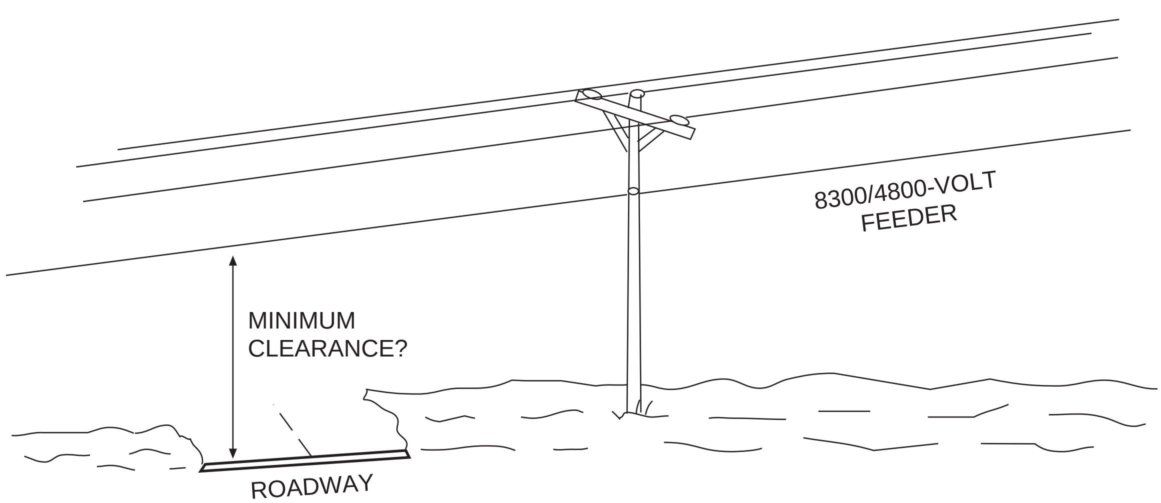


Figure 3.31 Overhead feeder conductors serving building on industrial property operate at 8300 volts between conductors and 4800 volts to ground. Determine the minimum clearance from a roadway subject to truck traffic and the overhead conductor.

15. Several Class 2 cables, with a $^{1}/_{4}$-in. (6 mm) diameter, are installed in an existing building with a suspended ceiling, and it is ruled that attaching the cables to the structural components above the ceiling will be difficult. The Class 2 cables are:
    A. permitted to be supported by the ceiling grid support wires.
    B. required to be supported by building structural components.
    C. permitted to be run across the ceiling grid and removable tiles.
    D. limited only to one cable run across the ceiling grid and removable tiles.
    E. not permitted to be supported by the ceiling grid support wires.

Code reference ___________________

UNIT 4

Services and Feeder Calculations

OBJECTIVES

After completion of this unit, the student should be able to:

- determine the minimum permitted service entrance conductor size.
- determine the demand load to be included in a multifamily service calculation for more than two electric ranges in the building.
- determine the minimum permitted ampere rating for a single-family dwelling using the methods of *Article 220, Part III* or the optional calculation method.
- determine the maximum unbalance load for a single-family dwelling for the purpose of sizing the neutral conductor.
- determine the minimum ampere demand load for a small commercial building.
- determine the minimum permitted service entrance demand load for a multifamily dwelling.
- determine the minimum ampere rating of the service entrance for an existing dwelling where there has been an addition to the structure.
- determine the minimum demand load in amperes for a farm building where the loads that operate simultaneously and other loads are known.
- look up the installation requirements for a service entrance from the Code.
- determine the minimum permitted ampere rating of central distribution equipment for a group of farm buildings, where the demand loads at each building are known.
- answer wiring installation questions relating to *Articles 215*, *220*, *Parts III*, *IV*, and *V*, *230*, and *Annex D*, *Examples.*
- state at least five significant changes that occurred from the 2005 to the 2008 Code from the previously stated articles.

CODE DISCUSSION

The installation of service equipment and calculations for the determination of the minimum rating of service equipment and feeders are covered in this unit. Grounding and bonding of service equipment are discussed in *Unit 5*.

Article 215 provides the minimum requirements for feeder conductor size and overcurrent protection. Feeders are main conductors that are ultimately subdivided into smaller circuits. The rules that are in *Article 220, Parts III, IV,* and *V* are used to determine the minimum load to be supplied by a set of feeder conductors. The total load must be subdivided into continuous and noncontinuous loads. Continuous loads, as defined in *Article 100,* are those that generally operate for three hours or longer. Lighting is usually considered to be a continuous load. Some appliances and equipment may also be considered continuous loads. Electric motors are frequently operated continuously but there is a separate rule for determining electric motor loads. Feeder load calculations are frequently figured in volt-amperes. A 150-watt incandescent lamp operating at a nominal 120 volts would be taken as a 150-volt-ampere load. A 3.5-kW electric water heater operating at 240 volts would be taken as a 3500-volt-ampere load. For some equipment, such as electric motors, the load in volt-amperes or watts is not provided. It is necessary to determine the load in volt-amperes for an electric motor by looking up the full-load current of the motor in *Table 430.248* for single-phase motors or *Table 430.250* for 3-phase motors and multiplying by the nominal voltage to get the volt-amperes. Equations 4.1 and 4.2 are used to determine load in volt-amperes for motors and similar equipment. Example 4.1 shows how to find the load for a 3-phase motor to be included in a feeder calculation.

Single-phase motors:

Motor Load = (Amperes from *Table 430.248*) × Nominal Voltage **Eq. 4.1**

Three-phase motors:

Motor Load = 1.73 × (Amperes from *Table 430.250*) × Nominal Voltage **Eq. 4.2**

Example 4.1 A 208Y/120-volt feeder in a commercial building supplies lighting and receptacle loads as well as several 3-phase electric motors, one of which is rated 10 horsepower. Determine the load in volt-amperes for the 10-horsepower, 208-volt, 3-phase electric motor to be used in the feeder calculation.

Answer: This is a 3-phase motor, therefore, Equation 4.2 can be used to calculate the motor load. Look up the full-load current of the motor in *Table 430.250* and find 30.8 amperes. The load for the motor is 11,083 VA.

$$\text{Motor Load}_{(10\text{ hp, 3-phase, 208 V})} = 1.73 \times 30.8\text{ A} \times 208\text{ V} = 11{,}083\text{ VA}$$

When determining the minimum load to be supplied by a feeder, it is often convenient to add up the loads in the following three categories: continuous load, noncontinuous load, and motor load. If there is more than one motor supplied by the feeder, the rule of *430.24* will apply, and the largest motor load is multiplied by 1.25, and the other smaller motor loads are taken at their calculated value.

NEC® 215.2(A)(1) sets the minimum feeder conductor ampacity at 1.25 times the continuous load plus the noncontinuous load. Add motor loads by taking the largest motor load times 1.25 and the remaining motor loads at 100%. This is done without any consideration of adjustment factors for more than three current-carrying conductors in a raceway or cable or any temperature correction factors. The same method is used to determine the minimum ampere rating required for service conductors in *230.42(A).* Examples of applying correction and adjustment factors are worked out in *Unit 1, Unit 2,* and *Example D3(a)* in the Code.

NEC® 215.3 specifies the same method for determining the minimum rating of overcurrent protection for the feeder as was used for determining the minimum ampacity of the feeder conductors. As illustrated in Figure 4.1, multiply the continuous load by 1.25 and add the noncontinuous load. Actually, figuring the

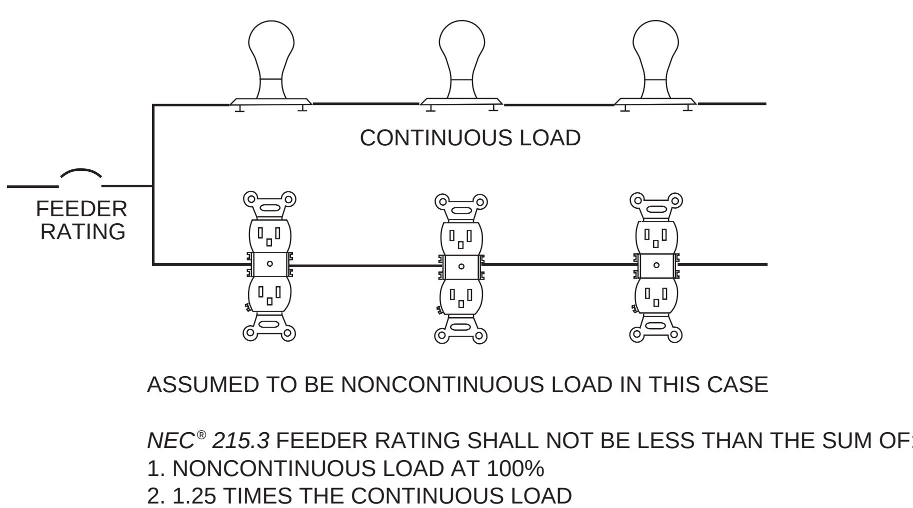


Figure 4.1 The feeder rating is not permitted to be less than the noncontinuous load plus 1.25 times the continuous load.

minimum rating of feeder overcurrent protection should be the first step in the process. Refer to *240.6(A)* for standard ratings of overcurrent devices once the minimum feeder load has been determined. The minimum size of conductor not only depends upon the load to be served but also upon the rating of the feeder overcurrent protection. *NEC® 240.4* requires a conductor to have an allowable ampacity not less than the rating of the overcurrent device. *NEC® 240.4(B)* applies in the case where the allowable ampacity of the conductor does not match a standard rating of overcurrent device. Provided the overcurrent device rating does not exceed 800 amperes, the next higher standard rating is permitted to protect a conductor. The following example will illustrate the application of *240.4(B).*

Example 4.2 The calculated load for a feeder according to *215.2(A)(1)* and *215.3* is 260 amperes. The feeder will be protected with a 300-ampere circuit breaker. If the feeder conductors are copper with 75°C insulation and terminations and no adjustment or corrections factors apply, determine the minimum size conductor permitted for this feeder.

Answer: According to *215.2(A)(1)*, the conductor is required to have an allowable ampacity not less than 260 amperes. From *Table 310.16*, this is a size 300 kcmil conductor rated at 285 amperes. *NEC® 240.4(B)* permits this conductor to be protected at 300 amperes since it has an ampacity higher than the calculated load. The minimum size is 300 kcmil.

Solidly grounded wye electrical systems operating at more than 150 volts-to-ground from the phase conductors but not over 600 volts between conductors are required to be provided with protection from damage due to ground faults if the disconnecting means is rated 1000 or more amperes. The arcing that can occur during a ground fault of feeders and services that have high ampere ratings can cause extensive damage and possible injury to personnel. For these services and feeders, a ground-fault sensor is required for feeders, *215.10*, and for services, *230.95.* There are two types of equipment ground-fault sensors. A current transformer, similar to a clamp-around ammeter, is installed after the main circuit breaker with the three phase conductors and neutral passing through the current transformer. This type is shown in Figure 4.2. The equipment grounding conductor does not pass through the sensor. The setting of the sensor is not permitted to be higher than 1200 amperes. Lower settings are desirable, although nuisance tripping may become a problem. With the second type of ground-fault protection, the sensor is installed around the main bonding jumper as shown in Figure 4.2. Fault current returning to the source must flow on the main bonding jumper. Care must

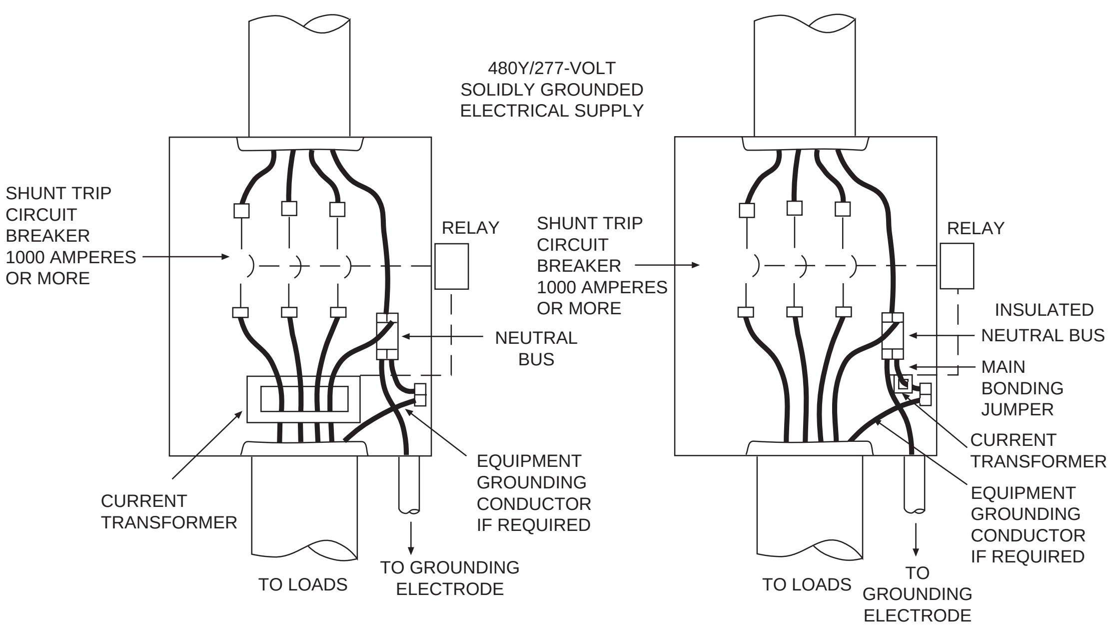


Figure 4.2 Equipment ground-fault protection is permitted to be installed around all phase conductors and the neutral, or it can be installed to sense current flow on the main bonding jumper at the service disconnect.

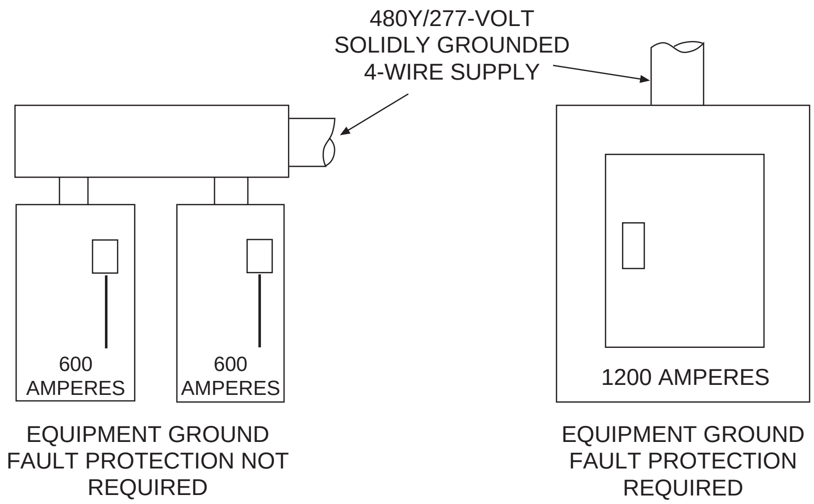


Figure 4.3 Equipment ground-fault protection is not required for a 480Y/277-volt solidly grounded electrical system if all disconnecting means are rated less than 1000 amperes.

be taken to make sure there are no parallel return paths to the source with this type of sensor. For more about grounding and grounding terminology, refer to *Unit 5.*

Equipment ground-fault protection can sometimes be avoided by using multiple disconnects each rated less than 1000 amperes as shown in Figure 4.3. The disconnect rating is the highest rating of fuse that can be installed in the disconnect, not necessarily the rating of the fuse installed. In the case of a circuit breaker used as a disconnect, the maximum rating is the maximum continuous current setting of the circuit breaker.

Article 220, Part III, specifies a basic method of calculating the load for a feeder or service. This load is used to size the conductors and the rating of overcurrent protection. It is important to note these calculations only provide for the known load. Provisions for future load growth is a matter of judgment and is not covered in the Code. This discussion will concentrate on load calculations for single-family dwellings, multifamily dwellings, a small commercial building, and farm buildings. *Part IV* provides optional methods for making some load calculations.

NEC® 220.40 requires the feeder or service calculation to include all appropriate loads described in *Part II* of *Article 220. NEC® 220.12* specifies the minimum load that is required to be included for general illumination for any type of facility listed in *Table 220.12.* This is a minimum load that is required to be included. If the actual lighting installed represents a larger load, then the larger load is used in the calculation. The feeder or service conductors must be capable of supplying the minimum load even if a smaller lighting load in installed. It is also required to provide an adequate number of circuits in the panelboard to supply the minimum listed lighting load even if a smaller lighting load is actually installed. In the case of dwellings according to *220.14(J),* the receptacles, except for small appliance, laundry, and dedicated circuits, are included as outlets for general illumination, which means no additional load is required to be included for these receptacles. The load for general illumination is determined by multiplying the area of the building times the unit load from *Table 220.12* for the type of building. In the case of a single-family dwelling, the area to be included is the total area of the dwelling not including open porches, garages, and unused or unfinished spaces not practical for future use as living space in the dwelling. A finished portion of a basement would be included in the total floor area of the dwelling to which the unit lighting load would apply. The following example illustrates the calculation of general illumination load for a single-family dwelling.

Example 4.3 A single-family dwelling has two floors of living space with a total area of 2600 sq. ft (241.6 m^2). The basement is not finished and is not used as living space in the dwelling. Determine the minimum general illumination load required to be included in the service calculation for the dwelling.

Answer: Look up the unit load of 3 VA/ft^2 (33 VA/m^2) for a dwelling unit in *Table 220.12*. Next, multiply the living area of the dwelling by the unit general illumination load to get the minimum load of 7800 VA (7973 VA for the metric calculation).

General illumination load = 2600 ft^2 × 3 VA/ft^2 = 7800 VA

(= 241.6 m^2 × 33 VA/m^2 = 7973 VA)

In the case of receptacle loads, it may be necessary to include a specific load if the receptacle is for specific equipment. The load for receptacles on 15- and 20-ampere, 125-volt general circuits generally depends upon the actual number of receptacles installed. *NEC® 220.14(I)* specifies that general use receptacles are to be included in the feeder or service calculation as 180 volt-amperes for each receptacle strap or yoke. A duplex receptacle represents a load of 180 VA. This rule does not apply to dwellings, *220.14(J). NEC® 220.14(K)* requires that for an office building, a minimum receptacle load of 1 VA/ft^2 (11 VA/m^2) is required to be included for general-use receptacles. Generally the actual receptacle load will be higher than this value and the higher load is required to be included in the calculation. *NEC® 220.44* recognizes that it is not likely that all receptacle outlets will be utilized at the 180-volt-ampere level at the same time. A 50% demand according to *Table 220.44* is permitted to be applied to receptacle load in excess of 10,000 VA. The following example will illustrate how the general use receptacle load is determined:

Example 4.4 An office building has a total floor area of 1800 sq. ft (167.3 m^2). Also, 72 general-use receptacles on 20-ampere, 125-volt circuits are installed. Determine the minimum receptacle load required to be included in the service load calculation.

Answer: First, determine the minimum load that is required to be included for general use receptacles by multiplying the area of the office by 1 VA/ft^2 (11 VA/m^2) to get 1800 VA (1840 VA). Next, determine the minimum load that is required to be included in the calculation for each receptacle installed by multiplying the number of receptacles by 180 VA/receptacle to get 12,960 VA. The larger load is included, but this load is in excess of 10,000 VA. *NEC® 220.44* permits the excess over 10,000 VA to be taken at half the value which will result in a total demand for receptacle load in this building of 11,480 VA [(12,960 – 10,000) × 0.50] + 10,000 = 11,480 VA.

NEC® 220.18(C) permits an electric range load for a dwelling to be figured using the demand factors of *220.55*. If the individual living units in a multifamily dwelling have electric ranges, *Table 220.55*, according to *Note 1*, can be used to determine the minimum load that must be included in the total building service or feeder load. If the electric ranges are not less than 8 3/4 kW or more than 12 kW in rating, the demand load for all the ranges can be looked up in column C of *Table 220.55*. The following example will illustrate the method of determining the total service demand load for electric ranges in a multifamily dwelling:

Example 4.5 A multifamily dwelling has 18 living units each with a 12-kW electric range. Determine the demand load for the ranges that is required to be included in the total service load calculation.

Answer: The ranges are not rated more than 12 kW, therefore, the demand load of 33 kVA can be looked up in column C of *Table 220.55.*

When the electric ranges in a multifamily dwelling have different ratings, it will be necessary to determine the average range rating if some of the electric ranges are rated more than 12 kW. *Note 2* of *Table 220.55* describes the method used to determine the average range size for the multifamily dwelling. All electric ranges rated greater than 8 3/4 kW but not greater than 12 kW are to be taken as though they were rated at 12 kW when determining the average. The following example will illustrate how the average range rating is determined:

Example 4.6 A multifamily dwelling has 18 living units—six with 10-kW electric ranges, six with 12-kW electric ranges, and six with 16-kW electric ranges. Determine the average rating range for the 18 living units.

Answer: *Note 2* of *Table 220.55* describes the process of determining the average range rating. All ranges 12 kW or less in rating are to be taken as though all were rated at 12 kW for the purpose of determining the average range size. The average range size is 13.3 kW.

12 ranges × 12 kW	= 144 kW	
6 ranges × 16 kW	= 96 kW	
18 ranges	240 kW	

$$\text{Average range rating} = \frac{240 \text{ kW}}{18 \text{ ranges}} = 13.3 \text{ kW}$$

Note 1 of *Table 220.55* describes how to determine the demand load for electric ranges in a multi-family dwelling when the average range rating is greater than 12 kW. The value in column C is increased by 0.05 for each kW the average rating exceeds 12 kW. As was described in the single electric range example of *Unit 3,* round the average range rating to the nearest whole number before figuring the range demand load. Equation 4.3 can be used to determine the range demand load to be included in the service calculation for the entire building. The following example will illustrate the process.

Range Demand Load = [(Average range rating – 12) × 0.05 × (Value from column C of Table 220.55)] + (Value from column C of Table 220.55) **Eq. 4.3**

Example 4.7 A multifamily dwelling has 18 living units with electric ranges of different ratings and the average range rating is 13.3 kW. Determine the minimum demand load for the electric ranges permitted to be included in the service calculation for the building.

Answer: *Note 1* of *Table 220.55* describes the process of determining the total minimum range demand load, which is summarized in Equation 4.3. Look up the demand load for 18 ranges rated at 12 kW from column C of *Table 220.55.* Round 13.3 kW off to 13 kW. Now put these values into Equation 4.2 and find the minimum range load for the building to be 34.65 kVA.

Range Demand Load = [(13 – 12) × 0.05 × 33 kVA] + 33 kVA = 34.65 kVA

NEC® 220.42 provides demand factors that are permitted to be applied to lighting loads for several types of buildings. In particular, the demand factors can be applied to the general illumination load for dwellings when calculating the service or feeder demand load using the method of *Article 220, Part III. NEC® 220.52* requires 1500 volt-amperes to be included in the load for each of the two required small appliance branch-circuits and the one required laundry branch-circuit. *NEC® 220.52* states that the small appliance and laundry branch-circuit loads are permitted to be included in the load to which the demand factors of *Table 220.42* apply. The following example will illustrate how the demand factors of *Table 220.42* are used:

Example 4.8 The demand load for a single-family dwelling service is calculated using the method of *Article 220, Part III.* The dwelling has a living area of 2400 sq. ft (223 m^2). Determine the minimum load permitted to be included in the service calculation for general illumination, small appliance circuits, and the laundry circuit.

Answer: The general illumination, small appliance, and laundry circuit loads before applying the demand factors total 11,700 VA.

General illumination	2400 ft^2 × 3 VA/ft^2	= 7,200 VA	
	(223m^2 × 33VA/m^2)		(7359 VA)
Small appliance		3,000 VA	
Laundry		1,500 VA	
		11,700 VA	(11,859 VA)

Look up the demand factors for a dwelling in *Table 220.42.* The first 3000 VA of this load must be taken at 100% and the balance is taken at 35% to arrive at a minimum permitted load of 6045 VA (6101 VA).

[(11,700 VA – 3000 VA) × 0.35] + 3000 VA = 6045 VA

NEC® 220.53 permits a 75% demand factor to be applied to fastened in place appliance loads in a dwelling when there are four or more appliances. This demand factor can be applied when the method of *Article 220, Part III* is used for the service demand load calculation. This demand factor does not apply to the electric range, clothes dryer, space heat, or air-conditioner. Typical loads in a dwelling to which this factor does apply are the electric water heater, garbage disposer, dishwasher, and built-in microwave oven. *NEC® 220.60* permits the smaller of two loads to be disregarded in the calculation if it is not likely the loads will operate at the same time. An example would be electric heating and air-conditioning. There may be cases where they would operate at the same time, but generally the smaller of the two loads is permitted to be disregarded.

NEC® 220.61 explains the rules for determining the maximum unbalanced load for a service, which is the maximum load that could be expected on the neutral conductor. In the case of a 120/240-volt 3-wire service or feeder, even though the maximum unbalance load may be a substantial amount of current, the load on the neutral conductor is generally only a few amperes. This section is used to determine the maximum unbalance load whether the ungrounded conductors and the rating of the service is determined using the method of *Article 220, Part III*, or one of the optional methods in *Part IV.* To determine the maximum unbalanced load, identify all of the loads that operate at the lower voltage and would use the neutral. This would be 120-volt loads for a single-phase, 120/240-volt, 3-wire system and a 3-phase 208Y/120-volt, 4-wire system or a single-phase, or a 3-wire system derived from a 208Y/120-volt 3-phase system. Equipment and circuits operating at 277 volts would be considered in the determination of the maximum unbalanced load for a 3-phase 480Y/277-volt, 4-wire system.

It is not uncommon in commercial, industrial, or farm buildings for the load to operate mostly at the higher voltage and not utilize the neutral conductor. The load in the building requiring a neutral conductor may be very small. A single-phase, 120/240-volt 3-wire service to a building may supply several 240-volt single-phase motors. Lighting and receptacles are needed only for servicing the equipment in the building. In this case, the unbalanced load will be very small compared to the rating of the service disconnecting means. *NEC® 230.42(C)* sets a lower limit to the size of the neutral, regardless of how small the expected neutral load. The neutral conductor is not permitted to be smaller than the size specified in *250.24(C)(1),* which specifies the size to be found in *Table 250.66.* The following example illustrates the method of finding the minimum neutral conductor size for a building with a small unbalanced load:

Example 4.9 A building is supplied with a 400-ampere, 3-phase, 208Y/120-volt, 4-wire service with the ungrounded conductors size 500 kcmil copper. The maximum calculated unbalanced load for this building is 20 amperes. Determine the minimum size copper neutral conductor for the service.

Answer: Look up the minimum size neutral conductor in *Table 250.66.* The neutral is not permitted to be smaller than the minimum size grounding electrode conductor for the service. The minimum neutral size is 1/0 AWG copper.

Article 220, Part V, covers the methods of determining the demand loads for farm buildings. These methods use amperes for the calculations, where the methods of the previous parts of *Article 220* use volt-amperes. It is important to keep in mind that amperes at 120 volts are different than amperes at 240 volts for the purpose of making a service calculation for a farm building. It is suggested that all loads be converted to a 240-volt basis. For example, assume there are lighting circuits that draw a total of 26 amperes at 120 volts. When making the service calculation of *220.102,* consider this lighting load as 13 amperes at 240 volts. Conversion of a farm building 120-volt demand load to a 240-volt basis is illustrated in Figure 4.4.

NEC® 220.102
FARM BUILDING DEMAND LOAD

LOAD	120 VOLTS	240 VOLTS
RECEPTACLES	22 AMPERES	(11 AMPERES)
LIGHTING (TIMES 1.25)	26 AMPERES	(13 AMPERES)
MOTOR	3.6 AMPERES	(1.8 AMPERES)
TOTAL		(25.8 AMPERES)

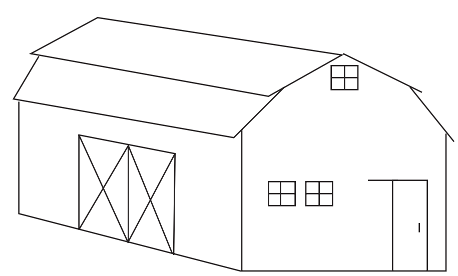


Figure 4.4 Farm building feeder demand loads are determined as current in amperes on a 240-volt basis.

Table 220.102 refers to loads that operate simultaneously and other loads. When calculating the demand load for a farm building, make a list of loads that will operate at the same time. For a milking barn, add up all equipment and lighting that will operate when cows are being milked. This will be the load that operates simultaneously. Make a second list of equipment, receptacles, and lighting that will normally operate at other times. This is equipment that is considered other load. Finally, identify any equipment that cannot operate when other equipment is operating. That equipment can be deleted from the calculation because of *220.60.* An example would be the milk tank washer in a milk house. The washer certainly will not be in operation when there is milk in the tank and the cooling compressor is operating. A control system may prevent some equipment from operating at certain times when other equipment is operating. *NEC® 220.102* requires that loads that operates simultaneously be taken at 100% in the calculation. Remember to multiply the largest motor current by 1.25 in the calculation.

A group of farm buildings, often including the dwelling, is generally supplied power from a central electrical distribution point. This may be a service at one building or it may be a service or disconnect, called a site isolation switch, at a central location. A common practice for a farm is to provide a meter pole, as shown in Figure 4.5, which shall have a minimum ampere rating determined by using *220.103.* Requirements for equipment at the central distribution point are covered in *Article 547.* Overhead feeders or underground feeders will run from the central distribution point to the various buildings.

Article 220, Part IV, describes alternative methods of making the service and feeder calculations instead of the method of *Article 220, Part III. NEC® 220.82* is an optional calculation method for a single-family dwelling. *NEC® 220.83* deals with the special case of an addition to an existing dwelling. This method can be used to determine if an addition to an existing dwelling will require an increase in the size of the service entrance. *NEC® 220.84* is the optional method for determining the demand load for a multifamily dwelling. This method cannot be used unless each living unit is equipped with electric cooking and either air-conditioning or electric heat or both.

Article 230 covers the requirements for the rating and installation of services. A service is defined as the conductors and equipment that deliver electrical energy from the utility to a wiring system. The Code does not specifically define the components that make up a service, but *Article 230* does set some specific requirements and provide rules for sizing service components. Figure 4.6 is shown as two services—one with the overcurrent protection as an integral part of the disconnecting means (circuit breaker) and one with the overcurrent protection located adjacent to the disconnecting means (fusible switch). The service conductors are protected from overcurrent on the load end of the conductors. For other electrical installations, the conductors are protected from overcurrent at their supply end. The service conductors are connected directly to a utility system and the current that will flow during a ground fault or a short circuit is limited only by the impedance of the utility system. *NEC® 230.66* requires that equipment used as a part of a service be rated as

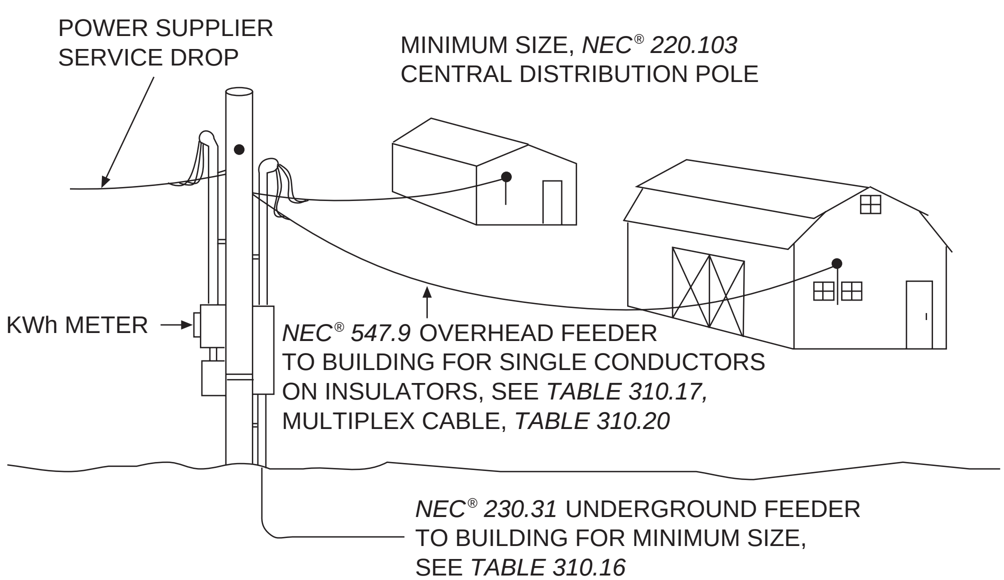


Figure 4.5 A center distribution pole provides a location for metering and a distribution point for conductors supplying power to farm buildings.

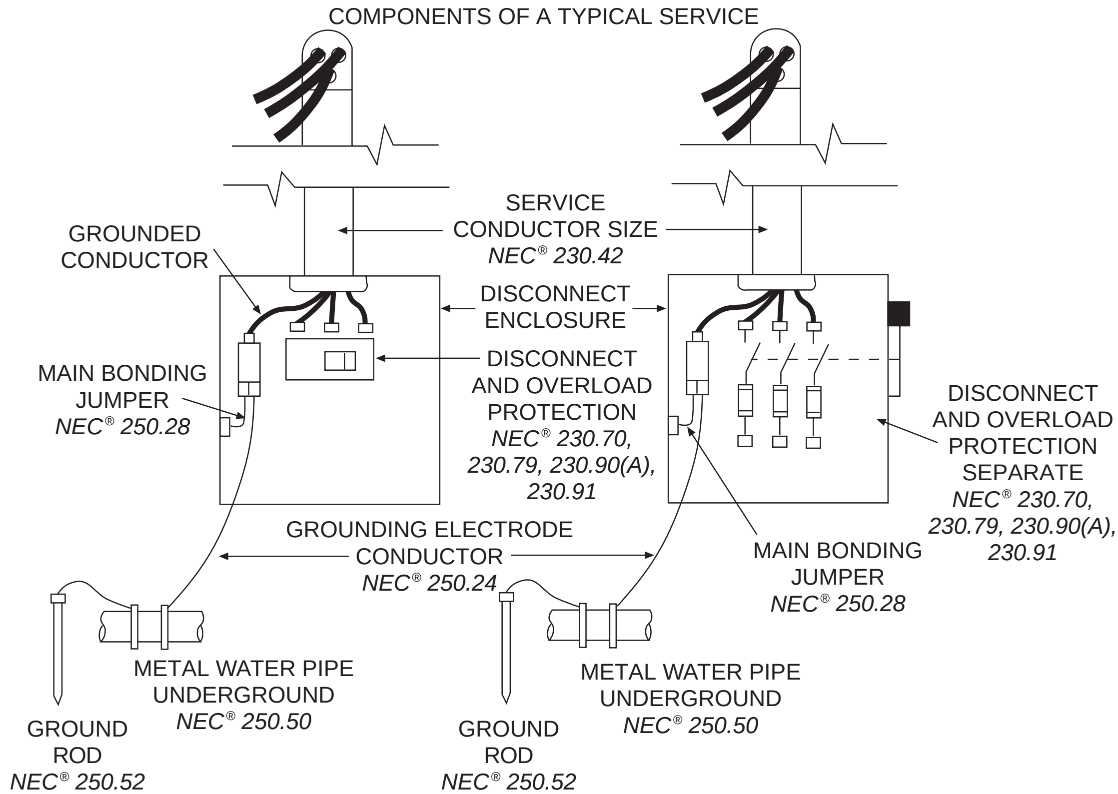


Figure 4.6 Components that make up a typical service are the service conductors, the disconnect enclosure, the disconnecting means for the ungrounded conductor, overload protection for the ungrounded conductors, a grounding electrode, a grounding electrode conductor, and if the system has a grounded conductor, a main bonding jumper.

suitable for use as service equipment. This designation will be marked on the enclosure label. In addition, *110.9* requires the equipment to be capable of interrupting whatever level of fault current that may be available from the utility supply to the service equipment.

The components that make up a typical service are the service conductors, the disconnecting means, the service conductor overcurrent protection, the grounding electrode and the grounding electrode conductor, and the main bonding jumper. These parts are pointed out in Figure 4.6. The function of the disconnecting means is to disconnect all conductors in a building from the service-entrance conductors. Each ungrounded service conductor is required to be provided with overload protection. Each service is required to have the grounded conductor connected to a grounding electrode. In the case of an ungrounded system, the metal disconnect enclosure is required to be connected to a grounding electrode. The load to be supplied by the service is determined using the methods described in *Article 220.* The disconnecting means is required to have a rating not less than the calculated demand load. The service conductors are required to have an allowable ampacity not less than the demand load. If the disconnect rating and overcurrent device rating are larger than required, then the service conductor size must be increased until *230.90(A)* is satisfied.

If a service is supplied with only one overcurrent device, then *230.90(A)* requires the conductor to have an allowable ampacity not less than the rating of the overcurrent device. The conductor may have an allowable ampacity less than the rating of the overcurrent device, according to *240.4(B).* Example 4.2 illustrates the sizing of service conductors. *NEC® 230.71(A)* permits a set of service conductors to terminate in up to six individual disconnecting means. These disconnects can be grouped together or they can be six switches or circuit breakers in a single enclosure. *NEC® 408.36(B) Exception* permits up to six switches or circuit breakers in a power panelboard to serve as the service disconnecting means. When there are more than two disconnecting means for a service, *230.90(A) Exception 3* permits the individual overcurrent devices to add up to more than the allowable ampacity of the service conductors. This is illustrated in Figure 4.7. *NEC® 230.42(A)* requires the service conductors to have an allowable ampacity not less than the calculated demand load for the service.

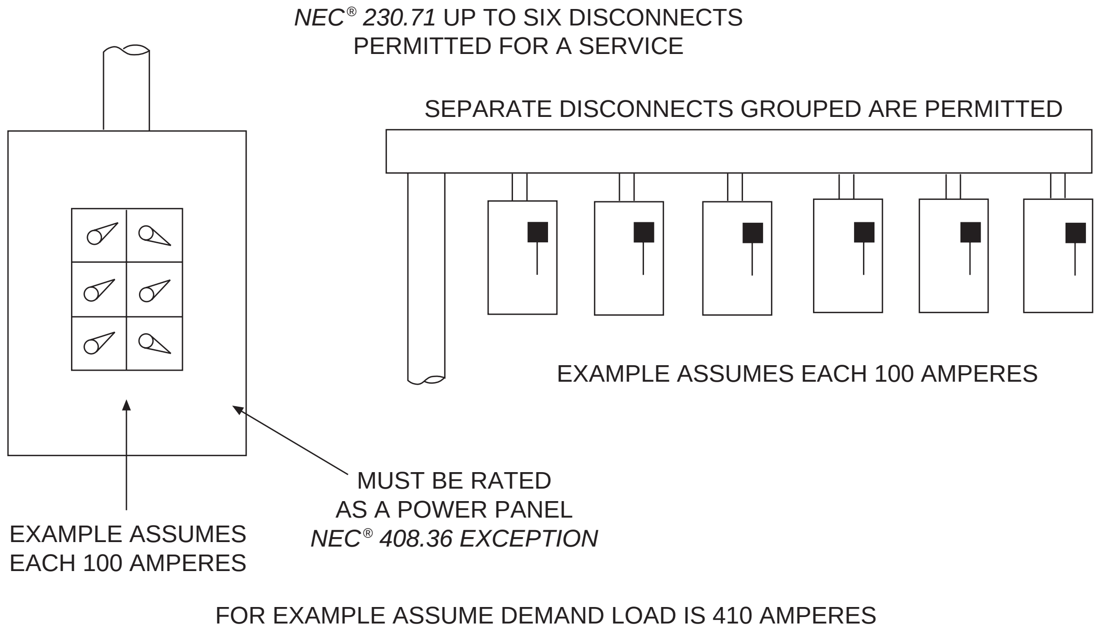


Figure 4.7 A service is permitted to consist of up to six disconnecting means grouped in one location, or located in a single panelboard if it qualifies as a power panelboard.

Example 4.10 A service has a calculated demand load of 410 amperes. The service conductors terminate at six disconnecting means arranged in one location that add up to a combined rating of 600 amperes. Determine the minimum size copper conductors for this service.

Answer: When there are more than two disconnecting means for a service, it is permitted to size the conductors not less than the calculated demand load. *Exception 3* of *230.90(A)* permits the overcurrent devices to total more than the ampacity of the conductor. *NEC® 230.42* only requires the conductors to be capable of supplying the load. Look up a conductor in the 75° C column of *Table 310.16* and get size 600 kcmil.

In the case of a service for a single-family dwelling supplied with a 120/240-volt, single-phase, 3-wire service, it is permitted to size the conductors according to *Table 310.15(B)(6).* This requirement is found in *Exception 5* of *230.90(A).* This rule applies in the case of 120/240-volt, single-phase, 3-wire, single-family dwellings only. The rule is permitted to be applied in the case of service conductors to individual living units of two-family dwellings and multifamily dwellings. Rather than looking up the minimum conductor size in *Table 310.16*, the minimum size is found in *Table 310.15(B)(6).* This rule applies only to the ungrounded service conductors. In the case of the neutral conductor, once the maximum unbalanced load is determined, the minimum neutral conductor size is found in *Table 310.16.*

Article 230 provides rules and specifications for the installation of services. For example, clearances of service-drop conductors and open-service conductors are found in *230.24.* A typical service supplied by an overhead service drop is illustrated in Figure 4.8. The general rule is that one set of overhead service-drop or underground-service lateral conductors supplies only one set of service-entrance conductors. Exceptions to this rule are found in *230.40.* Wiring methods permitted for service-entrance conductors are found in *Part IV.* The rules for the location of the service disconnecting means is found in *230.70.* The service disconnect is permitted to be located inside the building but as near as practical to the point where the conductors enter the building. The service disconnect is permitted to be located outside of the building, and it is not required to be located near the point where the conductors enter the building. The disconnect is even permitted to be located outside and off the actual building as long as it is readily accessible. *Part VIII* provides rules for services with conductors operating at more than 600 volts.

A disconnecting means inside a building is required to be installed near the point where supply conductors enter the building or structure. The point where the conductors are considered to enter the building is important. Service conductors considered to be outside the building are covered in *230.6.* In the case of outside branch-circuits and feeders, *225.32* makes reference to *230.6* for the determination of whether the

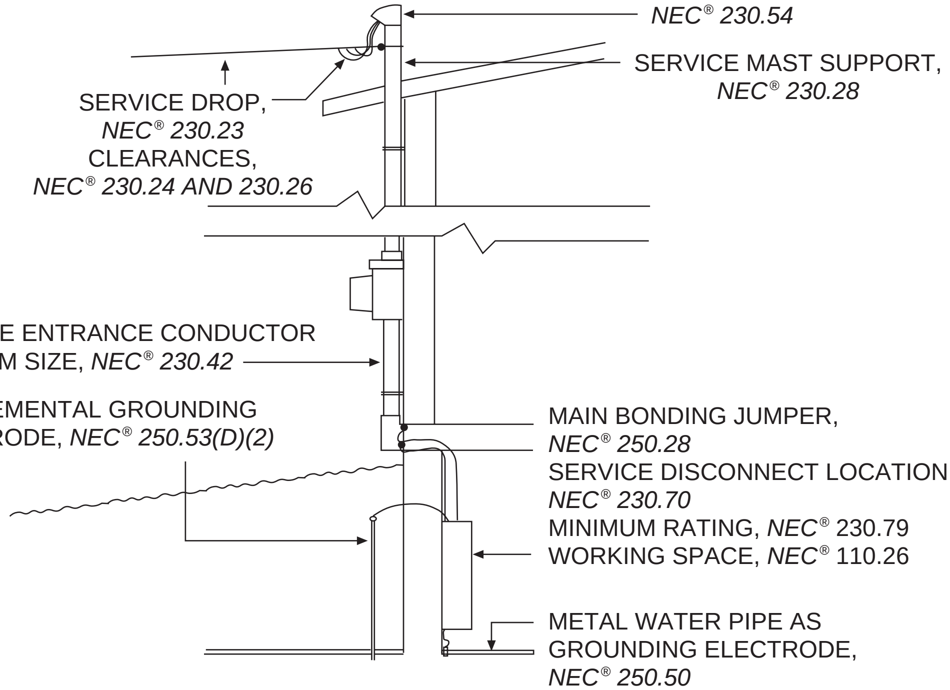


Figure 4.8 Information needed for sizing and installing components of a service entrance is found in *Article 230* and *Article 250.*

conductors are considered to be inside the building or structure. Conductors run under a building or structure and under a minimum of 2 in. (50 mm) of concrete are considered to be outside of the building. Since a concrete floor is generally about 4 in. thick (100 mm), service or feeder conductors run in raceway under a concrete floor are not considered to be in the building until the conductors emerge up though the floor. As illustrated in Figure 4.9, service or feeder conductors run in Rigid Metal Conduit, Intermediate Metallic Conduit, Rigid Nonmetallic Conduit, or Liquidtight Flexible Conduit listed for direct burial are considered outside the building if buried to a depth of not less than 18 in. (450 mm). In this case, a concrete cover is not required. This rule may be useful for a dirt floor farm building or commercial building. Service or feeder conductors entering a basement where it is necessary to pass under a portion of a building that only has a crawl

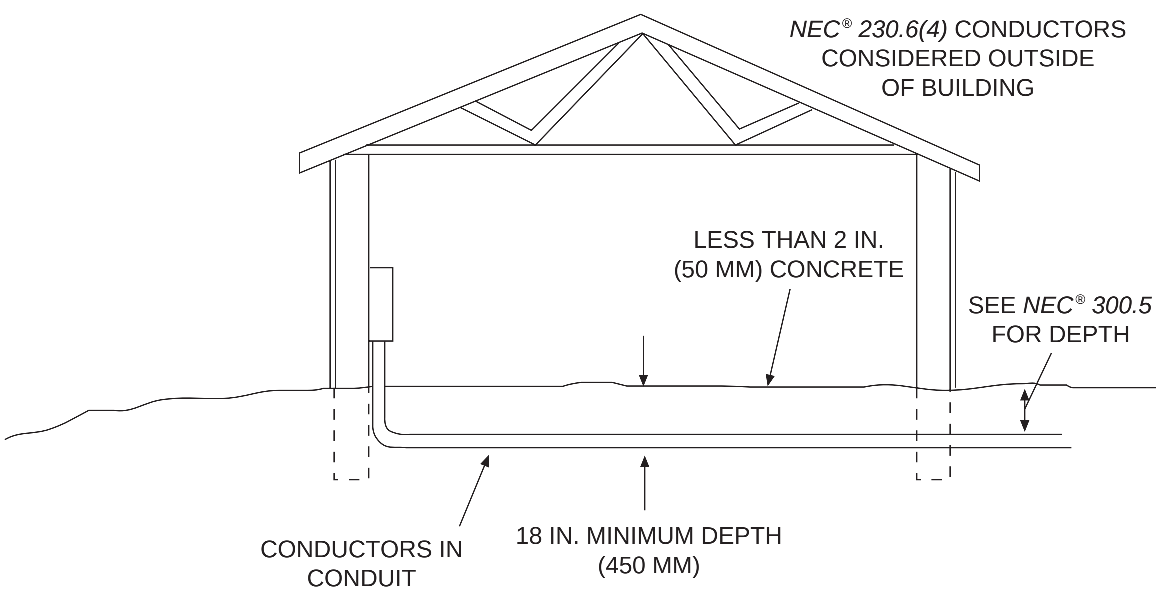


Figure 4.9 Conductors installed under a building with a minimum earth cover of 18 in. (450 mm) are considered to be outside the building.

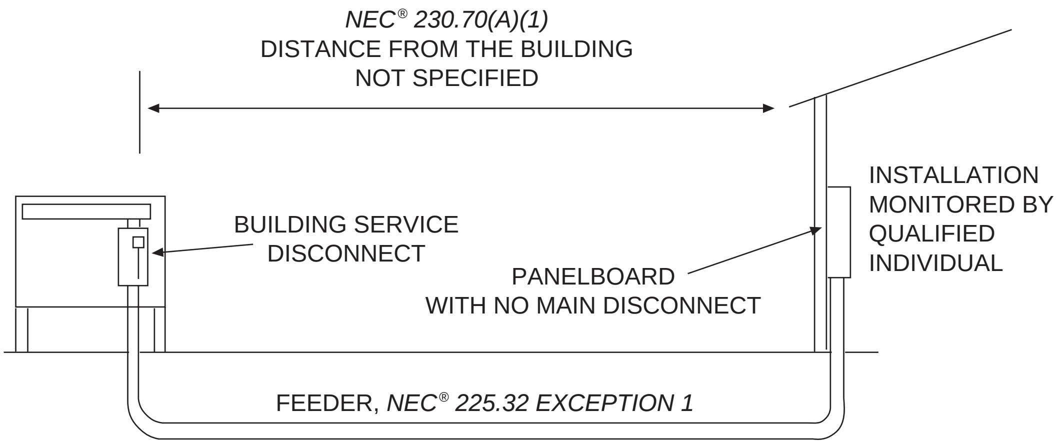


Figure 4.10 The service disconnecting means for a building is permitted to be located outside of the building.

space is permitted by this rule. The depth of burial of the conduit below the surface of the earth is required to be not less than 18 in. (450 mm). Conductors run in conduit that is encased in at least 2 in. (50 mm) of concrete or brick are also considered to be outside the building even though this encasement may be run through a portion of the building. Vaults constructed to the specifications of *Part III* of *Article 450* are also considered to be outside the building or structure.

The service disconnecting means is permitted to be located inside the building or structure. If it is located inside the building or structure, it is required to be located as close as practical to the point where the conductors enter the building. The service disconnecting means is permitted to be located outside the building, in which case it is not required to be located near the point where the conductors enter the building or structure. It is even permitted to be located off the building as shown in Figure 4.10, and no distance from the building is specified. Whether the service disconnecting means is located off the building, or at some point on the outside of the building but away from the point of entry of the conductors to the building, the conductors on the load side of the service disconnecting means are considered feeder conductors. According to *225.32,* a disconnecting means is required to be located near the point of entry of the feeder conductors to the building, either inside or outside. A disconnecting means at the point of entry of the feeder conductors to the building can be omitted if the conditions of *Exception 1* of *225.32* are met and the installation is monitored by a qualified individual.

Annex D provides detailed examples to show the intent of the Code in determining the size of services and feeders and how to determine the minimum number of branch-circuits required for some installations. The notes at the beginning of *Annex D* state that the nominal voltages of 120, 208, and 240 shall be used to make calculations. They also state that when making calculations, fractions of amperes may be rounded down when the fraction is less than 0.5 amperes and rounded up when the fraction is 0.5 amperes and larger. This is also stated in *220.5(B).* The notes also state that when a calculation for ranges results in a fraction of a kilowatt or kilovolt-ampere, it is permitted to round down if the fraction is less than 0.5. Table 4.1 is a summary of the type of calculations found in the examples.

Several examples of service and feeder calculations are included in *Annex D* of the Code. These examples are helpful in understanding the methods of *Article 220.* There are two variations of *Example D1,* which is of a single-family dwelling using the method of *Article 220, Part III. Example D2* is the optional calculation method of *220.82* for a single-family dwelling. There are three different variations of this example.

Example D3 is the service calculation for a commercial store building. This is an important example because it illustrates the use of the 1.25 factor for continuous loads. It also illustrates which loads are taken as continuous loads. Receptacle outlets in a commercial building are not always considered continuous loads.

Example D3 can be confusing. The service entrance main overcurrent device is required to have a rating not less than the noncontinuous load plus 1.25 times the continuous load. This turns out to be 135 amperes for the example. Looking at *240.6(A)* for the next standard overcurrent device rating higher than 135 amperes results in a minimum service entrance rating of 150 amperes. Keep in mind that the Code specifies the minimum permitted, and not necessarily the recommended size for a particular application. The service-entrance conductors are sized based on the same current. The allowable ampacity values listed in the tables of *Article 310* are continuous currents. Therefore, the current used to size the conductors is the sum of the noncontinuous loads and 125% of the continuous loads. For *Example D3,* the current used to size the

Table 4.1. Summary of the type of calculations found in the *Examples* of *Annex D.*

Example number	Number of branch-circuits	Service calculations *NEC® 220, Part III* method	Optional method	Neutral calculation	Range demand load
D1(a)	Yes	Yes	—	Yes	Yes
D1(b)	—	—	—	Yes	—
D2(a)	—	—	Yes	Yes	Yes
D2(b)	—	—	Yes	Yes	Yes
D2(c)	—	—	Yes	—	—
D3	Yes	Yes	—	—	—
D3(a)	—	Yes	—	Yes	—
D4(a)	Yes	Yes	—	Yes	Yes
D4(b)	Yes	—	Yes	Yes	Yes
D5(a)	Yes	Yes	—	Yes	Yes
D5(b)	Yes	Yes	—	Yes	—
D6	—	—	—	—	Yes

conductors is 135 amperes. The 75°C column of *Table 310.16* is used to select the minimum permitted service-entrance conductor size, which is 1/0 AWG, rated at 150 amperes.

Example 3D(a) is a load calculation for a 3-phase feeder supplying an industrial building. This example shows how a motor load is included in the calculation. The building 3-phase load in volt-amperes is converted to amperes for selection of the minimum rating of the feeder and selection of the minimum conductor size. The feeder ampacity is required to be adjusted for a high ambient temperature and eight current-carrying wires in the raceway. This is a good example of how to apply the rules in *215.2(A)(1)* to determine minimum feeder conductor size.

Example D4 is for a multifamily dwelling served with a single-phase electrical system. The service is sized for the entire building, and a calculation of the feeder size for the individual living units is included. This calculation is performed using the method of *Article 220*, *Part III* and the optional method of *220.84*. *Example D5* is a service calculation for a multifamily dwelling served with a 208/120-volt, 3-phase electrical system. *Example D6* illustrates how to determine the demand load for multiple electric ranges in a dwelling for the purpose of determining the size of service-entrance conductors or feeder conductors. Methods are described for determination of the load on the service neutral in several of the examples. There are also several calculations to determine the minimum number of lighting and receptacle branch-circuits.

SAMPLE CALCULATIONS

Examples of calculations of service entrances are included in this section to supplement the examples of *Annex D*. The examples in the Code should be studied with these service calculations.

Example of a Commercial Service Calculation

A store has an area of 3850 sq. ft (357.8 m^2). There are 70 receptacle outlets and 1400 watts of outside lighting, which may operate during store hours. There is also an outside electric sign. The store also contains three refrigerated coolers with 240-volt, $^1/_2$-horsepower, single-phase motors and a walk-in cooler with a 3-horsepower, 240-volt, single-phase motor. The central furnace has a $^3/_4$-horsepower, 240-volt, single-phase motor on the blower.

1. Determine the noncontinuous, continuous, and motor load for the store to be used to size the ungrounded service-entrance conductors and main overcurrent protection.

Before proceeding with the calculation of the demand load for this store building, read *215.2(A)(1)* and *230.42(A)*. The overcurrent device rating protecting the service-entrance conductors shall have an ampacity not less than 100% of the noncontinuous load, plus 125% of the continuous load. It is required that the feeder conductors be sized to carry 125% of the continuous load. The demand load used for determining the minimum size ungrounded conductors for the service is 125% of the continuous load, plus 100% of non-continuous loads.

Noncontinuous loads:			
Receptacles *(NEC® 220.14(I)* and *220.44)*			
70 × 180 VA = 12,600 VA			
First 10 kVA at 100%	=	10,000 VA	
Remainder over 10 kVA at 50%	=	1,300 VA	
Total noncontinuous load			11,300 VA
Continuous loads:			
General lighting load *(NEC® 220.12)*			
3850 ft^2 × 3 VA/ft^2	=	11,550 VA	
(357.8 m^2 × 33 VA/m^2)	=	(11,807 VA)	
Outside sign circuit *(NEC® 220.14(F)* and *600.5(A))*			
Not specified, so use minimum	=	1,200 VA	
Outside lighting			
1,400 VA	=	1,400 VA	
Total continuous load			14,150 VA
(metric total)			(14,407 VA)
Motor loads *(NEC® 220.14(C)* and *430.24)*			
3 hp 240 V × 17 A × 1.25	=	5,100 VA	
1/2 hp 240 V × 4.9 A × 3 motors	=	3,528 VA	
3/4 hp 240 V × 6.9 A	=	1,656 VA	
Total motor load			10,284 VA

2. Determine the minimum rating permitted for the overcurrent device protecting the service-entrance conductors, assuming one circuit breaker or set of fuses is protecting the ungrounded conductors.

According to *215.3*, the minimum permitted rating of the single overcurrent device protecting the service-entrance conductors shall be not less than the noncontinuous load plus 125% of the continuous load.

Noncontinuous load	11,300 VA	
Continuous load, 14,150 VA × 1.25 =	17,688 VA	(18,009 VA)
Motor load	10,284 VA	
Total	39,272 VA	(39,593 VA)

$$\frac{39{,}272\ \text{VA}}{240\ \text{V}} = 164\ \text{A} \qquad (165\ \text{A})$$

The next higher standard rating of overcurrent device listed in *240.6(A)* is 175 amperes, but from a practical standpoint, the size of main overcurrent device in a panelboard used as service equipment for this building would be 200 amperes.

3. Determine the minimum permitted size of ungrounded conductors for the service entrance to this store building, assuming that the conductors are copper with 75°C insulation and terminations and a single service-entrance main overcurrent device rated at 200 amperes.

The demand load for determining the minimum size service-entrance conductors is the same used for determining the rating of the service, *215.2(A)(1).* The minimum size copper conductor, with 75°C insulation and terminations permitted for the calculated demand load of 164 amperes (165 A), is size 2/0 AWG as determined using *Table 310.16* and *240.4(B).* But the maximum overcurrent device permitted for this conductor is 175 amperes. Therefore, the minimum permitted size of service-entrance conductors when the main overcurrent device is 200 amperes is size 3/0 AWG copper with 75°C insulation.

If according to *230.90, Exception 3* there were two to six overcurrent devices rather than only one main overcurrent device, then the service-entrance conductor would only have to be sized to carry the load of 164 amperes. In that case, the minimum permitted copper service-entrance conductor size with 75°C insulation and terminations would then be size 2/0 AWG.

4. Determine the minimum permitted size of neutral service conductor for the store, assuming that the conductor is copper with type THWN insulation.

The minimum size of neutral conductor permitted for this service is determined by the rules of *220.61*. The maximum unbalanced load is 50% of all line-to-neutral load in the case of a 3-wire, single-phase and 34% of line-to-neutral load in the case of a 4-wire wye, 3-phase system.

Total noncontinuous load		11,300 VA	
Total continuous load	14,150 VA × 1.25 =	17,688 VA	
(metric total)	(14,407 VA)		(18,009 VA)
Total		28,988 VA	(29,309 VA)

$$\frac{28{,}988 \text{ VA}}{240 \text{ V}} = 121 \text{ A} \qquad (122 \text{ A})$$

The minimum size neutral conductor permitted is 1 AWG, with 75°C insulation and terminations. It may be necessary to check to see if this is smaller than the minimum permitted neutral conductor size, according to *230.42(C)*.

5. Establish a grounding electrode and determine the minimum copper grounding electrode conductor size permitted. See *Unit 5* for more information.

Select an available electrode from *250.52*. If a metal underground water-pipe is used, then supplement it with one additional electrode *(250.53(D)(2))*. The minimum size grounding electrode conductor is found in *Table 250.66*. If the only electrode available is a rod, pipe, or plate, then the minimum size required is size 6 AWG copper. In this example of a 200-ampere service, the minimum size bare copper grounding electrode conductor is 4 AWG.

6. Determine the minimum number of 20-ampere, 120-volt general lighting circuits for the inside of the store. Continuous load is considered because the rating of the circuit is the size of overcurrent protection. The overcurrent device is not permitted to be loaded continuously at more than 80% of the overcurrent device rating. The minimum number of general illumination branch-circuits is determined based on the actual lighting load even if it is less than the calculated load based on *220.12*. The actual general illumination load was not stated in the problem, so the calculated value will be used to determine the minimum number of lighting circuits.

11,550 × 1.25 = 14,438 VA
(11,807 × 1.25 = 14,759 VA)

$$\frac{14{,}438 \text{ VA}}{120 \text{ V}} = 120 \text{ A} \qquad \frac{14{,}759 \text{ VA}}{120 \text{ V}} = 123 \text{ A}$$

$$\frac{120 \text{ A}}{20 \text{ A / circuit}} = 6 \text{ circuits} \qquad \frac{123 \text{ A}}{20 \text{ A / circuit}} = 6.14 \text{ circuits}$$

7. Determine the minimum number of 20-ampere, 120-volt receptacle circuits for the store. Some inspectors may judge a receptacle circuit to be a continuous load; however, this issue is not clear in the Code. It depends on the use of the circuit. For this example, we will consider the receptacle load to be a noncontinuous load. A minimum of six circuits is required.

$$\frac{12{,}600 \text{ VA}}{120 \text{ V}} = 105 \text{ amperes}$$

$$\frac{105 \text{ A}}{20 \text{ A / circuit}} = 5.25 \text{ circuits}$$

Example of a Single-Family Dwelling Demand Load

A single-family dwelling has a living area of 1800 sq. ft (167.3 m^2), and the dwelling is to contain the following appliances at the time of construction:

Electric range	240 V	14 kW
Microwave oven (built-in)	12 A	120 V
Electric water heater	240 V	6 kW
Dishwasher	120 V	1.8 kW
Clothes dryer	240 V	5 kW
Water pump	8 A	240 V
Food waste disposer	7.2 A	120 V
Baseboard electric heat (8 total units)	240 V	15 kW
Air-conditioner	3 at 8 A	240 V

1. Determine the service demand load using the method of *Article 220, Part III.*

General lighting load *(220.12)*		
1800 ft² × 3 VA/ft² =	5,400 VA	
(167.3 m² x 33 VA/m² = 5521 VA)	(5,521 VA)	
Small-appliance circuits *(220.52(A))*		
2 × 1500 VA =	3,000 VA	
Laundry circuit *(220.52(B))*		
1 × 1500 VA =	1,500 VA	
Subtotal *(220.42, 220.52)*	9,900 VA	
	(10,021 VA)	
First 3000 VA at 100%		3,000 VA
Remainder at 35%		2,415 VA
		(2,457 VA)
Electric range *(Table 220.55)*		8,800 VA
Electric space heating *(220.51)*		15,000 VA
Air conditioning *(220.60)*		
3 × 8 A = 24 A		
24 A × 240 V = 5760 VA		0 VA
Clothes dryer *(220.54)*		
5 kW at 100%		5,000 VA
Other appliances (*220.53*)		
Microwave oven (built-in)		
12 A × 120 V =	1,440 VA	
Electric water heater =	6,000 VA	
Dishwasher	1,800 VA	
Water pump (*430.24*)		
8 A × 240 V × 1.25 =	2,400 VA	
Food waste disposer		
7.2 A × 120 V =	864 VA	
Subtotal	12,504 VA	
12,504 VA × 0.75 =		9,378 VA
Total demand load		43,593 VA
Service load		(43,635 VA)

$$\frac{43{,}593 \text{ VA}}{240 \text{ V}} = 182 \text{ amperes}$$

2. Determine the minimum size neutral conductor for the service entrance. The rule for sizing the neutral is found in *220.61.*

General lighting, small-appliance, and laundry load			5,415 VA
			(5,457 VA)
Electric range	8800 VA × 0.7 =		6,160 VA
Electric clothes dryer	5000 VA × 0.7 =		3,500 VA
Other electric appliances			
Microwave oven (built-in)		1,440 VA	
Dishwasher		1,800 VA	

Food waste disposer		
7.2 A × 120 V =	864 VA	
		4,104 VA
Total 120-volt load (unbalanced load)		19,179 VA
Unbalanced load		(19,221 VA)

$$\frac{19{,}179\text{ VA}}{240\text{ V}} = 80 \text{ amperes}$$

Optional Dwelling Service Calculation

The optional method of determining demand load for a single-family dwelling usually, *220.82*, results in a smaller value than the previous method in *220, Part III*. The minimum size service wires, however, is 100 amperes.

Electric space heater 15,000 × 0.4 =		6,000 VA
(Each room separately controlled *220.82(C)(6)*)		
Air conditioner (*NEC*® *220.82(C)*)		OMIT
General lighting load		
1800 ft^2 × 3 VA/ft^2 =	5,400 VA	
(167.3 m^2 × 33 VA/m^2=)	(5,521 VA)	
Small appliance circuits		
2 × 1500 VA =	3,000 VA	
Laundry circuit		
1 × 1500 VA =	1,500 VA	
Electric range	14,000 VA	
Clothes dryer	5,000 VA	
Microwave oven (built-in)	1,440 VA	
Electric water heater	6,000 VA	
Dishwasher	1,800 VA	
Water pump	2,400 VA	
Garbage disposer	864 VA	
Subtotal	41,404 VA	
	(41,525 VA)	
Apply the demand factors of *NEC*® *220.82:*		
First 10 kVA of all other load at 100%		10,000 VA
Remainder of other load at 40%		
31,404 VA × 0.4 =		12,562 VA
(31,525 VA × 0.4 =)		(12,610 VA)
Total load		28,562 VA
Service load		(28,610 VA)

$$\frac{28{,}562\text{ VA}}{240\text{ V}} = 119 \text{ amperes}$$

Note: Earlier, the demand load was determined to be 182 amperes. The minimum neutral size is determined using *220.61*, as shown earlier.

Farm Building Demand Load

A hog-farrowing barn contains outlets for twenty heat lamps at 250 watts each, six 2-lamp, 32-watt fluorescent water-tight luminaires that draw 0.5 amperes each at 120 volts, and three electric fans operating at 240 volts: 1/6 horsepower, 2.2 amperes; 1/4 horsepower, 2.9 amperes; and 1/2 horsepower, 4.9 amperes. In addition, there are eight general-purpose, 120-volt receptacle outlets.

1. Determine the minimum service demand load for the building. All loads are considered to operate simultaneously except the general-purpose receptacle outlets. The heat lamps are considered a continuous load.

The 120-volt heat lamp, receptacles, and lighting loads are divided by 240 volts rather than 120 volts, because all amperes for the service calculation must be on a 240-volt basis.

Loads operating simultaneously			
	Heat lamps	$\frac{20 \times 250\ \text{W} \times 1.25}{240\ \text{V}} =$	26.0 A
	Lights	$\frac{6 \times 0.5\ \text{A} \times 120\ \text{V} \times 1.25}{240\ \text{V}} =$	1.9 A
	Fans		
		$4.9\ \text{A} \times 1.25 =$	6.1 A
		2.9 A =	2.9 A
		2.2 A =	2.2 A
			39.1 A
Other loads:			
	Receptacles	$\frac{8 \times 180\ \text{VA}}{240\ \text{V}} =$	6.0 A
Loads operating simultaneously 100%			39.1 A
Other loads, but not			6.0 A
	less than first 60 amperes of all loads at 100%		
Total load			45.1 A

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 215 Feeders

215.2(A)(1) Exception 2: The minimum size of ungrounded feeder conductor is based on the sum of the noncontinuous load and 125% of the continuous load. It is the overcurrent device that requires the continuous load to be increased by 25%, and therefore, the minimum conductor size must be based upon the same ampere rating as the overcurrent device. Most of the time, the neutral or grounded conductor is not protected by an overcurrent device, and this 25% adjustment for continuous load is not necessary. This new exception recognizes this point and now makes it clear that if the grounded conductor is not connected to an overcurrent device, the ampere rating and size need only be based upon 100% of the load including continuous load. This new rule is illustrated in Figure 4.11. It is important to note that this rule applies to branch circuits and feeders, but it does not apply to service entrance conductors, *230.42*. The following example of a feeder within a building will illustrate how this new exception applies in the case of a commercial building.

Example 4.11: A portion of a retail store is supplied from a single-phase, 120/240 volt, 3-wire subpanel. The load on the feeder supplying the subpanel consists of 16,200 VA of lighting (continuous load) and 12,200 VA of receptacles (noncontinuous load). Determine the minimum size copper ungrounded, and grounded conductors permitted for this feeder.

Answer: The ungrounded conductors are required to have an ampere rating not less than necessary to supply 125% of the continuous load ($1.25 \times 16{,}200$ VA = 20,250 VA). The ungrounded conductors also must carry 100% of the noncontinuous load (12,200 VA). The total load on the ungrounded conductors is 32,450 VA, which divided by 240 volts gives 135 amperes. Since this is more than 100 amperes, the

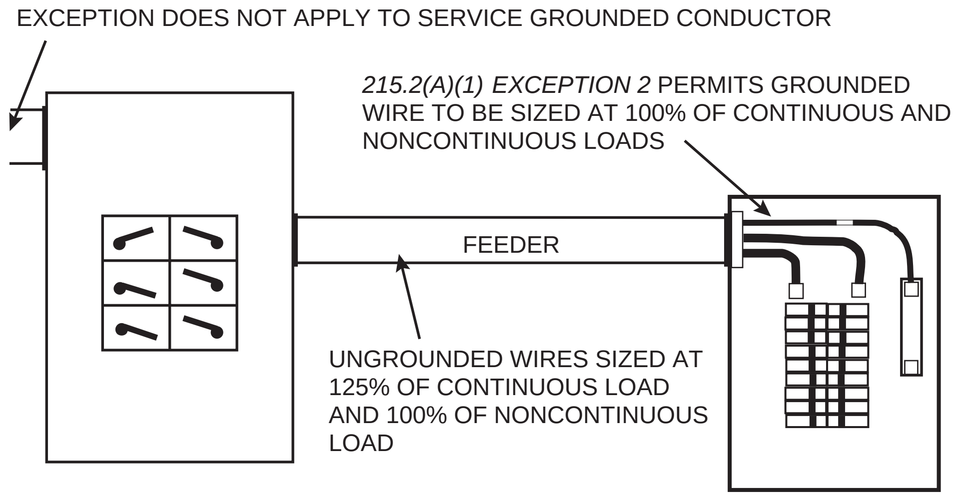


Figure 4.11 A feeder-grounded conductor (neutral) shall be sized not less than the calculated load, and not smaller than the equipment grounding conductor required for the feeder based on *Table 250.122.*

insulation and terminations are required to have a 75ºC rating unless otherwise marked. The minimum ungrounded feeder wire size for this load is 1/0 AWG copper. The grounded conductor is only required to have an ampere rating of 100% of both the continuous and noncontinuous loads, which is 28,400 VA (16,200 VA + 12,200 VA) This load is assumed to be equally distributed on both ungrounded conductors; therefore, divide by 240 volts to get the unbalanced load on the neutral, which is 118 amperes. The minimum neutral conductor size for this feeder is 1 AWG copper.

215.6: This is a new sentence that is intended to remove a conflict between this section and the *Exception* to *250.32(B).* It is really not a change. It deals with the case where a feeder supplies one building from another where conditions are such that the grounded conductor (neutral) is acting also as the equipment grounding conductor. At the second building, the neutral is bonded to the frame of the entrance enclosure and also connected to a grounding electrode. See Figure 5.5 in the next unit. This section requires an equipment grounding conductor to be run as a part of the feeder. When a building is supplied with a feeder according to *250.32(B) Exception,* this section was making a conflicting requirement. If the neutral is acting as the equipment grounding conductor, a separate equipment grounding conductor is not permitted to be run with the feeder.

215.12(C): This section requires feeders of different electrical systems serving the same building to be identified at terminations, connecting points, and splices. Now it is required to label the feeder wires by phase as well as label the feeder by system. It was also required that a directory stating the method of system and phase identification be placed at each feeder panelboard, or similar equipment. Now the identification directory is permitted to be placed on file at a readily available location.

Article 220, Parts III, IV, and V Feeder and Service Calculations

220.52(A): This section mandates a load of 1500 VA for each dwelling small appliance branch circuit. Instead of stating that for each small appliance branch circuit "required" by *210.11(C)(1),* it now uses the terms "as covered by" *210.11(C)(1).* The point is to clear up an ambiguity in the meaning of this section. In *210.11(C)(1)* it is required that there be a minimum of two small appliance branch circuits. It was taken to mean by many that when this section was applied that the small appliance load was included in a service or feeder calculation as a maximum of 3000 VA, no matter how many small appliance branch circuits were installed. That apparently is not the intent. If more than the minimum number of small appliance branch circuits are installed, then 1500 VA is required to be included in the service or feeder calculation for each branch circuit. If, for example, in a dwelling the owner wanted three extra branch circuits for the kitchen, diningroom and similar areas requiring small appliance branch circuits rather than the minimum of two, then all would be required to be included in the calculation at 1500 VA. For this example with five small appliance branch circuits, 7500 VA would be required to be included in the feeder or service calculation. An example of more than the minimum number of

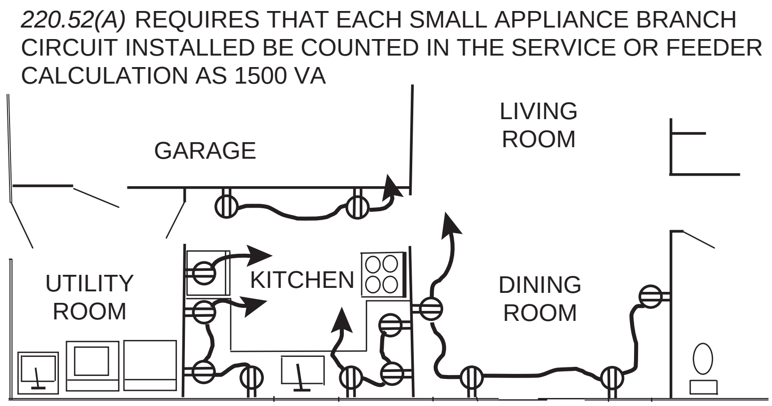


Figure 4.12 When a single-family dwelling service load calculation is performed using the optional method of *NEC*® *220.82* and there is a heat pump with supplemental electric heating, the supplemental heating can be taken at a demand factor of 65%.

small appliance branch circuits is shown in Figure 4.12. None of the dwelling service calculations in *Annex D* of the Code have more than two small appliance branch circuits.

This rule also applies in the case of additions to an existing dwelling as covered in *220.83(A)* and for the single-family dwelling optional service calculation *220.82(B).* This rule also applies in the case of the multi-family dwelling optional calculation, *220.84(C).*

220.52(B): This paragraph requires 1500 VA to be included in a dwelling feeder or service calculation for each laundry branch circuit installed. If a dwelling has two separate areas where laundry appliances are located, then it would be required to include 1500 VA for each area in the feeder or service calculation. If two washers were installed at one location, it would be necessary to have two circuits to handle the load, and then 3000 VA would be required to be included in the feeder or service calculation. This rule also applies in the case of an addition to an existing dwelling, *220.83(A),* for the dwelling optional service calculation, *220.82(B),* and the optional multifamily dwelling calculation, *220.84(C).*

Article 230 Services

230.44 Exception: Cable trays are permitted to support service entrance conductors, and generally only service conductors are permitted in the cable tray when it is used for that purpose. The exception permits other conductors to also be installed in the same cable tray with the service conductors, but a solid fixed barrier is required between the service conductors and the other conductors. The change in this exception deals with identification of the service conductors. A permanent label with the words “Service Entrance Conductors” is required to be installed at intervals along the cable tray to make the service conductors readily traceable. An example is shown in Figure 4.13.

230.53: This section specifies the requirements for raceway that is located such that it is exposed to the weather. The word “raintight” was removed. Raceways are not listed as raintight; they are listed as suitable for use in wet locations. An area outside exposed to the weather is considered a wet location. There were interpretation problems in the past when a raintight listing was required and raceways with such listings are not available.

230.54: This section places requirements on service heads for raceway and cable. The word “raintight” was removed. These weather heads are listed as suitable for use in wet locations, and not listed as raintight.

230.82(3): A meter disconnect switch located on the supply side of the service disconnecting means is now required to be capable of interrupting the load serve. This means the switch must be able to handle the meter load current when opened under load.

230.82(4): This is a list of equipment and devices that are permitted to be installed on the supply side of the service disconnecting means. The term “transient voltage surge suppressor” was deleted and replaced with Type 1, surge-protective device (SPD). An SPD is a transient voltage surge suppressor, but the real change is that it must be listed as a Type 1, which is the type suitable for connection ahead of the service disconnect and overcurrent protection.

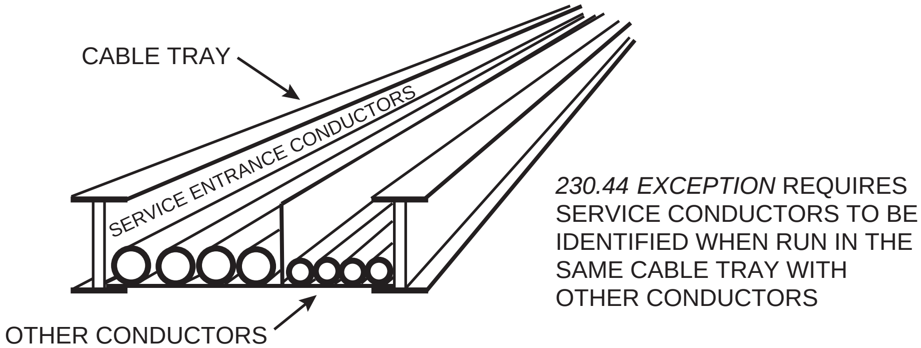


Figure 4.13 When service conductors are run in cable tray there shall be no other conductors in the cable tray, or a fixed barrier compatible with the cable tray material shall be installed to separate the service conductors from the other conductors.

230.82(8): A Type 2 surge-protective device was added to the list of equipment that is permitted to be connected ahead of the service disconnect, provided it is equipped with its own disconnecting means and overcurrent protection.

230.94 Exception 2: A Type 1 surge-protective device was added to the list of equipment that is permitted to be installed on the supply side of the service overcurrent protection.

230.205(A): This section specifies the location of the disconnecting means for electrical systems operating at more than 600 volts. This is a high-voltage switch, and now it states that the switch is permitted to be installed in a location that is not readily accessible.

WORKSHEET NO. 4—BEGINNING SERVICES AND FEEDER CALCULATIONS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer, or indicates where the answer is found, as well as the Code reference where the answer is found.

1. Service entrance cable Type SE style U is installed on the outside of a building for a service entrance as shown in Figure 4.14. The weather head is fastened to the side of the building and the cable is supported within 12 in. (300 mm) of the weather head. The maximum distance permitted between supports for the cable is:
   A. 18 in. (450 mm).
   B. 24 in. (60 mm).
   C. 30 in. (750 mm).
   D. 3 ft (900 mm).
   E. 4 1/2 ft (1.4 m).

   Code reference ___________________

2. The calculated demand load for the ungrounded conductors of a single-family living unit in an apartment building is 68 amperes. The rating of the disconnecting means and feeder from the meter location to the service panel in the living unit is not permitted to be less than:
   A. 70 amperes.
   B. 80 amperes.
   C. 90 amperes.
   D. 100 amperes.
   E. 110 amperes.

   Code reference ___________________

3. A 5-horsepower, single-phase, 240-volt electric motor when included in a service calculation represents a load of not less than: (not necessarily the largest motor)
   A. 4245 VA.
   B. 4820 VA.
   C. 5000 VA.
   D. 6720 VA.
   E. 8800 VA.

   Code reference ___________________

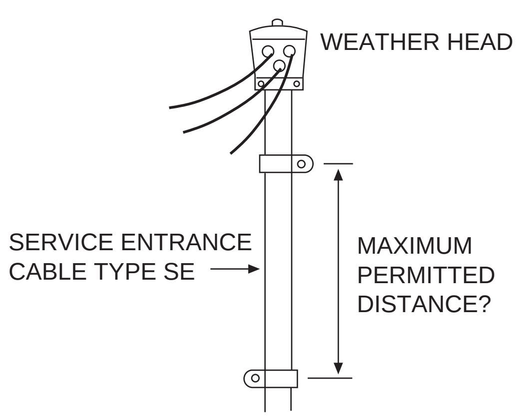


Figure 4.14 Determine the maximum permitted spacing between supports for Type SE Cable used as service conductors.

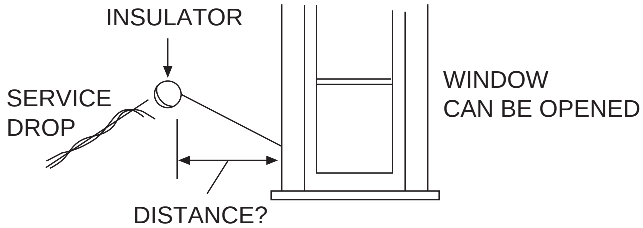


Figure 4.15 Determine the minimum distance permitted from the edge of a window that can be opened and open conductors of a service.

4. A service-drop terminates at an insulator attached to the side of a building next to a window that can be opened as shown in Figure 4.15. The minimum distance from the edge of the window to the open conductors is not permitted to be less than:
   A. 3 in. (75 mm).
   B. 12 in. (300 mm).
   C. 24 in. (600 mm).
   D. 3 ft (900 mm).
   E. 6 ft (1.8 m).

   Code reference ___________________

5. A 120/240-volt, 3-wire, single-phase feeder supplies a small panelboard with four 2-wire branch-circuits where the calculated load is only 15 amperes on each ungrounded conductor. The minimum conductor ampacity permitted for this feeder is:
   A. 15 amperes.
   B. 20 amperes.
   C. 30 amperes.
   D. 40 amperes.
   E. 50 amperes.

   Code reference ___________________

6. A single-family dwelling is served with single-phase, 3-wire, 120/240-volt service using aluminum conductors with 75°C insulation and terminations. The demand load for the dwelling is 149 amperes, and the main circuit breaker is rated 200 amperes as shown in Figure 4.16. The minimum size ungrounded conductors permitted for this service is:
   A. 1/0 AWG.
   B. 2/0 AWG.
   C. 3/0 AWG.
   D. 4/0 AWG.
   E. 250 kcmil.

   Code reference ___________________

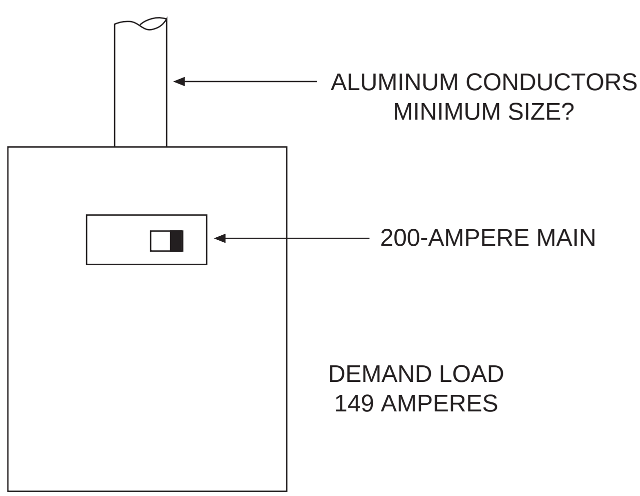


Figure 4.16 Determine the minimum size aluminum conductors for a service with a demand load of 149 amperes, and terminating at a 200-ampere main circuit breaker.

7. A wiring method installed, suitable for the conditions but not permitted for use as a part of a service entrance installation, is:
   A. insulated conductors run in PVC Rigid Nonmetallic Conduit.
   B. insulated conductors run in Electrical Nonmetallic Tubing.
   C. Metal Clad Cable, Type MC.
   D. insulated conductors in Liquidtight Flexible Nonmetallic Conduit.
   E. Type AC Armored Cable.

Code reference ___________________

8. In the case where a service entrance receives the source of power from an overhead service drop, the connection of service-entrance conductors to the service drop:
   A. has no specific requirements other than a tight connection.
   B. is required to be made above the level of the service head.
   C. shall be located below the level of the service head.
   D. is required to be formed into a drip loop and the actual connection is then permitted to be located above or below the service head.
   E. is only permitted to be made with an irreversible listed crimp-type connector.

Code reference ___________________

9. A single-family dwelling has four 20-ampere, 125-volt small-appliance branch-circuits installed to serve the receptacle outlets in the kitchen and dining room. When calculating the service demand load for the dwelling, the minimum load that is permitted to be included for the small-appliance branch-circuits in this dwelling is:
   A. 1500 VA.
   B. 6000 VA.
   C. 4500 VA.
   D. 3000 VA.
   E. 7500 VA.

Code reference ___________________

10. Service conductors are not considered outside a building when:
   A. installed on the outside surface of the building as Type SE Cable.
   B. run within an interior wall encased within 2 in. (50 mm) of concrete.
   C. installed in Rigid Nonmetallic Conduit under a building with a minimum of 2-in. (50 mm) of concrete above the conduit.
   D. installed beneath a building in Rigid Nonmetallic Conduit with at least 18-in. (450 mm) of earth cover.
   E. installed within Rigid Metal Conduit under a building with a minimum 6-in. (150 mm) earth cover.

Code reference ___________________

11. A dwelling 3-wire, 120/240-volt service has a trade size 2 (53) Rigid Metal Conduit mast extending up through the roof overhang, as shown in Figure 4.17, with a 4-in. by 12-in. (100 mm by 300 mm) roof slope. The roof overhang is 20 in. If the service drop terminates at an insulator mounted on the mast riser, the minimum clearance permitted from the roof to the conductors is:
   A. 18 in. (450 mm).
   B. 24 in. (600 mm).
   C. 30 in. (750 mm).
   D. 3 ft (900 mm).
   E. 4 ft (1.2 m).

Code reference ___________________

12. A building on a farm has a calculated load that is expected to operate simultaneously of 92 amperes and other load of 56 amperes. These load amperes are on a 240-volt basis. The minimum demand load permitted for this building to be used to size the conductors and rating of service equipment is:
   A. 106 amperes.
   B. 120 amperes.
   C. 136 amperes.
   D. 148 amperes.
   E. 171 amperes.

Code reference ___________________

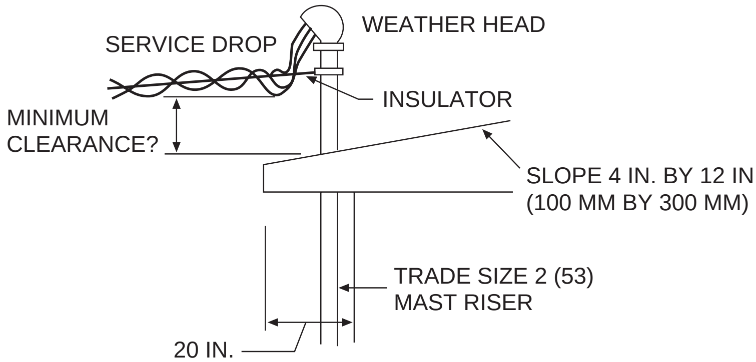


Figure 4.17 Determine the minimum distance from the roof to the open conductors when a mast riser extending up through a roof overhang, where the roof slope is 4 in. by 12 in. (100 mm by 300 mm), and the overhang is not more than 4 ft (1.2 m).

13. The calculated demand load for a commercial building served with 120/240-volt, single-phase power is 360 amperes. A single main 500-ampere overcurrent device is installed as the disconnect for the service as shown in Figure 4.18. The minimum size copper service-entrance conductors permitted for this service is:
A. 500 kcmil. C. 700 kcmil. E. 800 kcmil.
B. 600 kcmil. D. 750 kcmil.

Code reference ___________________

14. A multifamily dwelling consists of eight individual living units each with a 12-kW electric range. The method of *Article 220, Part III,* is used for the load calculation for the service conductors for the multifamily dwelling. The minimum load permitted to be included in the calculation for the electric ranges is:
A. 23 kVA. C. 76.8 kVA. E. 120 kVA.
B. 64 kVA. D. 96 kVA.

Code reference ___________________

15. A total length of 45 ft (13.7 m) of track lighting is installed in a commercial building. For the purpose of calculating the load on the feeder supplying the track lighting, the minimum load that is required to be included is:
A. 3450 VA. C. 4219 VA. E. 4800 VA.
B. 3840 VA. D. 4313 VA.

Code reference ___________________

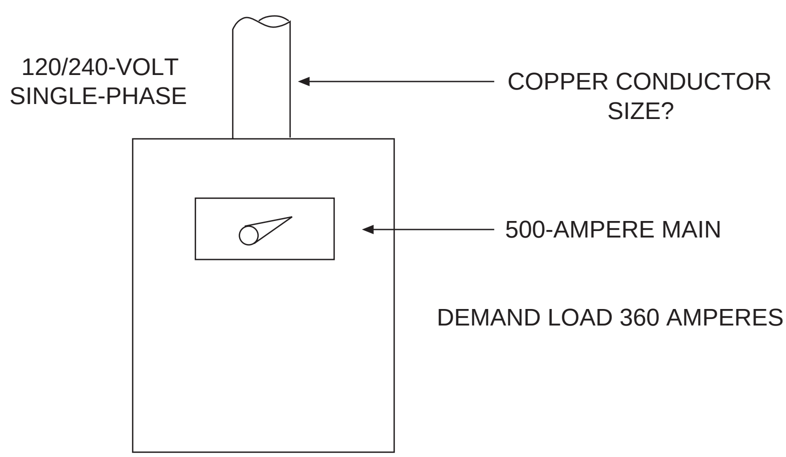


Figure 4.18 Determine the minimum size copper conductors for a service where the single main overcurrent device is rated 500 amperes and the demand load is 360 amperes.

WORKSHEET NO. 4—ADVANCED SERVICES AND FEEDER CALCULATIONS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. Equipment ground-fault protection is required to be installed on the service of a commercial building served with a 3-phase solidly grounded:
   A. 208Y/120-volt system greater than 1000 amperes.
   B. 480Y/277-volt system of any size.
   C. 240/120-volt delta 4-wire system over 1000 amperes.
   D. 480-volt corner-grounded delta 3-wire system 1000 amperes and larger.
   E. 480Y/277-volt system 1000 amperes and larger.

   Code reference ___________________

2. A commercial building has a 208Y/120-volt, 3-phase demand load of 130 amperes. However, the electrician installs a service with a 200-ampere main overcurrent device. The service conductors installed are Type THWN aluminum as shown in Figure 4.19. The minimum size ungrounded conductors permitted for this service is:
   A. 2/0 AWG. C. 4/0 AWG. E. 300 kcmil.
   B. 3/0 AWG. D. 250 kcmil.

   Code reference ___________________

3. A 208-volt, 3-phase, 5-horsepower electric motor when included in the service calculation for a commercial building is included at: (not necessarily the largest motor)
   A. 5000 VA. C. 6406 VA. E. 11,083 VA.
   B. 6009 VA. D. 8245 VA.

   Code reference ___________________

4. The calculated demand load for a commercial building served with 120/240-volt single-phase power is 360 amperes. Rather than installing a single main overcurrent device and disconnect for the service, a 200-ampere panelboard and three 100-ampere

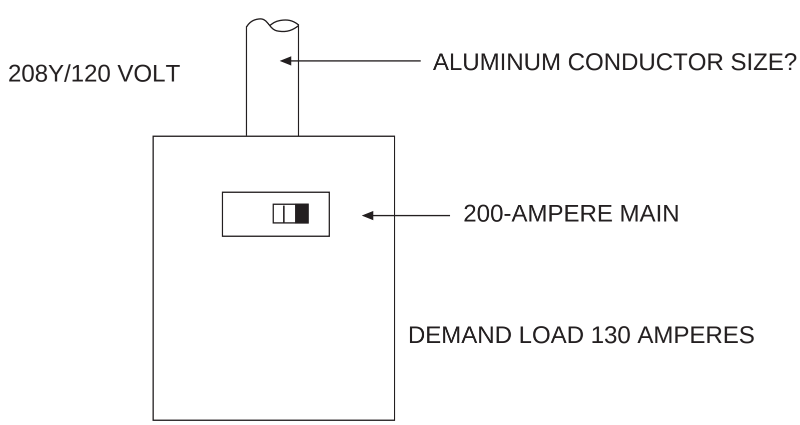


Figure 4.19 Determine the minimum size aluminum conductors for a 208Y/120-volt 3-phase service with a single 200-ampere main overcurrent device and a demand load of 130 amperes.

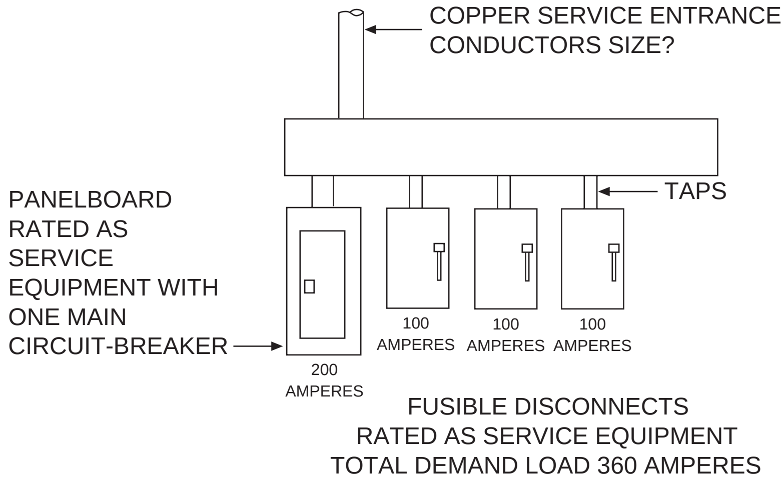


Figure 4.20 Determine the minimum rating copper service conductors when there are four disconnecting means adding up to 500 amperes and the demand load for the service is 360 amperes.

disconnect switches are installed in a group, as shown in Figure 4.20, and tapped from the service conductors entering the auxiliary gutter. The panelboard and disconnect switches are all rated as suitable for use as service equipment. The minimum size copper service-entrance conductors permitted for this service is:

A. 500 kcmil.
B. 600 kcmil.
C. 700 kcmil.
D. 750 kcmil.
E. 800 kcmil.

Code reference ___________________

5. The disconnecting means for a service to a building is:
   A. required to be located only inside the building near the point of entry of the service conductors.
   B. permitted to be located on the outside of the building provided it is not more than 10 ft (3 m) from the point where the conductors enter the building.
   C. permitted to be located on the outside of the building as long as it is located nearest the point where the conductors enter the building.
   D. required to be located on the outside of the building, or inside, and in either location must be nearest the point of entry of the service conductors.
   E. permitted to be located outdoors, and not necessarily on the building.

Code reference ___________________

6. A commercial office building supplied with a 208Y/120-volt, 3-phase electrical system has a calculated demand load of 127,380 VA. If the ungrounded service conductors terminate at a single main fixed rating circuit breaker, the minimum standard rating permitted for this service is:
   A. 350 amperes.
   B. 400 amperes.
   C. 500 amperes.
   D. 600 amperes.
   E. 700 amperes.

Code reference ___________________

7. A single-family dwelling with a total living area of 2100 ft^2 (195.2 m^2) is served with a single-phase, 120/240-volt electrical system. Appliances in the dwelling are a 12-kW electric range and a 5-kW electric clothes dryer operating at 120/240-volts, a 3.5-kW, 240-volt electric water heater, a 1.2-kW, 120-volt dishwasher, an 800-watt, 120-volt built-in microwave, a 1/2 horsepower, 120-volt garbage disposer, and a

central air conditioner with a nameplate rated-load current of 17 amperes at 240 volts. The minimum service demand load for the dwelling using the method of *Article 220, Part III* is:

A. 99 amperes. C. 123 amperes. E. 137 amperes.
B. 116 amperes. D. 133 amperes.

Code reference ___________________

8. For the single-family dwelling described in the previous question, the ampere rating of the minimum size neutral permitted for the service is: (maximum unbalanced load)

A. 60 amperes. C. 85 amperes. E. 116 amperes.
B. 75 amperes. D. 99 amperes.

Code reference ___________________

9. A commercial building is supplied with a 120/240-volt, single-phase service with 200 amperes main overcurrent protection and size 3/0 AWG copper ungrounded service conductors as shown in Figure 4.21. The load in the building is primarily 240-volt motors, and the maximum unbalanced load is only 24 amperes. Based upon the use of the building, additional 120-volt loads are not likely. The minimum size copper neutral conductor permitted for this service is:

A. 10 AWG. C. 6 AWG. E. 1/0 AWG.
B. 8 AWG. D. 4 AWG.

Code reference ___________________

10. A single-family dwelling with a total living area of 2100 ft^2 (195.2 m^2) is served with a single-phase, 120/240-volt electrical system. Appliances in the dwelling are a 12-kW electric range and a 5-kW electric clothes dryer operating at 120/240 volts, a 3.5-kW, 240-volt electric water heater, a 1.2-kW, 120-volt dishwasher, an 800-watt, 120-volt built-in microwave, a $^1/_2$-horsepower, 120-volt garbage disposer, and a central air conditioner with a nameplate rated-load current of 17 amperes at 240 volts. The minimum service demand load for the dwelling using the optional method of *220.82* is:

A. 74 amperes. C. 89 amperes. E. 99 amperes.
B. 79 amperes. D. 93 amperes.

Code reference ___________________

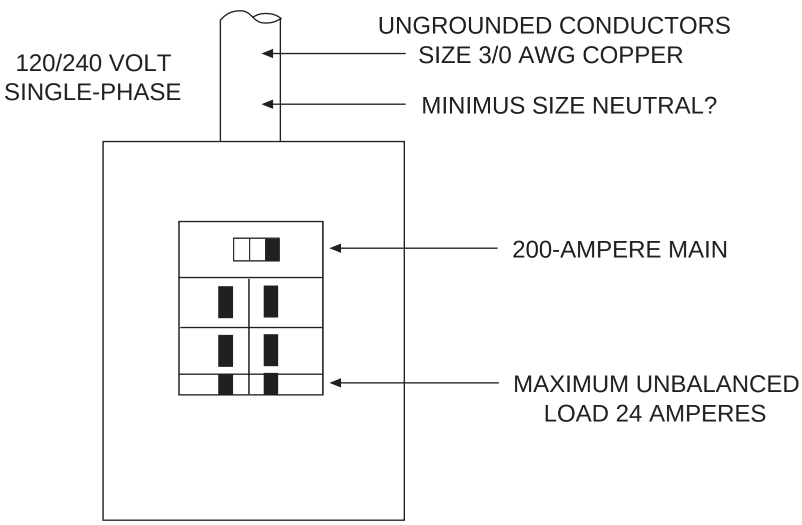


Figure 4.21 Determine the minimum size copper neutral for a single-phase 120/240-volt service with a 200–ampere main, size 3/0 AWG copper ungrounded conductors and a maximum calculated unbalanced load of 24 amperes.

11. A group of farm buildings is supplied from a center distribution point where the metering equipment and the main disconnecting means is located. The calculated demand loads for the individual buildings, shown in Figure 4.22, are listed.

dwelling	74 amperes
barn	66 amperes
shop	36 amperes
cattle barn	24 amperes
storage building	20 amperes

The minimum rating of the ungrounded conductors and equipment at the center distribution point is:

A. 119 amperes.
B. 169 amperes.
C. 176 amperes.
D. 193 amperes.
E. 220 amperes.

Code reference ___________________

12. An office building is supplied with 208Y/120-volt, 3-phase electrical service. The office space in the building is 3800 sq. ft (353.2 m^2). In addition to general lighting, other continuous loads in the building are 3.8 kW of 120-volt outside lighting, and an electric sign figured at the minimum load. The noncontinuous load consists of 68 receptacle outlets. In addition, there are several motors for the air conditioner and air circulation systems that are to be included into the service calculation at 8546 VA. Based upon these loads, the minimum demand load permitted for this office building used to determine the minimum service conductor size is:

A. 35,842 VA.
B. 37,966 VA.
C. 39,086 VA.
D. 42,541 VA.
E. 43,661 VA.

Code reference ___________________

13. A multifamily dwelling is supplied by 120/240-volt, single-phase power and has 24 individual living units each with an electric range. Eight living units have 10-kW electric ranges, another eight have 12-kW electric ranges, and the remaining eight have 15-kW electric ranges. When the service load is determined using the method

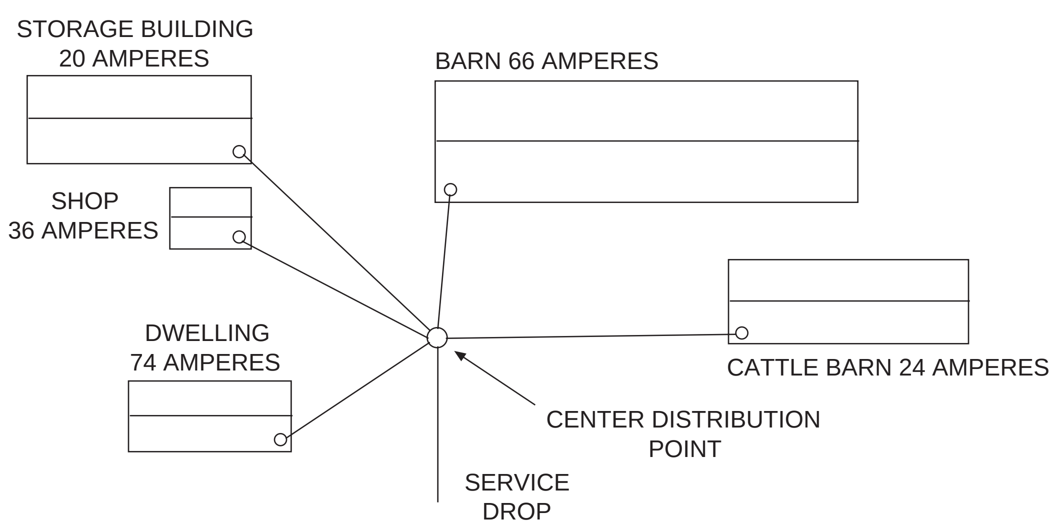


Figure 4.22 Determine the minimum rating of the center distribution conductors and equipment serving farm building with demand loads of 74 amperes for the dwelling, 66 amperes for the barn, 36 amperes for the shop, 24 amperes for the cattle barn, and 20 amperes for the storage building.

of *Article 220, Part III,* the minimum demand load permitted to be included in the service calculation for the building is:

A. 38.20 kVA.
B. 39.00 kVA.
C. 40.95 kVA.
D. 42.32 kVA.
E. 42.90 kVA.

Code reference ___________________

14. A multifamily dwelling consists of 12 single-family living units, each with a 1.2-kVA dishwasher. When the service load is determined using the method of *Article 220, Part III,* the minimum permitted demand load to be included in the service calculation for the building for the dishwashers is:

A. 10.8 kVA.
B. 11.0 kVA.
C. 12.6 kVA.
D. 14.4 kVA.
E. 18.0 kVA.

Code reference ___________________

15. A multifamily dwelling is supplied 120/240-volt, single-phase power, and consists of eight individual dwelling units with a living area of 800 sq. ft (74.3 m^2). In each living unit is a 10-kW electric range, a 2.5-kW electric water heater, a 1.2-kW dishwasher, 2 kW of electric space heat, and an air conditioner with a nameplate rated-load current of 8 amperes at 240 volts. Laundry facilities are provided in a common area of the building. The total house load to be included in the service demand load calculation is 16,250 VA and includes common area lighting, outside lighting, and laundry facilities. The minimum demand load, using the optional method of *220.84,* permitted for sizing the service conductors and service equipment is:

A. 324 amperes.
B. 358 amperes.
C. 370 amperes.
D. 420 amperes.
E. 465 amperes.

Code reference ___________________

UNIT 5

Grounding and Bonding

OBJECTIVES

After completion of this unit, the student should be able to:

- explain the purpose of equipment grounding.
- explain the purpose of electrical system grounding, and define bonding.
- diagram a single-phase, dual-voltage, 3-wire electrical system and label the voltages between the wires.
- diagram a 3-phase wye and a 3-phase delta electrical system and label the voltages between the wires.
- state when a single-phase and a 3-phase electrical system are required to be grounded if the voltages between the wires are known.
- show which wire of an electrical system is required to be grounded if the electrical system is one required to be grounded.
- name at least five methods considered by the Code as acceptable as a means of grounding electrical equipment not in a location with specific requirements.
- determine the minimum size equipment grounding conductor permitted for a branch-circuit and feeder if the rating of overcurrent protection is known.
- state the minimum requirement for a grounding electrode for a service entrance to a building.
- determine the minimum size of grounding electrode conductor permitted for a particular service entrance.
- specify the type required and the minimum size permitted of bonding conductor for a swimming pool.
- answer wiring installation questions relating to *Articles 250, 280, 285,* and *680.*
- state at least five significant changes that occurred from the 2005 to the 2008 Code for *Articles 250*, *280*, *285,* and *680*.

CODE DISCUSSION

The emphasis of this unit is to discuss the purpose of equipment grounding and of system grounding. Equipment grounding is easily understood if the electrical installer has a clear understanding of the purpose of equipment grounding, an understanding of the circuit involved, and an understanding of the requirements of a good equipment grounding conductor. This unit deals with grounding and bonding of electrical systems in general. There are several locations or types of materials with special grounding requirements. These cases will be discussed in later units. For example, requirements for cable tray to be used as an equipment grounding conductor will be covered in *Unit 12,* grounding of electrical equipment in agricultural buildings will be covered in *Unit 14,* hazardous locations in *Unit 9,* and health care facilities in *Unit 10.* Only the specific grounding and bonding requirements different from *Article 250* are covered in other articles of the Code.

Article 250 deals with the grounding of an electrical system and the grounding of equipment. The requirements of this article apply to all wiring installations, unless either specifically different or additional grounding requirements are covered elsewhere in the Code. *NEC® 250.3* references the other locations in the Code where there are different or additional grounding requirements for specific materials or locations.

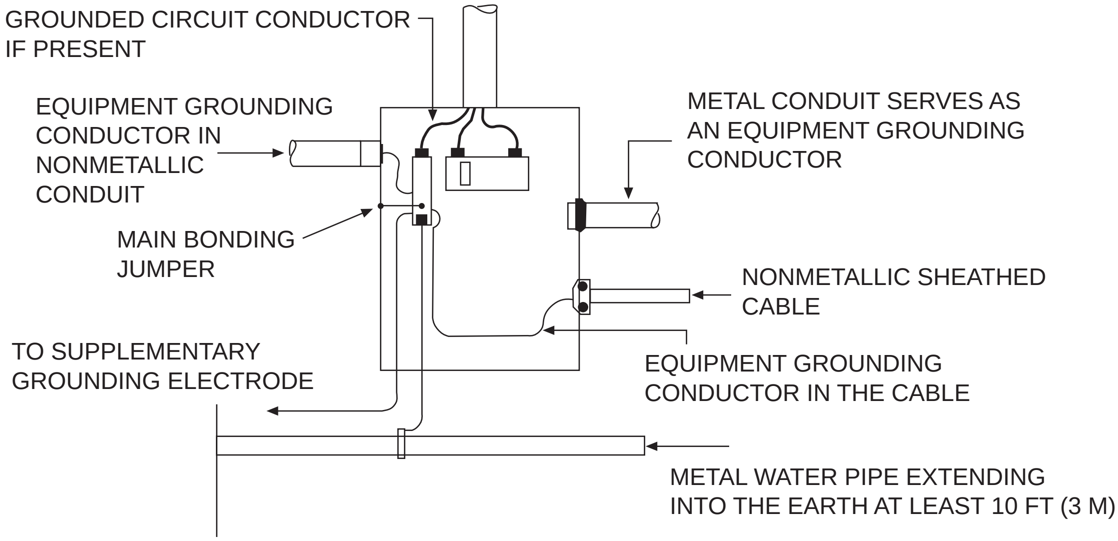


Figure 5.1 System grounding and equipment grounding are required to be considered in all electrical systems.

System grounding and equipment grounding are illustrated in Figure 5.1. The purpose of electrical system grounding and equipment grounding is explained in *250.4. Part VI* of *Article 250* requires that exposed metallic parts of equipment likely to become energized be grounded. Methods of equipment grounding are explained in *Part VII* of *Article 250* and acceptable equipment grounding conductors are described in *Part VI* of *Article 250,* in particular in *250.118.*

The metal enclosure of the service disconnect or a grounding bus at that location is the collecting point for all feeder and branch-circuit equipment grounding conductors. The basic standard for equipment grounding is explained in *250.2, 250.4(A)(5),* and *250.4(B)(4).* An electrically continuous path is required to be established to allow enough current to flow during a fault to operate overcurrent devices such as circuit breakers and fuses. To accomplish this task, all equipment likely to become energized must be grounded back to a common point. If a ground-fault occurs, current tries to return to the grounded terminal of the electrical supply of a grounded electrical system. That point is the grounded terminal of a transformer, generator, or other power source. In the case of a grounded electrical supply to a building, the grounded service conductor entering the building is bonded or connected to the metal enclosure of the service disconnect or equipment grounding bus. This **main bonding jumper** is the connecting link between the equipment grounding conductors in the building and the grounded terminal of the electrical supply to the building. The current path during a ground fault in a building supplied by a grounded electrical system is illustrated in Figure 5.2.

Some electrical systems are not grounded. A 3-phase, 3-wire, 480-volt electrical system may not be grounded. *NEC® 250.4(B)(1)* and *250.24(D)* require a grounding electrode to be established for an ungrounded electrical system and connected to the service disconnect enclosure. All equipment served by the ungrounded electrical system is grounded the same as if the system was grounded. The only difference is that there is no grounded circuit conductor with the service and there will be no main bonding jumper.

Grounding an electrical system to the earth has a different purpose than equipment grounding. *NEC® 250.4(A)(1)* states that the purpose is to stabilize voltages to ground during normal operation and to limit voltages due to lightning, line surges, and unintentional contact with high voltage conductors. There are cases where grounding is required and some where grounding is optional. These rules are discussed and illustrated in detail later in this unit. Which conductor is required to be grounded is described in *250.26.*

Part III of *Article 250* describes the types of grounding electrodes that are acceptable. All of the grounding electrodes described that are available at a building are required to be bonded together and used as a grounding electrode for the building electrical service. In many cases, there are no grounding electrodes available and one must be established. *NEC® 250.52(A)(1)* requires that a metal underground water pipe that is in contact with the earth for a minimum of 10 ft (3 m) be used as a grounding electrode for the service. The connection to the water pipe is required to be made within the first 5 ft (1.5 m) of the point where the water pipe enters the building. That connection is frequently permitted to be made a greater distance from the point of entry for many commercial and industrial buildings. *NEC® 250.53(D)(2)* requires a supplemental grounding

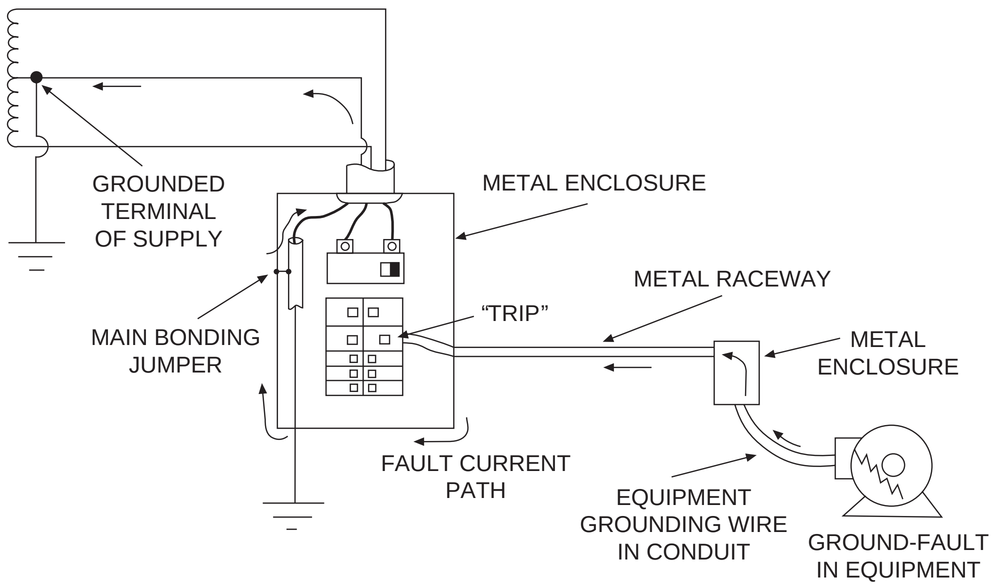


Figure 5.2 Ground-fault current returns to the grounded terminal of a grounded electrical system, and must be provided a low-resistance metallic path from all equipment back to the metal enclosure or grounding bus of the service disconnect.

electrode be established when using the metal water pipe as a grounding electrode. That would mean that if the metal water pipe was the only grounding electrode, then an additional grounding electrode would be required to be installed. Generally it is easiest to add a ground rod as the supplemental grounding electrode. When a ground rod is installed, it is required to have a resistance-to-earth of not more than 25 ohms. If that is not the case, then an additional electrode is needed. Generally it is easiest to add a second ground rod which is required by *250.56* to be located a minimum of 6 ft (1.8 m) from the first ground rod. This type of installation is shown in Figure 5.3.

The metal frame of the building is also a common grounding electrode for many commercial and industrial buildings. The stipulation is that the metal building frame must be effectively grounded. Simply bolting the steel frame to concrete pilings that extend above ground is not sufficient. The concrete is generally too dry to be a satisfactory conductor. Acceptable means of making earth connections for the metal building frame are listed

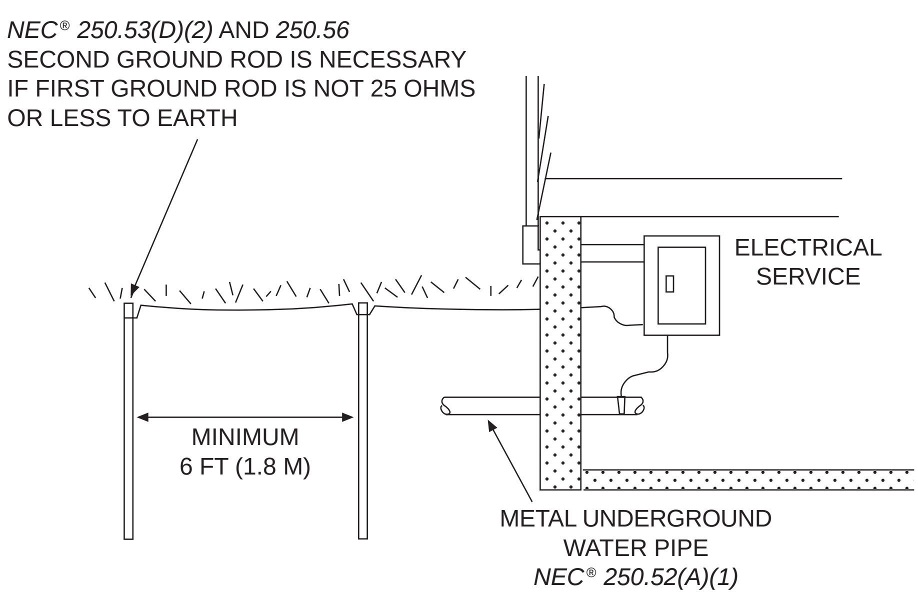


Figure 5.3 When a grounding electrode is installed as a supplementary grounding electrode for a water pipe electrode, if the ground rod does not have a resistance of 25 ohms or less to earth, it is required to be supplemented with one additional electrode.

in *250.52(A)(2).* If the mounting bolts are bonded to the reinforcing steel in the piling and the reinforcing steel extends down to a minimum of 3 ft (900 mm) below grade level, the steel frame is generally considered to be effectively grounded. *NEC® 250.52(A)(3)* permits bare or zinc galvanized steel reinforcing bars placed near the bottom of a building footing to serve as a grounding electrode if the length is not less than 20 ft (6 m). Steel tie wires used for the purpose of connecting sections of reinforcing steel is considered to be an adequate bonding means when measuring the 20 ft (6 m) minimum distance. One continuous length is not required.

The minimum size of grounding electrode conductor is specified in *250.66.* The size of the largest ungrounded conductor is used as the basis for determining the minimum grounding electrode conductor size from *Table 250.66.* Grounding electrodes generally have a resistance-to-earth ranging from several ohms to hundreds of ohms depending upon the soil conditions. *Table 250.66,* therefore, sets size 3/0 AWG copper as the maximum size grounding electrode conductor required in any situation. If the grounding electrode is a ground rod, the maximum grounding electrode conductor size required is size 6 AWG copper, *250.66(A).* In the case of a concrete-encased electrode such as a reinforcing steel in a footing, the maximum required is size 4 AWG copper, *250.66(B).*

A service is unique in that the conductors are protected from overcurrent at the load end of the conductors. For this reason, it is important that any metal service enclosure or raceway be electrically connected in such a way that enough fault-current may flow to open the utility primary overcurrent device. As a result, extra ordinary bonding is required for service equipment and raceways. Figure 5.4 is a diagram of a typical service panel with Code references where details on bonding and grounding are found. *NEC® 250.28(D)* specifies the minimum size of the main bonding jumper at not less than the minimum size of the grounding electrode conductor as determined from *Table 250.66.* If the ungrounded conductor size is larger than the maximum given in *Table 250.66*, then the minimum main bonding jumper size is determined by multiplying the cross-sectional area of the ungrounded conductor by 0.125. *NEC® 250.102(C)* specifies the minimum size bonding jumper for a metal service raceway. The rule is the same as for the main bonding jumper except it

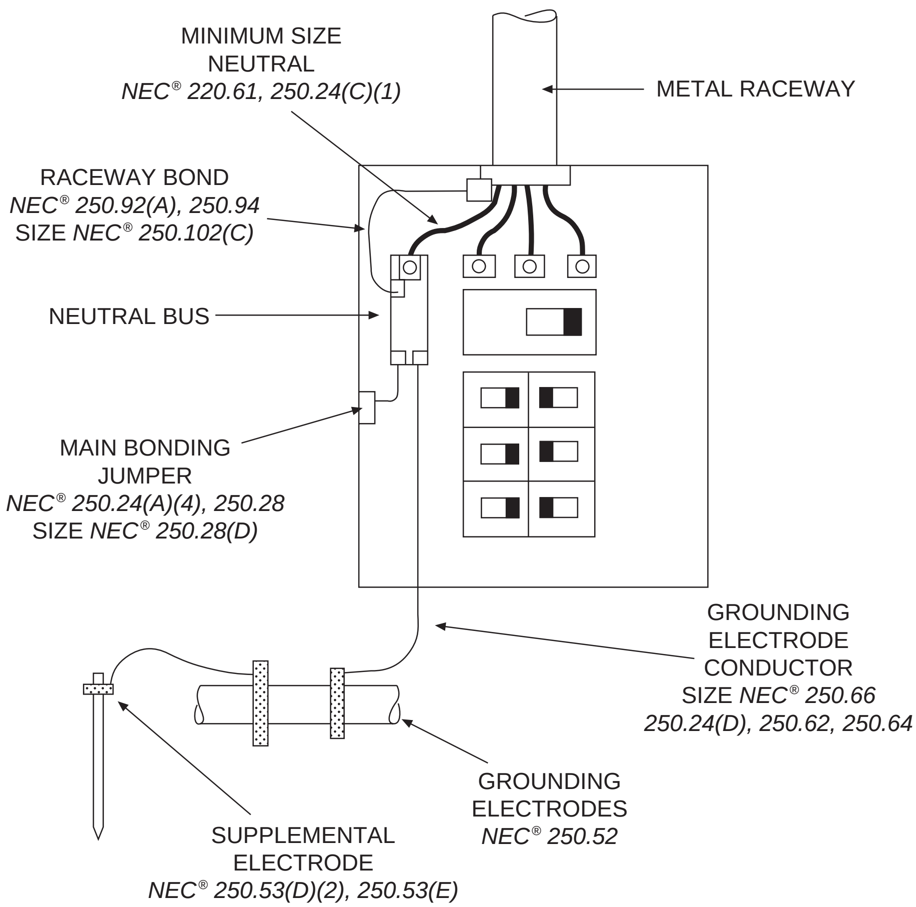


Figure 5.4 Grounding and bonding at the service disconnect is very important, and there are different rules for sizing the different components of the grounding system at the service.

is based upon the cross-sectional area of the largest ungrounded conductor in the service raceway. When the service conductors are run in parallel in separate raceways, the bonding jumper for the metal raceways will be smaller than the main bonding jumper.

NEC® 250.32 deals with supplying power to one building from another building. Power can be extended to the second building either overhead or underground. Rules for installation of the conductors are found in *Article 225*. Much of the confusion centers around grounding and whether an equipment grounding conductor separate from the neutral is required. The rules are summarized in Figure 5.5, which illustrates a single-phase, 120/240-volt, 3-wire electrical service to the property. The rules would be the same for a 3-phase, 4-wire electrical system with one additional ungrounded conductor. The first building is considered to be the service to the property. *NEC® 250.32(B) Exception* permits the supply to an existing (not new) second building to consist of two ungrounded conductors and a neutral conductor, with the neutral conductor grounded and bonded to the service enclosure at the second building. The minimum neutral conductor size

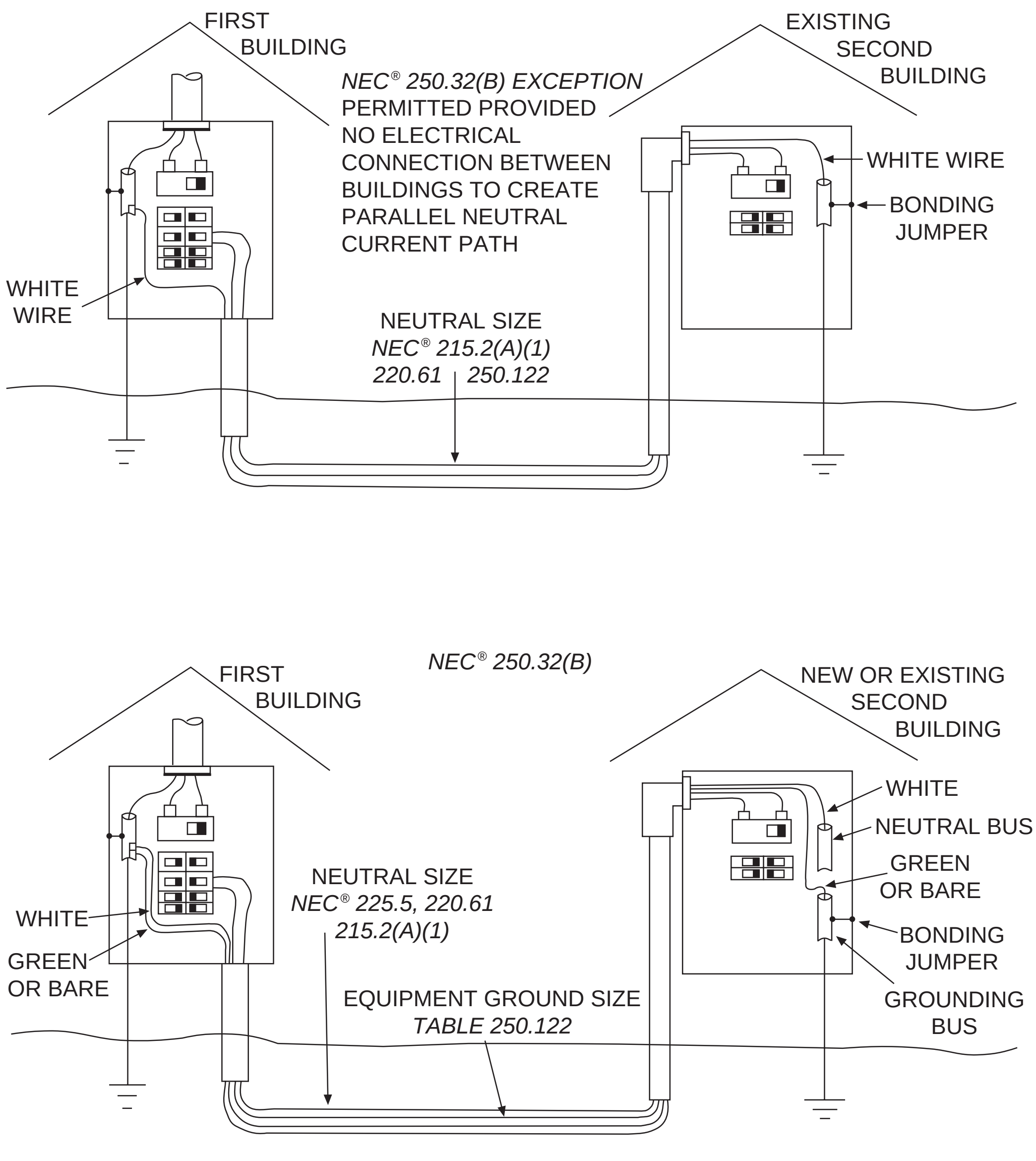


Figure 5.5 Electrical power from one building to a second existing building on the same property is permitted to be by means of a feeder with the grounded conductor acting both as the neutral and the equipment grounding conductor as in the top diagram, but if the second building is new, a separate neutral and equipment grounding conductor as in the bottom diagram are required.

is determined from the appropriate allowable ampacity table in *310.15* depending upon the calculation of unbalanced load according to *220.61*. The neutral conductor is not permitted to be sized smaller than the size given in *Table 250.122* based upon the rating of the feeder overcurrent device.

The neutral is permitted to serve also as the equipment grounding conductor for an existing second building or structure, provided there is no metal connection between the two buildings that could act as a parallel path for neutral current. If the property is served with a metal underground water-piping system, also used as the grounding electrode for both buildings, neutral current would flow on the metal water pipe between the two buildings as well as on the neutral conductor. If this was the case, then it is not permitted to use the neutral conductor as the equipment grounding conductor and ground the neutral at the second building. The method of *250.32(B)* is then required.

For the method of *250.32(B)*, a neutral conductor and a separate equipment grounding conductor are run to the second building, also illustrated in Figure 5.5. A separate neutral bus and equipment grounding bus are installed in the panel in the second building. The neutral conductor is *not* bonded at the second building and it is *not* connected to a grounding electrode at the second building. Because the neutral and equipment grounds are separate in the second building, neutral current is forced to flow only on the neutral conductor. The minimum size of the neutral conductor is determined from the appropriate allowable ampacity table in *310.15* depending upon the calculation of unbalanced load according to *220.61*. This is a feeder; therefore, the minimum size equipment grounding conductor is found in *Table 250.122* using the rating of the feeder overcurrent device.

The rules for distributing power to the various buildings on a farm are slightly different than described in *250.32* due to several special considerations. Power on a farm is frequently supplied to buildings from a central distribution point in the yard where only a disconnect or site isolation device is required. The feeders to the various buildings may not have individual overcurrent protection. The conductors are required to be installed according to the rules in *Article 225*, while minimum neutral and grounding conductor size is specified in *547.9*.

NEC® *250.30* covers the rules with respect to grounding of a separately derived alternating current electrical system. A transformer installed within a building is a common example of a separately derived system. This subject is discussed in detail in *Unit 8*.

Article 280 covers specifications for and the installation of a surge arrester installed on an electrical system operating at over 1000 volts. These requirements do not apply to a surge arrester associated with a primary electrical distribution system of an electrical power supplier. The *National Electrical Safety Code*® covers those installations.

High voltages can be induced into outdoor electric lines during lightning storms. These voltages produce surges of high voltage that travel along the lines. These high-voltage surges can enter buildings and equipment and cause damage. Surge arresters installed on systems operating at over 1000 volts *(Article 280)* and Type 1 Surge-Protective Devices (SPDs) *(285.23)* installed on systems operating at 1000 volts or less are used to limit these voltages to a safe level by providing a path to ground to dissipate the energy. A surge arrester or a Type 1 Surge-Protective Device is connected between an ungrounded conductor and the earth. The connection to earth is frequently made by connecting the surge arrester or SPD to the neutral conductor or the grounding electrode conductor.

Here is how a surge arrester works. When the voltage on the ungrounded conductor is normal, the surge arrester has a high resistance and acts like an open switch preventing current flow through the surge arrester to the neutral conductor. A surge voltage or impulse voltage is a sudden short duration large rise in voltage, usually positive or negative, but not both. Lightning striking near a power line is a frequent cause of surge or impulse voltages, which travel in both directions along a wire from the point of origin. When a surge or impulse reaches a surge arrester, the device must act like a closed switch to the voltage, higher than normal, allowing the voltage to dissipate by passing current through the surge arrester to earth. Once the voltage on the ungrounded conductor returns to normal, the surge arrester must once again act like an open switch, preventing current from flowing to ground at normal system voltage. Voltage surges or impulses are frequently only a few microseconds in duration, therefore, the surge arrester must be fast acting. It must also be capable of passing the energy of the surge so it will survive to be ready to repeat the process. A typical device that can provide this function for power systems in buildings of 1000 volts or less is a low-voltage metal-oxide varistor (MOV). The material has a high resistance at normal operating voltages, but switches to a low resistance when the voltage across the MOV rises above a critical value. The MOV conducts current until the voltage drops below the critical value and the resistance once again goes very high to prevent current flow. This device is now classified as a Type 1 Surge-Protective Device.

Article 285 deals with installation of Surge-Protective Devices (SPDs), of which transient voltage surge suppressors (TVSS) are included. A Surge-Protective Device is installed between the ungrounded

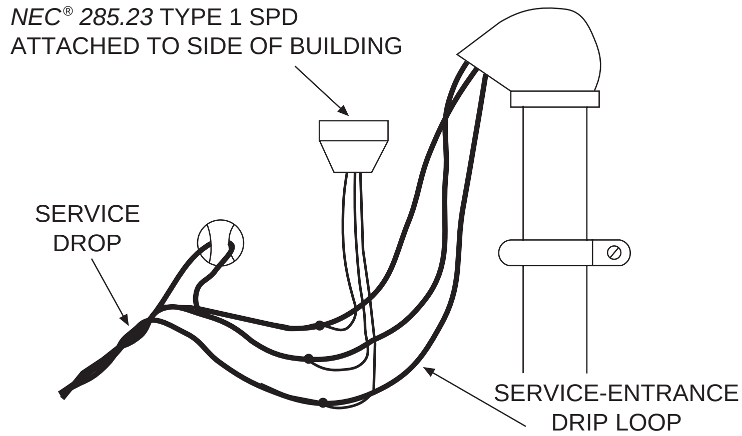


Figure 5.6 A Type 1 Surge-Protective Device (SPD), which provides lightning protection, is permitted to be installed outside the building at a service-entrance drip loop.

conductors and the grounded conductor or earth, usually near the point where the surge is likely to originate. An SPD installed on electrical systems operating at not more than 1000 volts is required to be listed and may be of three types. They are permitted to be installed indoors or outdoors. Figure 5.6 shows a metal-oxide varistor-type MOV SPD installed at the service entrance drip loop of a building. An SPD according to *285.3* is not permitted to be installed on an ungrounded electrical system unless specifically listed for the application.

A Type 1 Surge-Protective Device is permitted to be installed on the supply side of the first overcurrent device to a building such as shown in Figure 5.6, *285.23*. The Type 1 SPD is also permitted to be installed on the load side of the service disconnecting means and overcurrent protection. A Type 2 SPD is only permitted to be installed on the load side of the first overcurrent device of a building, *285.24*. A typical installation of a Type 2 SPD is shown in Figure 5.7, where it is acting as a transient voltage surge suppressor (TVSS) to protect sensitive equipment served by the panelboard from surges most likely originating within the building. A Type 3 SPD is only permitted to be installed on the load side of a branch circuit overcurrent device, *285.25*.

In the past, Type 2 and Type 2 Surge-Protective Devices were frequently called transient voltage surge suppressors (TVSS). Transient voltage surge suppressors are only permitted to be installed on grounded electrical systems operating at 1000 volts and under. A TVSS is not permitted to be installed on an ungrounded electrical system, because under fault conditions within the building, the TVSS can be exposed to an excessive over voltage. Type 2 and Type 3 SPDs are permitted to be installed on any circuit within a building, but

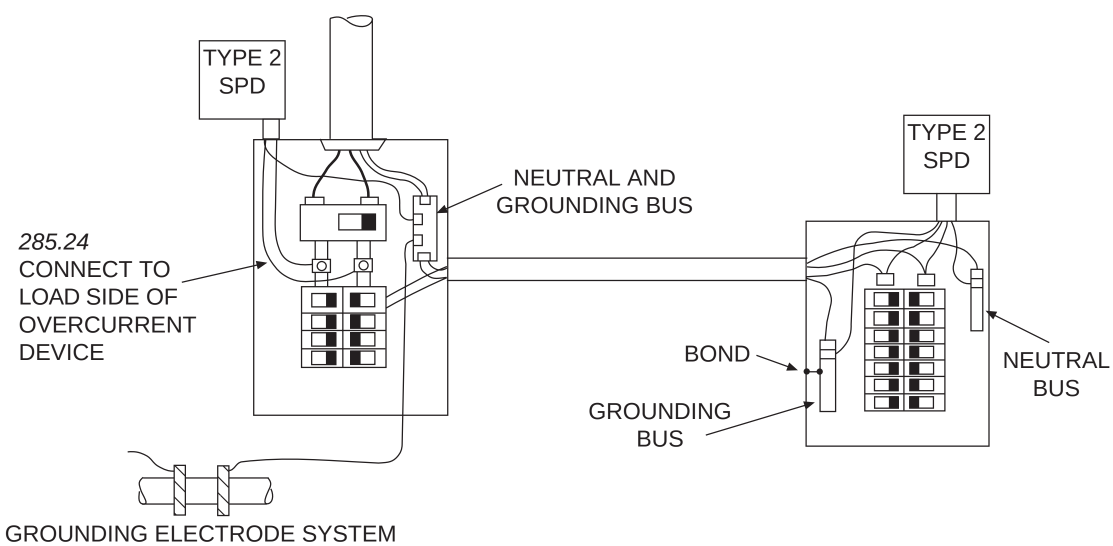


Figure 5.7 A Type 2 Surge-Protective Device (SPD) is required to be installed on the load side of the first overcurrent device of the building, and it helps protect sensitive electrical equipment from voltage surges and impulses.

they are always required to be installed on the load side of the first overcurrent device for the conductors entering the building. A TVSS is permitted to be installed either inside or outside a building but always on the load side of the first overcurrent device. Figure 5.7 shows a typical TVSS (Type 2 SPD) installation in a building with a device at the main service and one at a down-line panelboard. A voltage surge or impulse originating on a branch circuit would travel back to the panelboard and would be conducted to ground at the panelboard by the TVSS, thus preventing the voltage impulse from feeding to other circuits supplied from that panelboard.

The basic function of a Surge-Protective Device is to become conductive at a voltage only slightly higher than the ungrounded conductor operating voltage. Like a surge arrester, the SPD is generally connected between the ungrounded conductor and the neutral or equipment grounding conductor. However, an SPD is permitted to be installed between ungrounded conductors. The device becomes conductive when a surge voltage or an impulse voltage develops on the ungrounded conductors. That surge or impulse voltage is not necessarily due to lightning. It may be due to operation of switches and other equipment within or near the building. The SPD is generally installed to protect sensitive electronic equipment from over voltages. Because the SPD goes into conduction mode and passes surge current much more easily than a surge arrester, it must be installed on the load side of an overcurrent device to provide it with backup protection.

NEC® 285.6 requires that a Surge-Protective Device shall be marked with a fault-current rating. The available fault current at the point of installation is not permitted to be in excess of the fault-current rating of the SPD. A transient voltage surge suppressor (Type 2 or Type 3 SPD) can be a one-port device that is tapped to the ungrounded conductors, the grounded conductor, and the equipment grounding conductor. With a one-port device, the load current does not pass through the SPD. With the two-port SPD, there is an input port and an output port. The load current does pass through the device and the SPD must have a short-circuit current rating.

Article 680 covers the wiring of equipment associated with swimming pools, fountains, and similar equipment. Requirements are placed on the wiring installed in the area of pools, fountains, and similar installations. The types of installations covered are swimming, wading, therapeutic and decorative pools; fountains; hot tubs; spas; and hydromassage bathtubs. The terms **pool** and **fountain** are defined in *680.2*. Definitions important to the installation of equipment in these areas are covered in *680.2*.

Differences in voltage between two places around the pool, fountain, or similar installation may be of a sufficient level to create a hazard. To help prevent hazardous conditions from developing, metal parts of the swimming pool are required by *680.26* to be bonded together with a solid copper wire not smaller than size 8 AWG. Metal raceway, metal-sheathed cable, metal piping, and other metal parts fixed in place within 5 ft (1.5 m) horizontally of the inside edge of the pool shall also be bonded together. All metal parts shall be bonded to an equipotential bonding. This is illustrated in Figure 5.8. The specifications for an

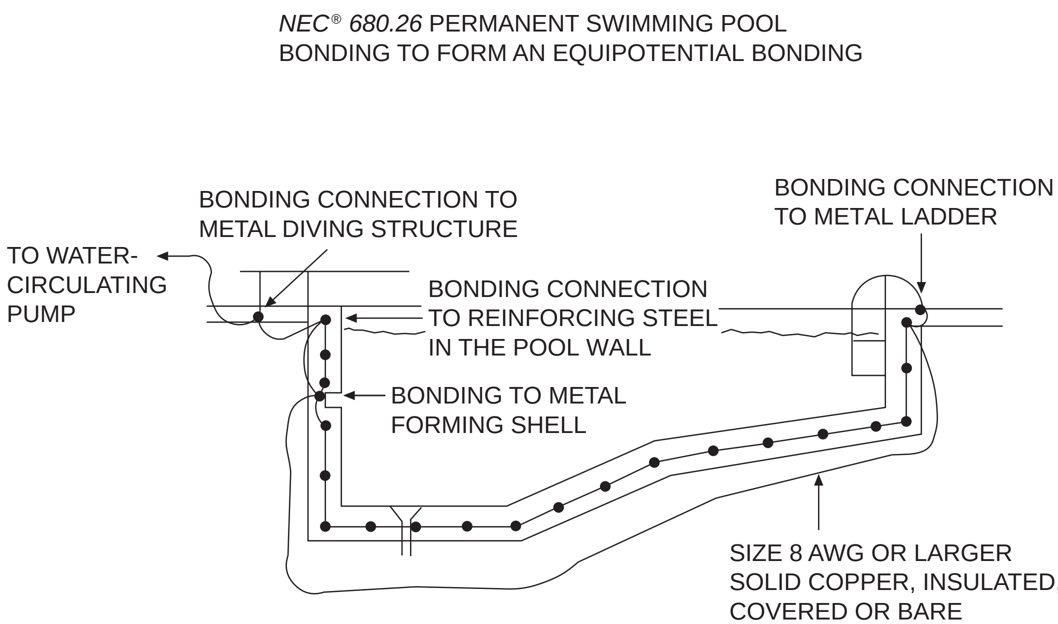


Figure 5.8 Metal parts of a permanent swimming pool are required to be bonded together to reduce the likelihood of voltage gradients in the pool area.

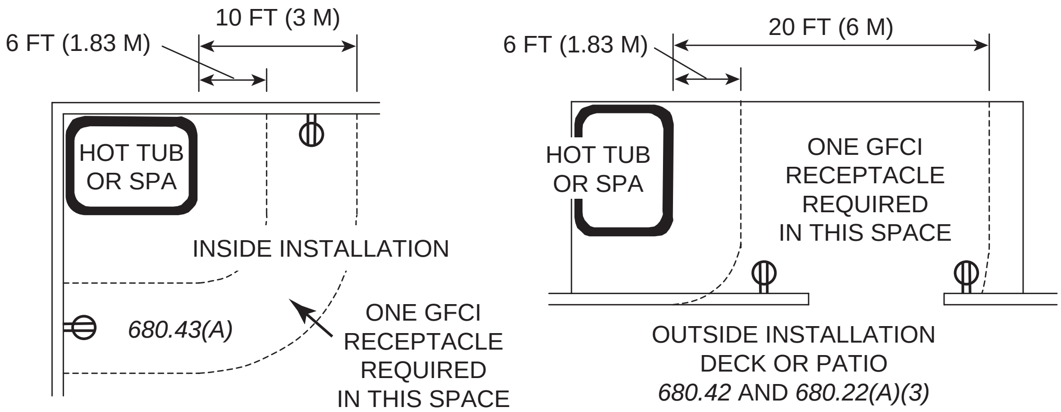


Figure 5.9 At least one ground-fault circuit-interrupter protected 125-volt receptacle outlet for an inside installation is required to be installed at least 6 ft (1.83 m), but not more than 10 ft (3 m) from the inside edge of an inside spa or hot tub, and between 6 ft (1.83 m) and 20 ft (6 m) for an outside spa or hot tub.

equipotential bonding are specifically stated in the Code in *680.26,* which states that structural reinforcing steel of a concrete pool or the wall of a bolted or welded metal pool is required to serve as part of the equipotential bonding.

At least one 125-volt receptacle outlet, not for the water-circulating pump, is required to be installed not more than 20 ft (6 m) and not closer than 6 ft (1.83 m) from the inside edge of a dwelling permanent swimming pool as stated in *680.22(A)(3). NEC® 680.22(A)(5)* covers the situation in which a receptacle outlet beyond a barrier or wall is within 20 ft (6 m) of the edge of a permanent swimming pool. All 125-volt receptacle outlets within 20 ft (6 m) of the inside edge of the pool shall be protected by a GFCI. These same rules apply in the case of a spa or hot tub installed on the outside of a building, as stated in *680.42* and illustrated in Figure 5.9. In the case of a spa or hot tub installed on the inside of a building, at least one 125-volt rated receptacle outlet, which is required to be GFCI protected, is required to be installed at a distance of not more than 10 ft (3 m) from the inside edge of the spa or hot tub, and not closer than 6 ft (1.83 m).

GROUNDING AND BONDING FUNDAMENTALS

Grounding and bonding is one of the most important parts of an electrical wiring system, and at the same time it is one subject of the Code that seems to be confusing. It is essential to understand the purpose of grounding and bonding, and then it will be easier to make sure the installation has met the requirements of the Code. Grounding and bonding are key elements to the backup safety system for an electrical circuit or electrical equipment. If the grounding system does not function properly, then other safety devices such as circuit breakers and fuses may not function when a problem develops. Grounding and bonding must be installed with as much care as any other part of the electrical system. One Code section in particular discusses important information necessary to understand system and equipment grounding and bonding. Read *250.4* to get an explanation of the purpose of grounding.

Equipment Grounding

The equipment grounding conductor is permitted to be a metal raceway or a metal box, cabinet, or frame of equipment. These and other permitted means of providing an equipment grounding conductor are covered in *250.118.* The equipment grounding conductor is permitted to be copper or aluminum wire. There is a restriction in the case of aluminum wire used for grounding. Aluminum as an equipment grounding wire that is not insulated or covered is not permitted to be installed where it is in direct contact with masonry or the earth, or where subject to corrosive conditions. When aluminum wire is exposed and used outside for grounding, it is not permitted to be installed within 18 in. (450 mm) of the earth. These restrictions on aluminum and copper-clad aluminum conductors are found in *250.120* and *250.64*.

Equipment grounding wires are permitted to be solid or stranded, insulated or bare. If the wire is insulated, it is required to have insulation that is green or green with yellow stripes. These requirements are found in *250.119*, and for flexible cords, *400.23*. If the equipment grounding wire is size 4 AWG or larger, it is permitted to be identified as an equipment grounding wire at the time of installation at every location where it is accessible. Acceptable means of identifying an equipment grounding conductor of size 4 AWG or larger that is not bare, green, or green with yellow stripes are: (1) to strip the insulation from the entire exposed wire, leaving the wire bare, or (2) to apply with green tape, green labels, or green paint encircling the wire at terminations.

All fittings, conduit, splices, and any other connections in the equipment grounding conductor shall be made up tight with proper tools. Flexible Metal Conduit is not considered to be as effective an equipment grounding conductor as Rigid Metal Conduit (RMC), Intermediate Metal Conduit (IMC), or Electrical Metallic Tubing (EMT). Therefore, limitations are placed on the use of Flexible Metal Conduit and Liquidtight Flexible Metal Conduit for use as an equipment grounding conductor. These restrictions are given in *250.118*. If these requirements are not satisfied, then an equipment grounding wire shall be provided to bond from the enclosure at one end of the Flexible Metal Conduit to the enclosure at the other end of the Flexible Metal Conduit.

There are several methods of installing and terminating an equipment bonding jumper from one end to the other of flexible conduit. Installation of equipment bonding jumpers is covered in *250.102*. The equipment bonding or grounding jumper is permitted to be run on the inside of a raceway, or it is permitted to be run on the outside. If run on the outside, the equipment bonding jumper is not permitted to be more than 6 ft (1.8 m) long. The bonding jumper shall be routed with the raceway or enclosure. Special fittings are manufactured for terminating the bonding wire on the outside of the Flexible Metal Conduit and Liquidtight Flexible Metal Conduit. Various methods are acceptable for terminating an equipment bonding jumper or an equipment grounding wire at an enclosure.

The methods permitted to terminate an equipment grounding conductor or an equipment bonding jumper to an enclosure are covered in *250.8*. Connecting an equipment grounding conductor to a metal box or enclosure is required to be done with a device listed for the purpose or by means of a grounding screw used for no other purpose, *250.148(C)*. Sheet metal screws are not permitted to be used to connect equipment grounding conductors to boxes and enclosures unless they are considered to be machine screws and have at least two threads in contact with the enclosure, *250.8(A)*. When an equipment grounding conductor is terminated at a lug in an enclosure, the screw or bolt used to connect the lug to the enclosure shall be used for no other purpose. Connections or fittings that depend on solder are not permitted. This does not prevent the use of solder at a connection where the connection is made mechanically secure before soldering. *NEC® 250.148* requires that the removal of a device at a box or enclosure shall not interrupt the continuity of the equipment grounding conductor.

Sizing Equipment Grounding Conductors

An equipment grounding wire size is based on the size of the overcurrent device protecting the circuit. *Table 250.122* in the Code lists the minimum wire size permitted for various overcurrent device ratings. In the case of electrical cable, the manufacturer has installed the correct size of equipment grounding wire based on the maximum size overcurrent device rating permitted to be used for that cable. When raceway is permitted as an equipment grounding conductor, cross-sectional area of the metal is adequate for the largest size wires permitted in the raceway. Usually, the only time when an equipment grounding wire must be sized is in the case of nonmetallic conduit or for bonding jumpers. The following examples illustrate how to determine the minimum permitted size of equipment grounding conductor for a branch-circuit or a feeder.

Example 5.1 Determine the minimum size copper equipment grounding conductor for a 30-ampere circuit consisting of Type THWN copper wires size 10 AWG installed in Rigid Nonmetallic Conduit.

Answer: From *Table 250.122*, the minimum size copper equipment grounding conductor permitted is 10 AWG.

Example 5.2 A 7-ft (2.13-m) length of Liquidtight Flexible Metal Conduit extends from a fusible disconnect switch to an electric furnace. The wires inside the flexible conduit are Type THHN copper size 4 AWG with 70-ampere overcurrent protection. Determine the minimum size copper equipment grounding conductor to bond around the Liquidtight Flexible Metal Conduit. There is an equipment grounding lug in the furnace for terminating the equipment grounding conductor.

Answer: A 70-ampere overcurrent device is not listed in *Table 250.122;* therefore, the next larger overcurrent device rating shall be used. For this example, use the equipment grounding wire size required for a 100-ampere overcurrent device. The minimum size copper equipment grounding wire size for this 70-ampere circuit is size 8 AWG.

Parallel Equipment Grounding Conductors

In *310.4,* conductors are permitted to be run in parallel. In general, the minimum conductor size permitted to be installed in parallel is 1/0 AWG. This minimum size applies to ungrounded conductors and to grounded conductors. There is no mention of equipment grounding conductors, bonding conductors, or grounding electrode conductors. *NEC® 250.122(F)* covers the situation where conductors are run in parallel. When the conductors are run in parallel sets within more than one raceway where an equipment grounding conductor is required, the equipment grounding conductors are required to be run in parallel. Each of the separate equipment grounding conductors required is determined using *Table 250.122* and based on the size of the circuit overcurrent device rating. Example 5.3 illustrates how the size of parallel equipment grounding conductors is determined.

Example 5.3 A feeder protected with 500-ampere time-delay fuses is run with two parallel sets of conductors in separate Rigid Nonmetallic Conduits as shown in Figure 5.10. Determine the minimum size of copper equipment grounding conductor required in each conduit run of the feeder.

Answer: A separate equipment grounding conductor is required to be run with each set of conductors. Each of the equipment grounding conductors is required to be sized according to *Table 250.122.* The minimum size copper equipment grounding conductor required for a 500-ampere overcurrent device is 2 AWG.

Equipment Grounding Conductor Size Adjustments

Equipment grounding conductors are sized in the Code to be capable of conducting sufficient current during fault conditions to open the circuit or feeder overcurrent device. The longer the circuit conductors, the higher the resistance of the equipment grounding conductor, and the more difficult it becomes to conduct sufficient current to open the overcurrent device. If a circuit or feeder is long enough to require an increase in ungrounded wire size to limit voltage drop, then a corresponding adjustment in equipment grounding

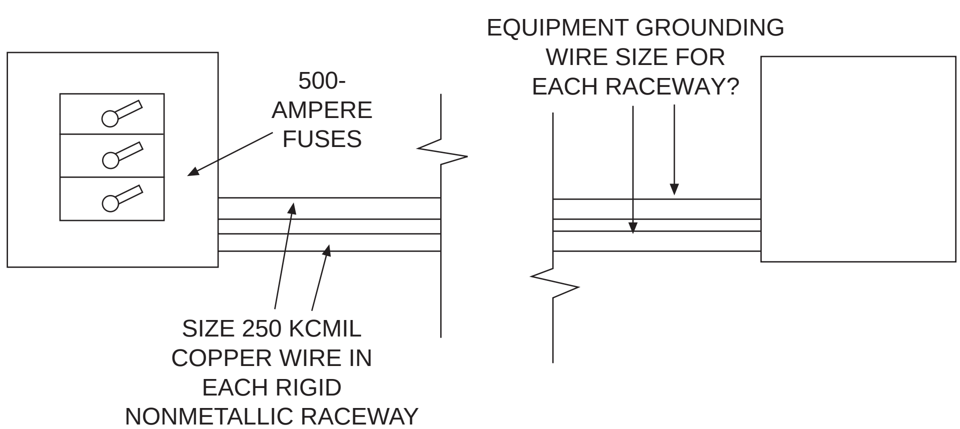


Figure 5.10 When conductors run in parallel in separate raceways require an equipment grounding conductor run with the circuit conductors, the equipment grounding conductor in each raceway is sized based upon the rating of the branch-circuit or feeder.

conductor size seems appropriate. *NEC® 250.122(B)* requires an adjustment in equipment grounding conductor cross-sectional area in proportion to the cross-sectional area increase of the ungrounded conductors. Equation 5.1 can be used to determine the adjusted equipment grounding conductor size.

$$\textbf{Adjusted equipment grounding conductor size} = \textbf{Area of minimum grounding wire size} \times \frac{\textbf{Adjusted ungrounded wire area}}{\textbf{Minimum ungrounded wire area}} \qquad \textbf{Eq. 5.1}$$

To determine the adjusted equipment grounding conductor size, start by finding the minimum size equipment grounding conductor for the circuit from *Table 250.122.* Next, look up the minimum ungrounded conductor size required for the branch-circuit or feeder. Assuming no adjustment factors apply, look up the minimum size conductor from *Table 310.16* in most cases. A larger size ungrounded conductor is actually being used to limit the voltage drop of the circuit. From *Table 8* in *Chapter 9*, look up the cross-sectional area of all of these conductors and put them into Equation 5.1 to determine the adjusted equipment grounding conductor size. Use *Table 8* again to convert the equipment grounding conductor area into an AWG size. The following example will illustrate how this process works:

Example 5.4 A 3-phase, 480-volt feeder is protected by a 100-ampere overcurrent device. The ungrounded conductors of the feeder are size 1/0 AWG copper to limit the voltage drop on the feeder. It will be assumed conductor insulation and terminations are 75°C rated. If the feeder is run in Rigid Nonmetallic Conduit, determine the minimum size copper equipment grounding conductor permitted.

Answer: First look up the minimum copper equipment grounding conductor size permitted for this feeder in *Table 250.122.* Next, look up the minimum ungrounded conductor size permitted for the feeder in *Table 310.16*, assuming voltage drop is not an issue. The minimum is size 3 AWG. Now look up the cross-sectional area of the conductors in *Table 8.* Then calculate the adjusted equipment grounding conductor area using Equation 5.1. The result will be 33,133 cmil (16.79 mm^2), which is a size 4 AWG from *Table 8.*

size 8 AWG	16,510 cmil	8.37 mm^2
size 3 AWG	52,620 cmil	26.67 mm^2
size 1/0 AWG	105,600 cmil	53.49 mm^2

$$\text{Adjusted eqpt. grnd. conductor size} = 16{,}510\text{ cmil} \times \frac{105{,}600\text{ cmil}}{52{,}620\text{ cmil}} = 33{,}133\text{ cmil}$$

$$\text{Adjusted eqpt. grnd. conductor size} = 8.37\text{ mm}^2 \times \frac{53.49\text{ mm}^2}{26.67\text{ mm}^2} = 16.79\text{ mm}^2$$

Electrical Shock

Electrical shock is caused by the flow of electrical current through the body or a part of the body. Current passing through the body can cause burns, muscle reaction, and injury to body organs. If the current travels through the head or central part of the body, severe injury or even death may occur. Dry skin has a high resistance to the flow of electricity. With under 15 volts, enough current generally will not flow through the body to be harmful to a human. This is not necessarily true for a human in wet conditions or for an animal standing in a moist environment. The moist hoof or foot of a farm animal offers low resistance to the flow of electrical current. The main factors involved in electrical shock to an animal or human are:

- voltage
- duration of the electrical shock
- condition of skin or body surface
- surface area contact with the source
- path the current takes

Voltage and condition of the skin usually determine the amount of current that flows. A normal person usually will just begin to feel the sensation of shock if 1/1000 ampere or 1 milliampere of 60 hertz alternating current flows through the body. Shock may become painful to humans with a continuous flow of 8 milliamperes or more.

Muscular contraction (cannot let go) may occur in humans with a continuous current flow of 15 milliamperes or more. Greater flows of current through the body are usually very serious. An effective equipment grounding system is important for the protection of people and animals with the damp and wet conditions that exist in many residential, commercial, and farm locations.

Electrical System Grounding

A building wiring system usually must have one conductor grounded to the earth. This grounding helps limit voltages caused by lightning surges. Grounding prevents high voltages from occurring on the wiring if a primary line should accidentally contact a secondary wire. Grounding limits the maximum voltage to ground from the hot wires. For most residential, commercial, and farm wiring systems, the maximum voltage to ground is not more than 125 volts. Several decisions must be made in the grounding of an electrical system to the earth. Three major decisions are which wire is permitted to be grounded, the type of grounding electrode, and determining the minimum permitted size of grounding electrode conductor.

Which Conductor of the Electrical System to Ground

The service-entrance wire required to be grounded is described in *250.20(B)* for an alternating current system operating between 50 volts and 1000 volts. The grounded-circuit conductor shall have white or gray insulation. Identification of the grounded-circuit conductor is covered in *200.6*. If the wire is larger than size 6 AWG, the wire is permitted to be labeled with white or gray tape or paint where the wire is visible. The following electrical systems are required to be grounded:

- Single-phase, 2-wire, 120 volts
- Single-phase, 3-wire, 120/240 volts
- Three-phase, 4-wire, 208/120 volts, wye
- Three-phase, 4-wire, 240/120 volts, delta
- Three-phase, 4-wire, 480/277 volts, wye, when supplying phase to neutral loads
- Three-phase, 4-wire, 600/347 volts, wye, when supplying phase to neutral loads

Grounding Electrode

The grounding electrode is the means by which electrical contact is made with the earth. The type of electrode permitted to be used for grounding an electrical system is given in *250.52*. The following grounding electrodes are covered in *250.52* and shall be used if available:

- Metal underground water pipe in direct contact with the earth for at least 10 ft (3 m). A metal underground water pipe shall be supplemented by at least one additional electrode.
- The metal frame of the building, where the metal frame is effectively grounded
- A bare size 4 AWG or larger copper wire or reinforcing steel at least $^1/_2$ in. (13 mm) in diameter at least 20 ft (6 m) long and encased in concrete in contact with the earth, with at least 2 in. of concrete around all sides of the wire or steel
- A bare copper wire circling the building at a depth of at least $2^1/_2$ ft (750 mm), size 2 AWG or larger, and at least 20 ft (6 m) long
- A rod or pipe electrode driven to a depth of at least 8 ft (2.5 m) into the soil. If rock bottom is encountered, it shall be permitted to drive the pipe or rod at an angle of not less than 45° from the horizontal. Or it may be laid in a trench at least $2^1/_2$ ft (750 mm) deep. The acceptable rods and pipes shall have the following minimum diameters: (1) trade size $^3/_4$ (21) galvanized steel pipe, (2) $^5/_8$-in. (16 mm) iron or steel rod, and (3) $^1/_2$-in. (13 mm) copper-coated rod
- A plate electrode is permitted to be used in areas where soil conditions prevent the use of a pipe or rod electrode. The plate shall make contact with at least 2 sq ft (0.186 m^2) of soil.
- Other metal underground structures or equipment such as a metal well casing are also permitted.

Rod, pipe, and plate electrodes sometimes do not make good low-resistance contact with the earth. They must be placed in areas not subject to damage but where the soil is most likely to be moist. They should not be installed in areas protected from the weather, such as under roof overhangs. The Code specifies in *250.56* that a single rod, pipe, or plate electrode shall have a resistance to ground not exceeding 25 ohms. If the resistance to earth is greater than 25 ohms, then one additional rod, pipe, plate, or other electrode shall be installed. Rod, pipe, or plate electrodes shall be at least 6 ft (1.8 m) apart.

Lightning-protection system grounding electrodes are not permitted to be used as one of the required electrodes for the electrical system, *250.60*. However, electrodes for the electrical and lightning systems shall be electrically connected together, as specified in *250.106*.

Grounding and Bonding for Service with Parallel Conductors

Several components of the grounding and bonding system must be sized when a service entrance consists of two or more parallel sets of service-entrance conductors. The grounding and bonding conductors may all be different sizes as illustrated in Figure 5.11. The minimum permitted size of grounding electrode conductor is found in *250.66*. When there are two or more parallel sets of service-entrance conductors, the minimum size of grounding electrode conductor is determined based on the sum of the cross-sectional areas of the ungrounded conductors for any one particular leg or phase. This information is found in *Note 1* to *Table 250.66*. With some 3-phase electrical systems, such as a 4-wire delta system, the phase conductors may not all be the same size. In this case, the phase that yields the largest sum of the cross-sectional areas of the conductors is used for the grounding electrode conductor determination. Note from *Table 250.66* that the largest size of grounding electrode conductor required to be installed for the service of Figure 5.11 is size 3/0 AWG copper or 250-kcmil aluminum. Some grounding electrodes, such as a ground rod, have a limited ability to dissipate ground fault current. Therefore, *250.66(A)* permits the grounding electrode conductor to be smaller in some cases than would normally be required by *Table 250.66*.

Bonding of metal enclosures and raceways is required for service equipment. What must be bonded is covered in *250.92(A)*, the method of bonding is covered in *250.92(B)*, and the minimum permitted size of bonding jumper is specified in *250.102*. A bonding means may be provided with the service equipment, or a copper or aluminum wire may be used as the bonding means. The main bonding jumper connects the service equipment enclosure to the grounding electrode conductor and to the grounded service conductor if the supply system has a grounded conductor. In the case of Figure 5.11, the main bonding jumper connects the grounding bus to the service equipment enclosure. The minimum permitted size of this main bonding jumper is determined from *250.28(D)*. This section is somewhat confusing in the case of parallel service-entrance conductors. First, the main bonding jumper is not permitted to be sized smaller than the size specified in *Table 250.66* for the service-entrance conductors where the cross-sectional area to use is the sum of the

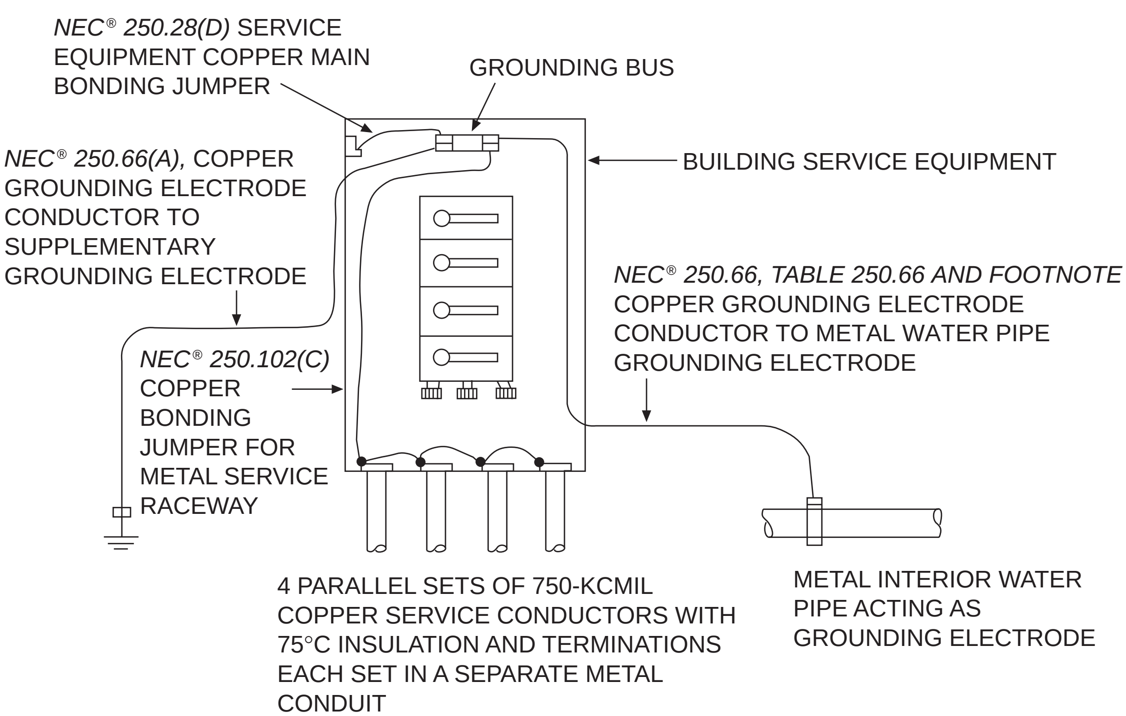


Figure 5.11 The minimum permitted size of the grounding electrode conductor and main bonding jumper are determined based on the sum of the cross-sectional areas of the conductors of any one phase.

cross-sectional areas of all conductors of one phase. For example, if there are two sets of 500-kcmil conductors in parallel for the service entrance, the cross-sectional area to be used is 1000 kcmil. Secondly, when the cross-sectional area of the service-entrance conductors for one phase is determined to be larger than 1100-kcmil copper or 1750-kcmil aluminum, then the minimum permitted size of conductor for the main bonding jumper is 12.5% (0.125 times the cross-sectional area) of the cross-sectional area of the conductors. The main bonding jumper in this latter case will be larger than the grounding electrode conductor.

If the service-entrance conductors are run in metal raceway, then the metal raceway must be bonded to the service equipment enclosure or to the service grounding bus. *NEC® 250.102(C)* explains how to determine the minimum size of service raceway bonding jumper. The minimum size is based on the size of the largest conductors in the raceway. If more than one set of parallel conductors are in a single raceway for each phase, then the cross-sectional area is taken as the sum of the cross-sectional areas of the individual conductors for that phase. Example 5.5 illustrates sizing of grounding electrode conductors and bonding jumpers for a service entrance with parallel sets of service-entrance conductors.

Example 5.5 The conductors for a service entrance consist of four parallel sets of 750-kcmil copper conductors with 75°C insulation and terminations. Each set of conductors is run in a separate Rigid Metal Conduit as shown in Figure 5.11. All bonding and grounding electrode conductors are copper. The metal water pipe is used as a grounding electrode, and it is supplemented with a driven ground rod. A separate copper grounding electrode conductor is run from the grounding bus in the service equipment to each grounding electrode. The grounding bus is bonded to the service equipment enclosure with a copper main bonding jumper. A single copper conductor is run from the service equipment grounding bus to a bonding bushing on each service entrance conduit. Determine the minimum permitted size of the following:

a. the copper grounding electrode conductor to the water pipe
b. the copper grounding electrode conductor to the ground rod
c. the copper main bonding jumper from the grounding bus to the service equipment enclosure
d. the copper bonding jumper from the grounding bus to each service conductor conduit

Answer: a. The minimum permitted size of the copper grounding electrode conductor to the water pipe is determined from *250.66, Table 250.66,* and the footnote to the table. First, determine the total cross-sectional area of the conductors of one phase by adding the cross-sectional areas of all conductors of that phase to get 3000 kcmil. This is larger than 1100 kcmil; therefore, the minimum permitted size is 3/0 AWG.

$$750 \text{ kcmil} \times 4 = 3000 \text{ kcmil}$$

b. *NEC® 250.66(A)* does not require the grounding electrode conductor to a made electrode such as a ground rod to be larger than size 6 AWG.

c. *NEC® 250.28(D)* requires the main bonding jumper to not be smaller than specified in *Table 250.66* or not less than 0.125 times the cross-sectional area of the conductors of one phase, whichever is larger. In this case, it is 0.125 times 3000 kcmil that gives 375 kcmil. If one of the standard wire sizes from the Code is used, the minimum wire size can be determined from *Table 310.16* or *Table 8* of *Chapter 9.* The minimum standard wire size would be 400 kcmil.

$$3000 \text{ kcmil} \times 0.125 = 375 \text{ kcmil}$$

d. The minimum permitted size of bonding jumper for the service-entrance conduit is based on the phase conductor cross-sectional area contained in the conduit according to *250.102(C).* In this case, the phase conductor size is 750 kcmil, and the minimum permitted raceway bonding jumper size from *Table 250.66* is size 2/0 AWG copper.

ELECTRICAL SYSTEM TYPES AND VOLTAGES

Selecting the type of electrical supply system for a commercial, farm, or industrial application involves careful consideration of several factors, some of which are (1) the size of the electrical service required, (2) the voltages required, (3) the anticipated kilowatt-hour usage, (4) the electrical energy rates available, and (5) the size and number of electrical motors. An electric power supplier customer service

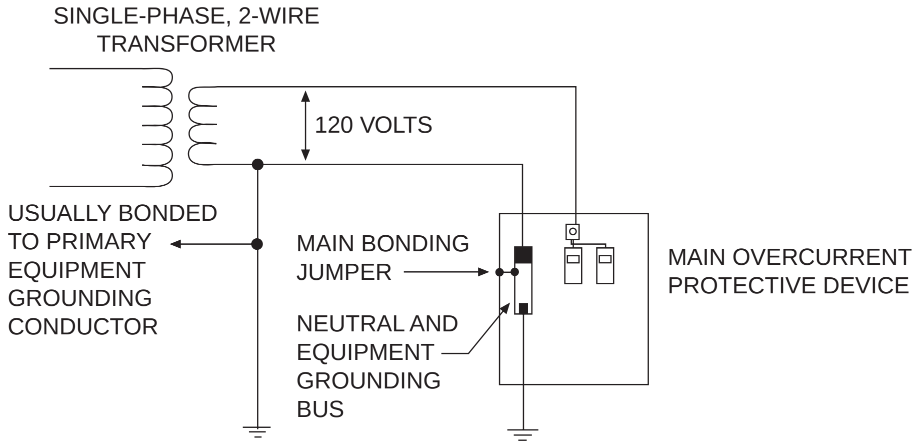


Figure 5.12 A 120-volt, 2-wire, single-phase electrical system.

representative is usually available to help evaluate these points when making a choice for the type of electrical system for a particular application.

Single-Phase Electrical Systems

Some buildings are served by a 2-wire, 120-volt electrical system, as shown in Figure 5.12. These systems are permitted as long as the building needs are limited to two circuits. This type of system is permitted to be installed in an outbuilding on a property where there is little electrical usage in the building. A 2-wire, 120-volt electrical system can be derived from a separate transformer, or it can be derived from a 120/240-volt, 3-wire, single-phase system or from a 208Y/120-volt, 4-wire, 3-phase electrical system.

The most common electrical system for dwellings is the 120/240-volt, 3-wire, single-phase system shown in Figure 5.13. The wire originating at the transformer center tap is grounded. The voltage from the grounded neutral wire to each ungrounded wire is 120 volts. A load powered at 240 volts, such as a motor, is supplied by the two ungrounded wires. The power supplier grounds the common conductor at the transformer, and the neutral conductor is required by *250.24* to be grounded again, usually at the service disconnecting means.

It is important to balance the 120-volt load so that half is connected between the neutral and each ungrounded wire. If the 120-volt loads are perfectly balanced, the current flowing on the neutral will be zero. Loads operating at 240 volts do not use the neutral; therefore, they do not place current on the neutral.

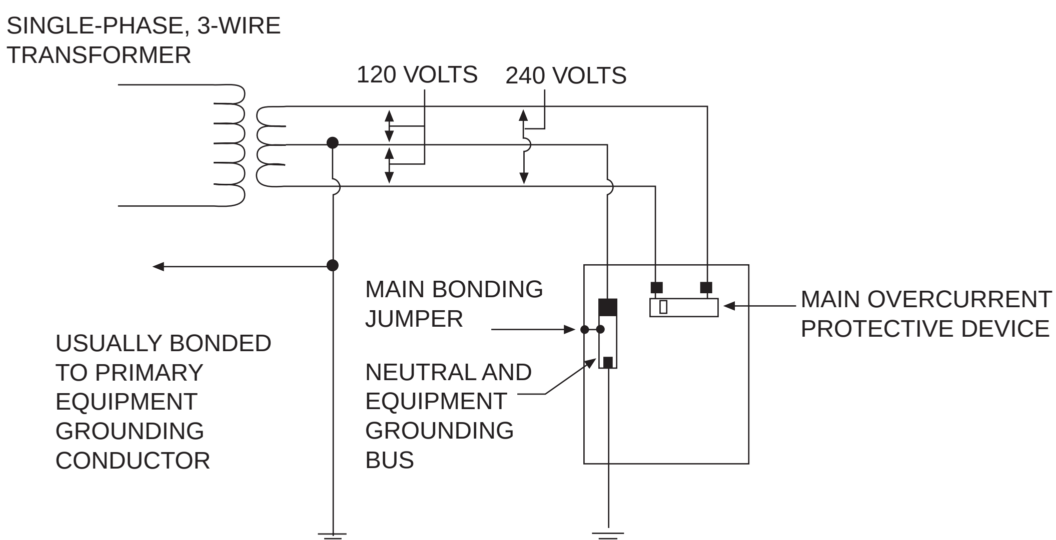


Figure 5.13 A 120/240-volt, 3-wire, single-phase electrical system.

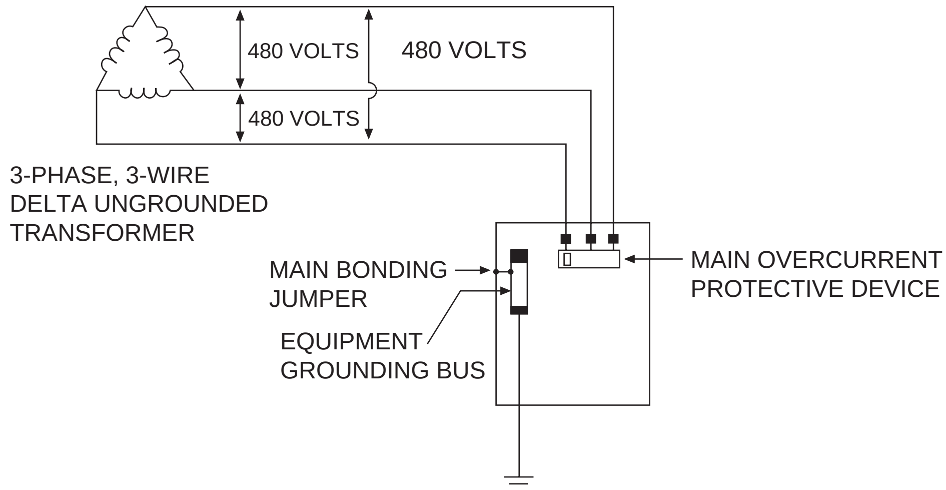


Figure 5.14 A 3-phase, 3-wire, ungrounded delta electrical system operating at 480 volts (sometimes 240 volts) is required to have the service disconnect enclosure grounded.

Three-Phase Electrical Systems

Three-phase electrical systems are of different types and voltages to fit different needs. There are three common types of delta electrical systems. One type of delta 3-phase electrical system is the 3-wire ungrounded electrical system. *NEC® 250.21* permits the 240-volt and the 480-volt 3-phase delta 3-wire systems to be operated without one of the conductors grounded. A 480-volt ungrounded 3-wire delta electrical system is illustrated in Figure 5.14.

It is important to remember that equipment is required to be grounded as specified in *250.110* and *250.112*. *NEC® 250.130(B)* states that the equipment grounding conductors shall be bonded to the grounding electrode conductor of the ungrounded system. This can be confusing. The system is considered ungrounded because one circuit conductor is not grounded. But a grounding electrode is required for the service.

A 3-phase, 3-wire electrical system operating either at 240 volts between phases or 480 volts between phases is permitted to be operated with one of the phase conductors grounded. This is frequently called a corner grounded delta 3-phase electrical system. A 3-wire, corner grounded, 3-phase electrical system is shown in Figure 5.15. *NEC® 240.22* states that an overcurrent device is not permitted to be installed in a

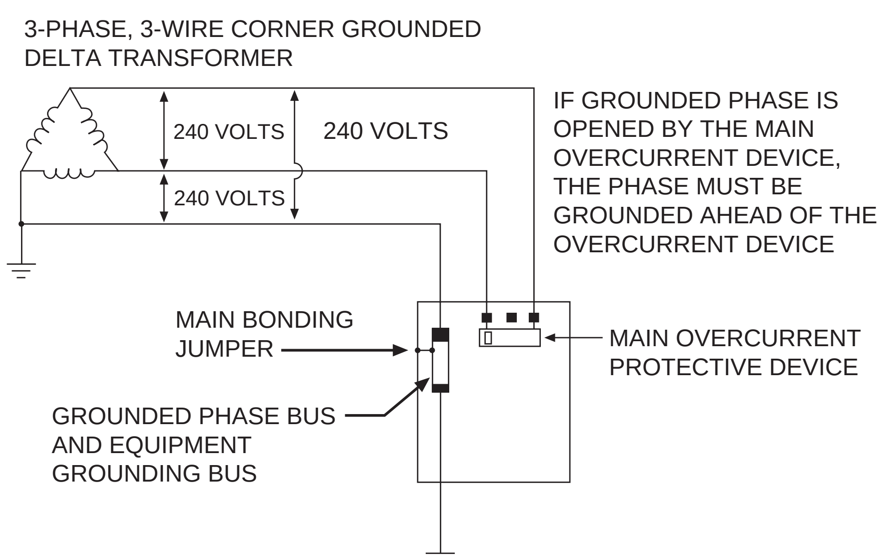


Figure 5.15 A 3-phase, 3-wire, delta electrical system, operating at either 240 volts or at 480 volts, is permitted to have one phase conductor grounded.

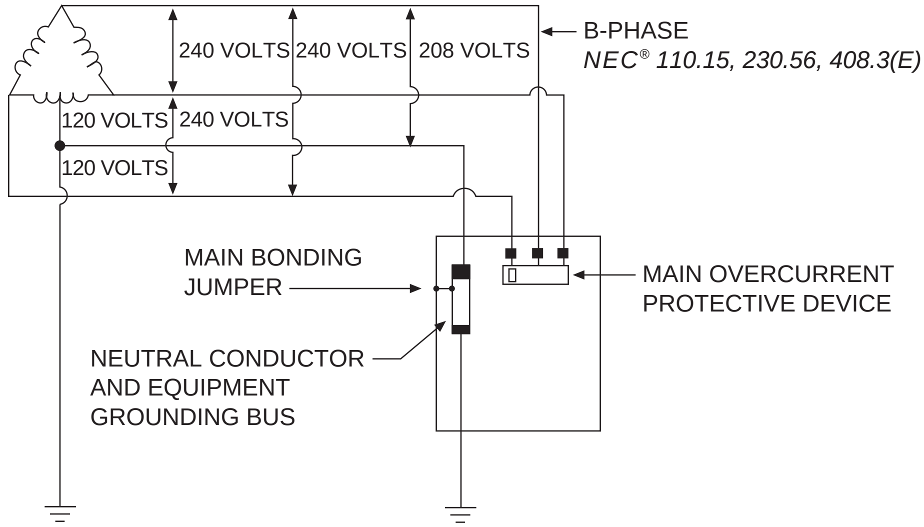


Figure 5.16 A 240/120-volt, 4-wire, 3-phase delta electrical system provides single-phase power at 120/240 volts and 3-phase power at 240 volts. One phase has a higher voltage to ground than the other two phases, and that phase must be identified with an orange marking.

grounded conductor unless all ungrounded conductors are opened when the overcurrent device operates. An overcurrent device is permitted to be installed in the grounded phase conductor when it serves as overload protection for an electric motor, as permitted in *430.36*.

The 4-wire, 240/120-volt delta 3-phase electrical system provides single-phase and 3-phase service at 240 volts and single-phase at 120 volts. This system is shown in Figure 5.16. There is a single-phase neutral conductor with this system. The voltage from two of the ungrounded phase conductors to the neutral is 120 volts. Voltage from one of the phase conductors to the neutral is 208 volts. This phase conductor is called the phase with the higher voltage to ground in *110.15*, *230.56*, and *408.3(E)*. In *408.3(E)*, the phase conductor with the higher voltage to ground is required to be the B-phase, which is required to be the center conductor in a disconnect or panelboard. There is an exception in the case of some metering equipment. The phase conductor with the higher voltage to ground is not intended to be combined with the neutral because the voltage is 208 instead of 120. Single-phase and 3-phase loads are permitted to be served from the same panel, but this must be done with care to keep the loads balanced on the phase conductors and the neutral conductor.

Any 3-phase delta electrical system can be operated with only two transformers. This is called an open delta system. If the electrical system of Figure 5.16 was operated as an open delta electrical system, the transformer between the B-phase and the A-phase or the transformer between the B-phase and the C-phase would be missing. The voltages delivered by this open delta electrical system should be the same as for the full delta 3-phase system. There may be a slight voltage variation between phase conductors.

Three-phase power may be supplied using a 4-wire wye electrical system. Figure 5.17 shows a 208/120-volt, 3-phase wye electrical system. A 480/277-volt, 4-wire wye, 3-phase system is also available. The voltage from any one of the ungrounded phase conductors to the neutral is the same with this system.

It is possible to install the neutral-to-phase circuits to balance the neutral-to-phase loads on the three transformers. This is frequently done using multiwire branch-circuits with one neutral common to three circuit conductors. Motors normally designed for 240-volt operation must not be connected to a 208/120-volt wye system unless marked on the nameplate as suitable for operation at 208 volts. Motors rated at 200 to 240 volts are available. With this system, equipment must be specified with 208-volt motors. The 3-phase, 4-wire, 480/277-volt wye electrical system is used commonly for industrial and commercial applications. Motors are powered using 3-phase, 480-volt circuits, and single-phase electric discharge lighting circuits are operated at 277 volts.

High-Impedance Grounding

High-impedance (high-resistance) grounding is permitted for some applications at 480 volts up to 1000 volts and where qualified maintenance staff are always on duty to immediately investigate ground faults *250.36*. This type of electrical system is carefully engineered for each application. It provides an alternative to the ungrounded 480- and 600-volt electrical system. The typical application is for industrial processes and similar situations where orderly shutdown is necessary. If a ground-fault occurs somewhere

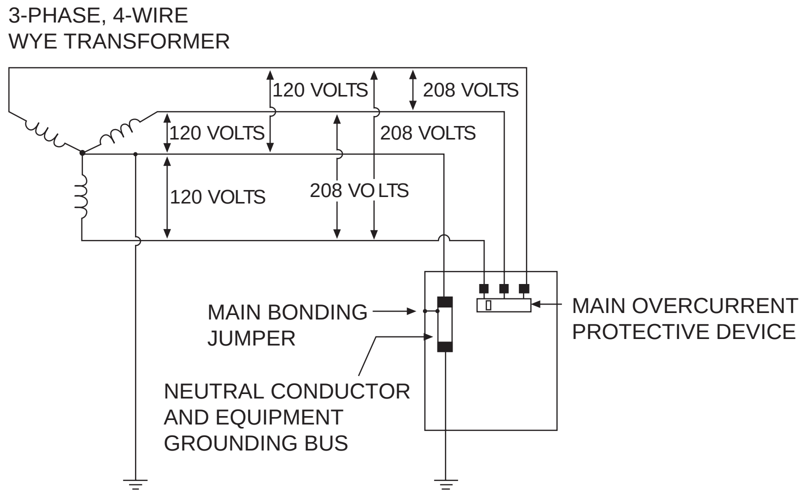


Figure 5.17 A 208/120-volt, 4-wire, 3-phase wye electrical system, common for commercial buildings, provides single-phase power at 120 and 208 volts and three-phase power at 208 volts. The wye electrical system can also operate at 480/277 volts.

on the system, it may not be desirable to allow that circuit or feeder to immediately shut down. On an ungrounded or high-resistance grounded system, a signal indicates that a ground fault has occurred on a particular phase, and the maintenance personnel immediately find the fault and assess the seriousness of the condition. To make repairs, usually a controlled shutdown can be accomplished. Sometimes repairs can be made without shutting down the system. The resistor installed in series with the equipment grounding conductor limits the value of fault current to a level that an overcurrent device will not open, but the fault condition will be indicated. A high-impedance grounded electrical system is shown in Figure 5.18. These systems are not permitted to supply line-to-neutral loads.

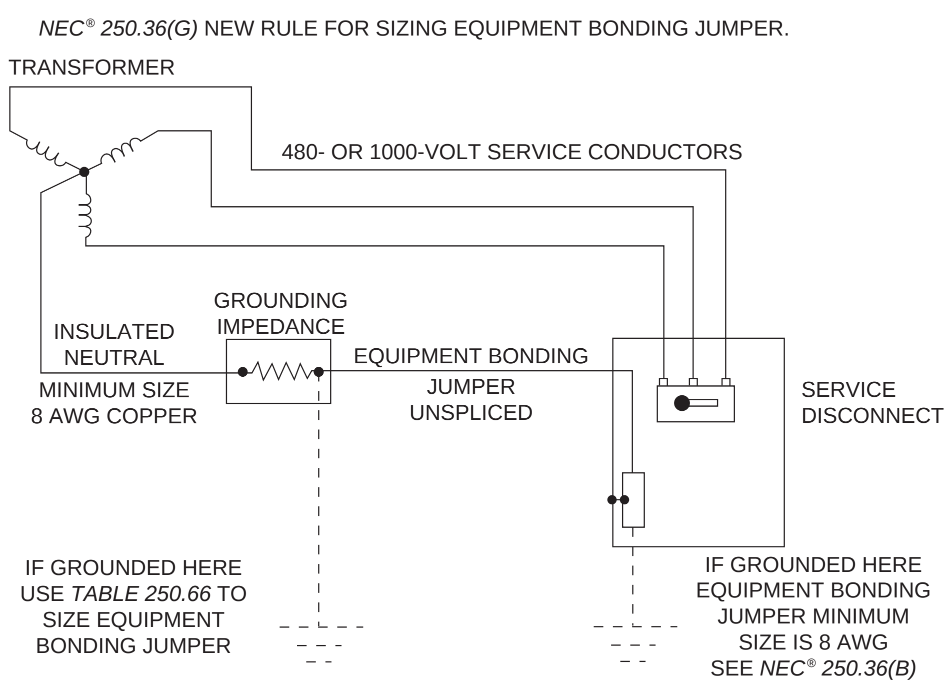


Figure 5.18 A high-impedance grounded 480-volt or 1000-volt wye electrical system has a resistance installed between the grounding electrode conductor connection and the neutral point of the supply transformer that limits the ground-fault current to a level that will sound a trouble alarm, but will not cause an overcurrent device to open.

With this type of system, the neutral conductors and the equipment grounding conductors are separated, and a resistor is connected between the neutral bus and the equipment grounding bus. Specifications for installing a high-impedance grounded electrical system are found in *250.36*.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 250 **Grounding and Bonding**

250.4(A)(1) FPN: This section relates to the installation of the grounding electrode conductor from the main disconnecting means to the grounding electrode. This is a new fine-print note that points out the importance of keeping the conductor as short as practical and avoiding unnecessary bends in the grounding electrode conductor. Unnecessary loops and bends in the conductor can reduce the effectiveness of the grounding electrode conductor at times when it is called upon to limit the voltage to ground that can be imposed on a grounding system by an event such as conducting a lightning surge to earth.

250.8(A)(5) & (6): This section specifies methods permitted and not permitted for terminating equipment grounding conductors. At issue in the past was the use of screws such as sheet metal screws and drywall screws for attaching terminals to enclosures. A machine screw in a threaded hole or one that is self-tapping is permitted, provided there are not less than two threads of contact between the screw and the box or enclosure. It also specifically states that a screw and nut is permitted as a means of terminating an equipment grounding conductor. Several acceptable methods of terminating an equipment grounding conductor with the use of sheet metal screws are illustrated in Figure 5.19.

250.20(D): There is actually no change of intent with this section, but there were some significant language changes to make the section clear. A separately derived system that provides power as described in paragraphs (A) or (B) of this section is required to be grounded. The same piece of electrical equipment used in one situation can be ruled a separately derived system, and in another case it is not ruled as a separately derived system. The rewording of the section deals with how to make that determination. Consider the case of a single-phase generator producing 120/240 volt power with three wires, one of which is the neutral. If all three wires, including the neutral, are switched, such as through a 3-pole circuit breaker, then there is no solid connection between the neutral of the generator and the neutral of the premises system supplied. In this case, the generator is ruled a separately derived system and must be provided with a grounding electrode because it is possible to operate the generator when it is disconnected from the premises wiring and also disconnected from a grounding electrode. If only the ungrounded wires pass through the circuit breaker and the neutral of the generator is solidly connected to the neutral of the premises wiring, then even when the circuit breaker is opened and the generator is operating, it is still connected to a grounding electrode. This is the point made by the rewording and a new *Exception 1*.

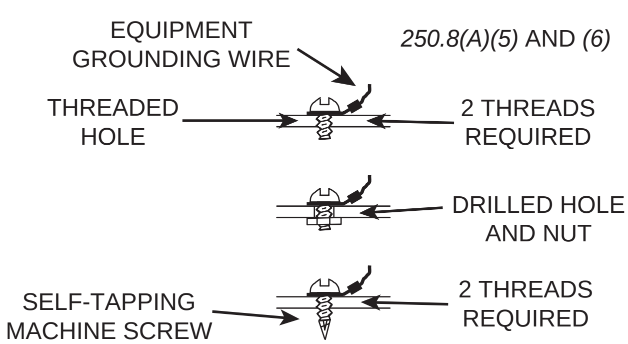


Figure 5.19 A grounding conductor or bonding jumper is permitted to be terminated with a bolt and nut to a metal enclosure or with a threaded screw or self-tapping machine screw if there are not less than two threads of contact with the enclosure.

250.28(D)(2): This section specifies the minimum size of the main bonding jumper to be installed at the service disconnecting means. The previous edition of the Code made reference to the service as though it consisted of only one enclosure. It was not clear how to deal with installation of the main bonding jumper if there was more than one enclosure. This new paragraph (2) requires that a main bonding jumper be installed at each service disconnect enclosure, based upon the largest size ungrounded conductor supplying that enclosure.

250.28(D)(3): This is a new paragraph that specifies the minimum size of system bonding jumper to be installed at each disconnect supplied from a separately derived system. Multiple feeders are permitted from the separately derived system to single enclosures with a single overcurrent device or single set of fuses. Sizing the system bonding jumper for these enclosures was clear, but it was not clear that an alternative was the installation of a single-system bonding jumper at the separately derived system that would take the place of individual bonding jumpers at each disconnect. It is now made clear that this single-system bonding jumper at the separately derived system is to be based upon the sum of the cross-sectional areas of the largest ungrounded conductor for the feeders to each disconnect supplied.

250.30(A)(4): This section provides rules for grounding a separately derived system to a common grounding electrode conductor. A system bonding jumper is required, and the change in this section is the added sentence that specifies that the connection for the grounding electrode is to be made at the same location as the system bonding jumper. Without this added sentence, it was permissible to install the system bonding jumper at the first overcurrent device and the grounding electrode connection at the separately derived system or vice versa. Now both must be at the same location.

250.32(B): This section deals with supply of electrical power to a building or structure on a single property from another building or structure. The previous edition of the Code permitted the grounded conductor (neutral) to act also as the equipment grounding conductor for the second building or structure, provided there were no alternate paths created for neutral current. Now this procedure is only permitted for an existing building or structure. Essentially, what this means is that for newly constructed buildings or structures it is required to supply them with a separate equipment grounding conductor and a separate neutral. This is illustrated in Figure 5.5. The neutral at the building or structure supplied is not permitted to be connected to the equipment grounding conductor or to a grounding electrode.

250.35: This is a new section dealing with the bonding of a permanently installed generator that is not considered to be a separately derived system. In paragraph (A) the rules of *250.30* apply if the generator is considered to be a separately derived system. Generally, the generator is not considered a separately derived system since the neutral conductor of the generator is solidly connected to the neutral of a premises wiring system. In this case, paragraph *(B)* provides the rules for installing and sizing an equipment bonding jumper between the disconnecting means supplied by the generator and the generator overcurrent device. This is illustrated in Figure 5.20. Generally, the disconnecting means will be

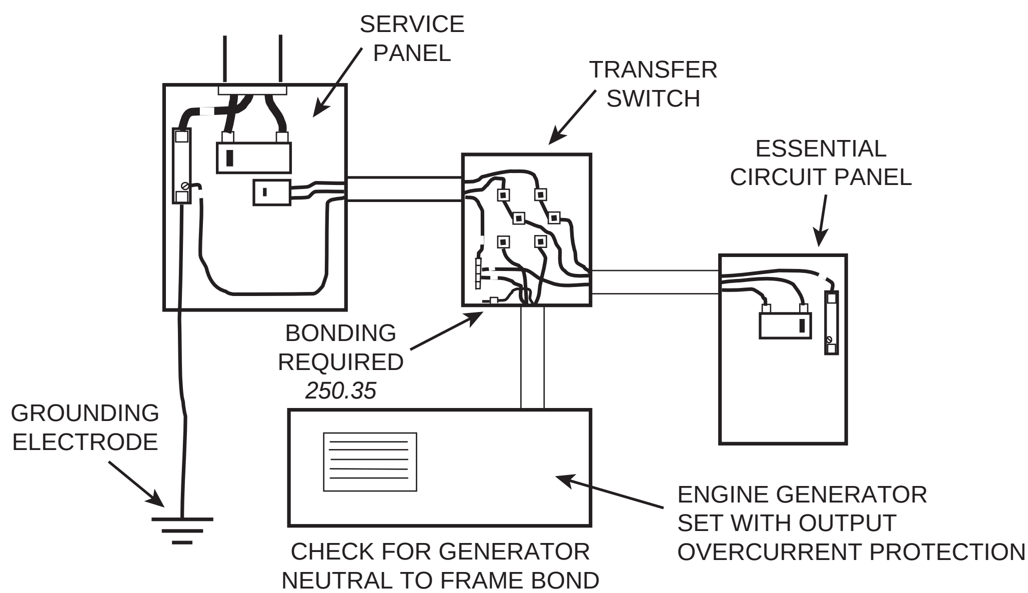


Figure 5.20 For a generator that is not installed as a separately derived system (neutrals solidly bonded), a bonding jumper is required to be installed from the disconnecting means to the generator where the overcurrent device is at the generator.

a manual or automatic transfer switch connected into the premises wiring. The size of the equipment bonding jumper is determined using the rules of *250.102(D)* which specifies the minimum size to be based upon the overcurrent device using *Table 250.122*.

If the generator manufacturer has bonded the neutral conductor of the generator to the generator frame, then that bond will need to be removed, or this bonding jumper will act as a parallel path of the neutral. In cases where the generator manufacturer has bonded the neutral to the generator frame, the neutral conductor acts as the main bonding jumper between the generator and the transfer switch enclosure. It is also important to make sure there is adequate bonding between the transfer switch enclosure and the service equipment grounding bus since the service grounding electrodes are also acting as the grounding electrodes for the permanently installed generator.

250.52(A)(1) Exception: This exception permits the connection of the service grounding electrode conductor to the underground metal water piping system to be located more than 5 ft (1.5 m) from the point at which the water pipe enters the building if certain criteria are met. This exception applied in the case of industrial and commercial buildings and structures. Now it also applies to institutional facilities, although the term institutional is not defined. Many contractors, inspectors, and engineers in the past considered institutional facilities to be included as a part of the commercial category.

250.52(A)(2)(2): This paragraph describes acceptable methods of grounding the metal frame of a building to the earth. The previous edition of the Code apparently inadvertently permitted the metal frame of a building to be considered grounded if it was bonded to a metal underground water pipe. Since a metal underground water piping system used as a grounding electrode is required to be supplemented by another grounding electrode, simple attachment to the metal building frame does not necessarily meet that requirement. Reference to attachment to a metal water pipe as a means of connecting a metal building frame to the earth was deleted.

250.52(A)(3): A new sentence was added to this paragraph that requires a concrete-encased electrode to be bonded as a part of the grounding electrode system. The new sentence makes it clear that only one such concrete-encased electrode is required to be bonded to the grounding electrode system and not all sections of a multisectional installation of reinforcing bars.

250.52(A)(6): This is a new item to the list of acceptable grounding electrodes. This new listing simply states that other listed grounding electrodes, whatever they may be, are acceptable.

250.64(D): This section deals with the installation of the grounding electrode conductors when there are multiple disconnecting means grouped in separate enclosures. There are two new paragraphs (2) and (3) that repeat requirements that are covered in paragraph (1). The new information that is in paragraph (2) is that it states the grounding electrode tap conductor is to be connected between the grounded conductor supplying the disconnect and the grounding electrode system. Paragraph (1) states the connection is directly to the common grounding electrode conductor. Paragraph (3) requires the common grounding electrode conductor to be connected to the grounded service conductors (neutral) on the supply side of the disconnects and in a service wireway or other enclosure. All connections are to be by means of exothermic welding or with connectors listed for grounding and bonding.

250.80: This section requires the grounding of metal service raceways and enclosures. The previous edition of the Code simply stated they were to be grounded. The change is that now it specifically states to what they are to be grounded, the grounded system conductor or to the grounding electrode conductor if it is an ungrounded system. This new language can be a problem if the direct connection to the conductor is taken literally.

250.94: The providing of a means for other systems to be easily connected to the service grounding electrode system by other electrical systems such as communications and CATV is covered by this section. The previous edition of the Code required that a grounding wire be run outside of service enclosures long enough to connect to other system grounding if the grounding electrode conductor or metal service raceway was not available for this connection. A means external to all service enclosures is required for connection to the grounding of these other systems. Now those methods of providing intersystem bonding are only permitted for existing buildings. For new construction, it is required that a set of terminals, listed for grounding and bonding, be mounted to the meter enclosure, and that a bonding bar be installed adjacent to either the service equipment enclosure, the meter enclosure, or the grounding electrode conductor. One method of providing for intersystem grounding is shown in Figure 5.21. There are no requirements provided for this bonding bar, but something similar to that described in *250.64(F)(1)* would be sufficient. If a bonding bar is provided, it is to be connected to the equipment grounding conductor in the service equipment by a conductor not smaller than 6 AWG copper. The intersystem bonding means is required to be installed in such a manner that it not interfere with the

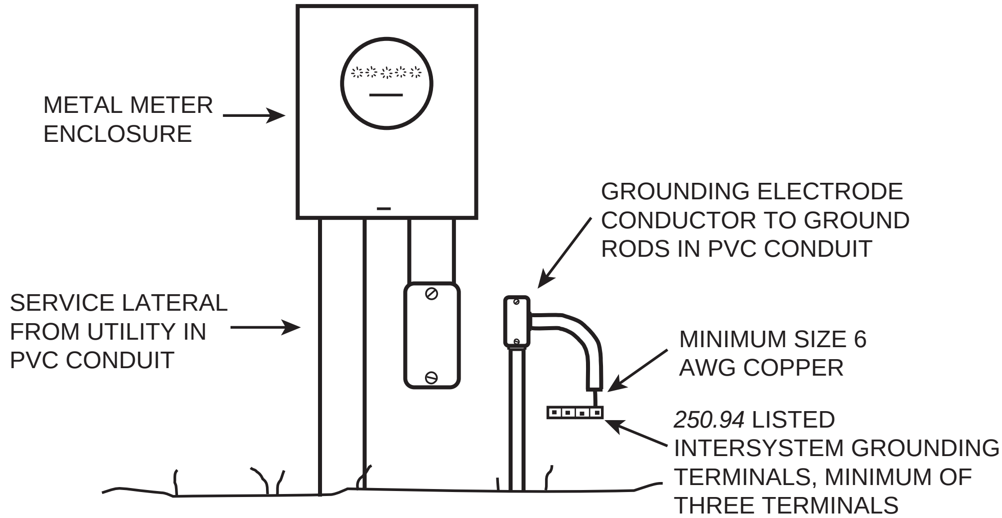


Figure 5.21 A listed intersystem bonding terminal that will accept not less than three grounding conductors is required to be installed at each service entrance.

opening of any service equipment enclosure. It is also required to be capable of accepting not fewer than three bonding conductors.

250.119 Exception: This section requires the insulation or covering on equipment grounding conductors to be bare, green, or green with yellow stripes. This section also prohibits conductors identified in this manner from being used as current-carrying conductors. This new exception recognizes that for power-limited, Class 2, or Class 3 circuits that operate at less than 50 volts, a wire with green insulation or green with yellow stripes is permitted to be used as a current-carrying conductor.

250.119(A)(2): When a conductor size 4 AWG and larger with insulation other than green is used as an equipment grounding conductor, the entire exposed length of insulation was required to be removed or covered green. Now the conductor is only required to be covered with green at the terminations.

250.122(D)(1): There is now a definitive statement of how to size the equipment grounding conductor for a motor. The previous edition of the Code only applied to instantaneous trip circuit breakers protecting motors. The equipment grounding conductor for a motor circuit is to be not smaller than the size determined from *Table 250.122* using the rating of the branch-circuit short-circuit and ground-fault protective device. The equipment grounding conductor is, however, never required to be sized larger than the largest circuit conductor.

250.122(D)(2): The method used to determine the size of the equipment grounding conductor for a motor protected with an instantaneous trip circuit breaker was changed. The previous edition of the Code permitted the wire size to be based on the rating of the overload protective device. Now it is required to be sized not smaller than determined from *Table 250.122* using the value of a time-delay fuse as the branch-circuit short-circuit and ground-fault protective device.

250.146(A): Now, under certain conditions, a raised-cover–mounted receptacle is permitted to be grounded through the raised cover rather than requiring a bonding wire to be run from the grounding terminal of the receptacle to the metal box.

Article 280 Surge Arresters, Over 1 kV

280.1: The scope states the major change, which is that this article only applies to surge arresters installed on electrical systems operating at over 1000 volts. All references to surge arresters that are installed on electrical systems operating at 1000 volts and less were deleted from this article and moved to *Article 285.*

280.2: This is a new section stating that surge arresters are not to be installed where the maximum continuous power frequency voltage exceeds the rating of the surge arrester. This is the peak voltage of the wave form, which for a sine wave is 41% higher than the rms voltage.

280.5: Surge arresters are now required to be listed.

280.21: This is a section that now applies to surge arresters installed on systems operating at over 1000 volts. It specifically states to what point the surge arrester grounding conductor is to be connected.

Article 285 Surge-Protective Devices (SPDs), 1 kV or Less

285.1: The scope now states that Surge-Protective Devices are to be installed only on systems operating at 1000 volts and less. An SPD includes a transient voltage surge suppressor and a surge arrester rated for a maximum of 1000 volts. This article now applies to three different types of SPDs.

285.23: The Type 1 SPD is actually a surge arrester that is permitted to be installed on an electrical system where there is a maximum of 1000 volts. The rules for installation are essentially the same as covered in *Article 280* of the previous edition of the Code. A Type 1 SPD is permitted to be installed on the supply side of the service overcurrent protective device.

285.24: A Type 2 SPD is actually a transient voltage surge suppressor that is required to be installed on the load side of the service overcurrent device. Paragraph *(B)* is new, and it deals with the situation where a feeder supplies power to another building or structure. The Type 2 SPD is required to be installed on the load side of the main overcurrent protective device for that building or structure. In the case where there is no single overcurrent protective device or set of fuses, the Type 2 SPD is required to be installed on the load side of a branch circuit overcurrent device.

285.25: A Type 3 SPD is intended to protect individual equipment or systems on a branch circuit. There is a new requirement that the Type 3 SPD is permitted to be installed anywhere on a branch circuit from the overcurrent device up to the equipment. There is an additional restriction that the Type 3 SPD is not permitted to be located on a branch circuit where it is less than 30 ft (10 m) from the service panel or a separately derived system.

Article 680 Swimming Pools, Fountains, and Similar Installations

680.2: The word immersion was added to the definition of a permanent pool and a storable pool to make it clear that such vessels used for the purposes of baptisms must also meet the appropriate rules with respect to electrical equipment associated with or located in the area.

680.7: It is now made clear that when reference is made to the connection of fixed or permanently installed equipment being permitted to be cord connected, it also means that it is permitted to be cord and plug connected.

680.12: The maintenance disconnecting means installed for pool-associated equipment was specified to be located within sight of the equipment, but no mention was made as to any distance from the edge of the pool. Now the disconnecting means is to be located not closer than 5 ft (1.5 m) horizontally from the edge of a pool, spa, or hot tub, unless separated by a barrier such as a wall.

680.22(A)(1): A receptacle for a water circulation pump or other equipment associated with the water circulation system was permitted to be located not less than 5 ft (1.5 m) from the inside edge of the pool if certain criteria were met. That distance has now been increased to 6 ft (1.83 m).

680.22(A)(2): This section applies in the general case to all permanent pool installations, and now receptacles are permitted to be located as close as 6 ft (1.83 m) from the inside edge of a pool. The previous edition of the Code required a minimum distance of 10 ft (3 m).

680.22(A)(3): This section applies to permanent pool installations at a dwelling. At least one 125-volt, 15- or 20-ampere receptacle is required to be installed not more than 20 ft (6 m) from the inside edge of the pool and not closer than 6 ft (1.83 m). The previous edition of the Code required a receptacle to be located at least 10 ft (3 m) and not closer than 5 ft (1.5 m) in cases where it was not practical to locate the receptacle further away. The real change is that in all cases the receptacle is permitted to be located as close as 6 ft (1.83 m) from the inside edge of the pool. This is illustrated in Figure 5.22. It is no longer permitted to locate a receptacle 5 ft (1.5 m) from the inside edge of the pool.

680.22(B): This is a new section that requires GFCI protection on all pool pump motor circuits rated 125- or 240-volts, single-phase, and either 15- or 20-ampere, whether cord and plug connected or hardwired. The previous edition of the Code only required GFCI protection where the circulation pump motor was cord and plug connected.

680.22(E): Other outlets such as communications circuits, remote-control, signaling, or fire alarm circuits are required to be located not closer than 10 ft (3 m) from the inside edge of the pool. The previous edition of the Code did not provide a minimum spacing from the pool for these types of outlets.

680.23(A)(6): A luminaire (lighting fixture) mounted in a face-up position in the bottom of a permanent swimming pool is now permitted to be installed without a guard to prevent contact by swimmers, provided it is listed to be mounted without a guard.

680.23(B)(6): This section requires wet-niche luminaires to be mounted such that they can be removed from the water for relamping and maintenance. The previous edition of the Code specified that a person

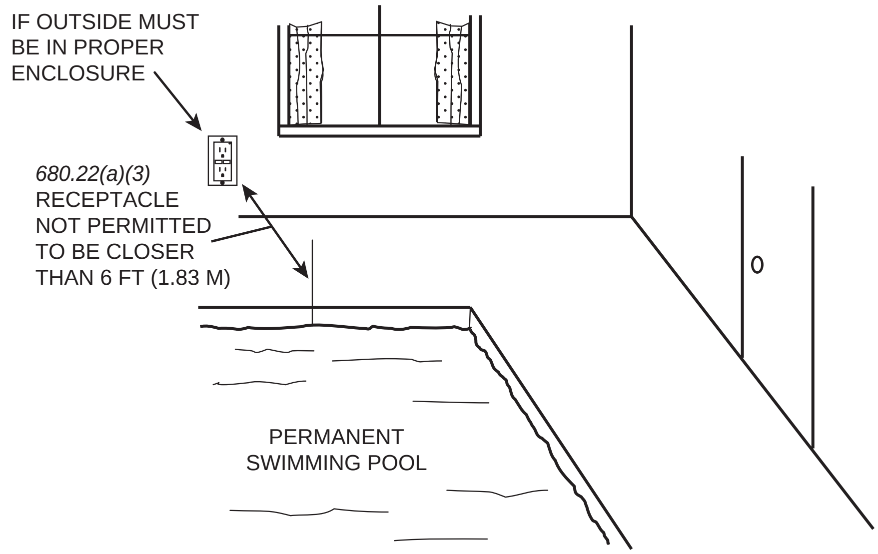


Figure 5.22 A receptacle on a 125-volt, 15- or 20-ampere branch circuit is not permitted to be installed closer than 6 ft (1.83 m) from the inside edge of a permanent swimming pool.

located on the deck must be able to reach and remove the luminaire without going into the water. That is not practical, and now it is permitted to locate the wet-niche luminaire such that a person may be required to go into the water to remove it, but it must have a cord long enough that it can be put on a dry space such as the deck for relamping and maintenance.

680.23(F)(1): This section specifies the branch-circuit wiring supplying wet-niche, no-niche, and dry-niche luminaires installed in permanent swimming pools. There are actually two changes. The first change is that Type AC cable with an insulated equipment grounding conductor is permitted to be installed within the building. The other change is that now the minimum size equipment grounding conductor in all cases for branch circuits supplying luminaires is 12 AWG insulated copper.

680.25(A) If a conduit for a feeder is installed in an area where corrosion is probable, aluminum conduit is not permitted in that area.

680.26: The term equipotential bonding *grid* is not used in this section as was the case in the previous edition of the Code. Reference is made to the process of equipotential bonding, and it is specified what and how electrically conductive elements are to be bonded. The previous edition of the Code listed permitted methods of creating an equipotential bonding grid. Now it is clearly specified that the reinforcing steel is required to be bonded and if the steel is nonconductive that the alternative is to be a copper wire grid with specifications as to how it is to be constructed.

680.26(B)(1): This paragraph specifies that poured concrete, pneumatically applied or sprayed concrete, and concrete block with a painted or plastered coating are considered to be conductive materials and are required to be bonded as a part of the equipotential bonding, and that vinyl pool liners and fiberglass composite shells are considered to be nonconductive materials.

680.26(B)(2): This paragraph specifies that the equipotential bonding is required to extend out from the edge of the pool a minimum of 3 ft (1 m) to include the walkway around the pool. The change is that this equipotential plane is now required under unpaved surfaces as well as paved surfaces. The other change is that the number and location of the bonding connections between this perimeter equipotential plane and the reinforcing steel in the pool shell are specified as a minimum of four (4) locations equally spaced around the pool. If the pool shell is nonconductive, then only one bonding connection is required. These requirements are illustrated in Figure 5.23.

680.26(C): Now it is required to make a deliberate bond to the pool water of a permanent swimming pool if a bond is not made by normal bonding of metal parts that make contact with the water. This bond is to consist of a minimum of 9 in.^{2} (5806 mm^2) of metal in contact with the water. This would be in the form of a metal plate if there are no parts in contact with the water, such as a metal ladder. An example of such a metal plate in the side of a pool under the water line is shown in Figure 5.24.

680.31: In the next section, *680.32*, all electrical equipment used with storable pools is required to be GFCI protected. A new paragraph was added to this section requiring all pumps used in conjunction with

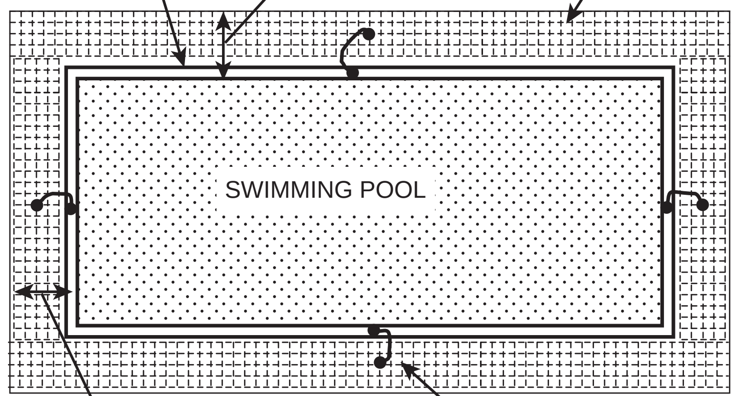


Figure 5.23 Reinforcing steel is required to be installed around a permanent swimming pool out to a minimum distance of 3 ft (1 m) of the inside edge of the pool, whether paved or unpaved and bonded to the pool reinforcing steel at a minimum of four places equally spaced around the pool. For a nonconductive pool liner, the bonding to the metal pool frame is only required at one location.

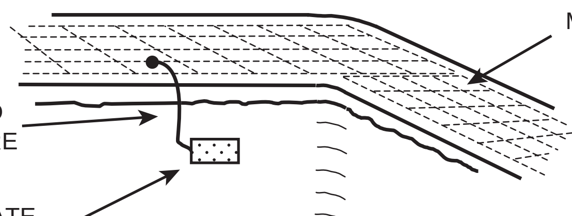


Figure 5.24 In the case of a nonconductive pool liner, if metal is not in contact with the water, such as a ladder, then a metal plate with a minimum area of 9 in.^{2} (5806 mm^2) is required to be in contact with the water and bonded to the reinforcing steel with a copper wire minimum size 8 AWG solid.

storable pools to have integral GFCI protection in the pump attachment cord. With this change, it will not be possible to plug in the pump motor in a location where a GFCI plug is not available.

680.43(A): In the case of a spa or hot tub, it was required that at least one 125-volt, 15- or 20-ampere receptacle be installed on a general-use circuit located not more than 10 ft (3 m) nor closer than 5 ft (1.5 m) from the hot tub or spa. Now a receptacle is required to be installed no closer than 6 ft (1.8 m) from the hot tub or spa. In *680.43(A)(1)* it is required that no receptacle of any voltage be located closer than 6 ft (1.8 m) from the hot tub or spa. The previous minimum distance was 5 ft (1.5 m).

680.43(D)(4) Exception 2: Metal parts associated with a water circulating system of a self-contained spa or hot tub are not required to be bonded separately on site. The bonding is already evaluated as a part of the listing of the equipment.

680.51(C)(2): A luminaire (lighting fixture) installed in a permanent fountain in the face-up position is now permitted to be installed without a guard to prevent contact by persons, provided it is listed for such use.

680.62(E): Now all receptacles installed within 6 ft (1.83 m) of a therapeutic tub are required to be GFCI protected. The previous edition of the Code specified 5 ft (1.5 m).

680.71: There are two changes in this section dealing with GFCI protection of hydromassage bathtubs and associated electrical equipment. One change is that the GFCI is now required to be readily accessible. The other change is that receptacles rated 30 amperes and less and located within 6 ft (1.83 m) of the hydromassage tub are required to be GFCI protected. The previous edition of the Code set 5 ft (.15 m) as the distance.

680.74: This section specifies the bonding for the equipment and metal parts making contact with the circulating water of a hydromassage bathtub. The change is that the bonding conductor must be connected to the bonding terminal provided on the circulating pump motor. If the circulating pump is of the double-insulated type, then it is not necessary to make a bonding connection to the pump motor. It is also pointed out that this bonding conductor is for local equipotential bonding of equipment and is not required to be connected to the grounding bus of any panelboard or run to any grounding electrode.

WORKSHEET NO. 5—BEGINNING GROUNDING AND BONDING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A single-family dwelling has a service with a 100-ampere main circuit breaker and size 2 AWG aluminum ungrounded conductors. A grounding electrode for this service is a ground rod driven so the top is below the surface of the earth and the clamp is listed as suitable for direct burial. As shown in Figure 5.25, the grounding electrode conductor is attached to the outside of the dwelling and through the earth to the ground rod. If the copper grounding electrode conductor is in a location not subject to physical damage, the minimum size permitted for this service is:
   A. 8 AWG. C. 4 AWG. E. 2 AWG.
   B. 6 AWG. D. 3 AWG.

   Code reference ___________________

2. A commercial service entrance with a 200-ampere main circuit breaker has size 3/0 AWG copper ungrounded service conductors. The service is grounded to a metal underground water pipe and a ground rod as the supplemental electrode. The minimum size copper grounding electrode conductor permitted to the metal water pipe is:
   A. 10 AWG. C. 6 AWG. E. 2 AWG.
   B. 8 AWG. D. 4 AWG.

   Code reference ___________________

3. A building is provided with a single-phase, 120/240-volt service with a 200-ampere main circuit breaker and size 4/0 AWG aluminum service conductors. The water pipe entering the building is nonmetallic and the grounding electrode is a 5/8 in.

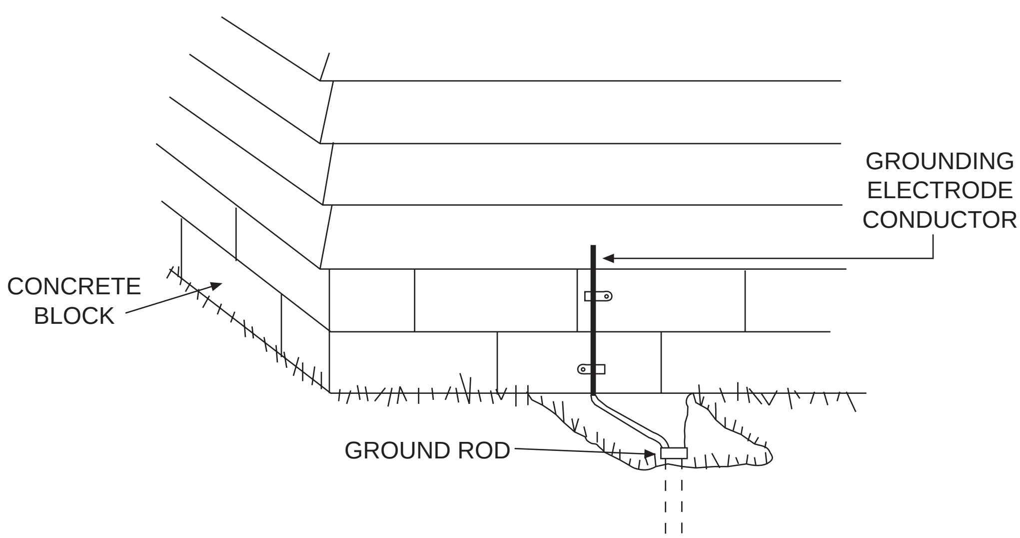


Figure 5.25 Determine the minimum size copper grounding electrode conductor run unprotected on the outside surface of a dwelling for a 100-ampere service entrance.

(15.87 mm) diameter galvanized steel rod driven 8 ft (2.44 m) into the earth. The minimum size copper grounding electrode conductor permitted for this service is:

A. 8 AWG. C. 4 AWG. E. 2 AWG.
B. 6 AWG. D. 3 AWG.

Code reference ___________________

4. A building is supplied water by a metal underground pipe, and the metal frame of the building connected to footing reinforcing steel is considered to be effectively grounded.
   A. Both the metal water pipe and the metal building structure are required to be bonded together and used as the grounding electrode system for the service.
   B. Even if both are used as the grounding electrode, a ground rod is still required to augment the metal water pipe.
   C. A ground rod is permitted to be used in place of either the metal water pipe or the metal building structure.
   D. The metal water pipe or the metal building frame, but not both, are required to serve as the grounding electrode.
   E. Only the metal building frame is required to be used as the grounding electrode.

Code reference ___________________

5. Flexible Metal Conduit trade size 3/4 (21) extends from the controller to a motor terminal housing to allow for ease of installation and maintenance and to provide for limited flexibility as shown in Figure 5.26. The end fittings provide the only support for the Flexible Metal Conduit and they are listed as suitable for equipment grounding but not the Flexible Metal Conduit. The circuit to the motor is protected by 20-ampere rated time-delay fuses. The maximum length of Flexible Metal Conduit permitted for this installation is:
   A. not limited. C. 18 in. (450 mm). E. 6 ft (1.8 m).
   B. 12 in. (300 mm). D. 3 ft (900 mm).

Code reference ___________________

6. An 8 ft (2.5 m) ground rod is installed at a service to augment a metal underground water pipe as the grounding electrode. The ground rod has a resistance of more than 25 ohms, therefore, it will be supplemented by a second 8 ft (2.5 m) ground rod, with

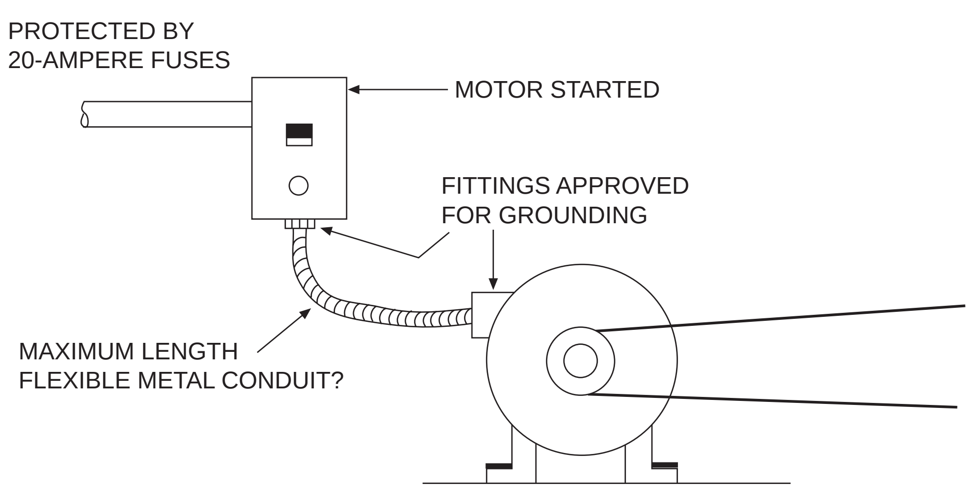


Figure 5.26 Determine the maximum length of Flexible Metal Conduit permitted to be installed between a motor controller and a motor terminal housing and supported only by the end connectors.

the two rods bonded together. These two ground rods shall be spaced a distance from each other of not less than:

A. 6 in. (150 mm).
B. 2 ft (600 mm).
C. 4 ft (1.2 m).
D. 6 ft (1.8 m).
E. 10 ft (3 m).

Code reference ___________________

7. An equipment grounding means *not* permitted is:
   A. Liquidtight Flexible Metal Conduit not smaller than trade size $1^1/_2$ (41).
   B. the metal sheath of Type MC Cable.
   C. Electrical Metallic Tubing.
   D. a bare aluminum wire.
   E. the armor of Type AC cable.

Code reference ___________________

8. A motor control center in a building is fed under the floor in Rigid Nonmetallic Conduit from a disconnect at the main service. The feeder is protected with 200-ampere time-delay fuses, and the ungrounded conductors are size 3/0 AWG copper with THHW insulation as shown in Figure 5.27. The minimum size copper equipment grounding conductor permitted to be run in this conduit for this feeder is:
   A. 8 AWG.
   B. 6 AWG.
   C. 4 AWG.
   D. 3 AWG.
   E. 2 AWG.

Code reference ___________________

9. A conductor that is not bare or does not have green covering or insulation, or green covering or insulation with yellow stripes, is permitted to be re-identified as an equipment grounding conductor. Acceptable methods of re-identifying the conductor are by stripping the covering or insulation from the entire exposed length, coloring the insulation termination green, or marking the insulation termination with green tape or green adhesive labels. This re-identification is only permitted for conductors sizes:
   A. smaller than 4 AWG.
   B. larger than 8 AWG copper and 4 AWG aluminum.
   C. larger than 12 AWG copper and 10 AWG aluminum.
   D. smaller than 8 AWG copper and 6 AWG aluminum.
   E. larger than 6 AWG.

Code reference ___________________

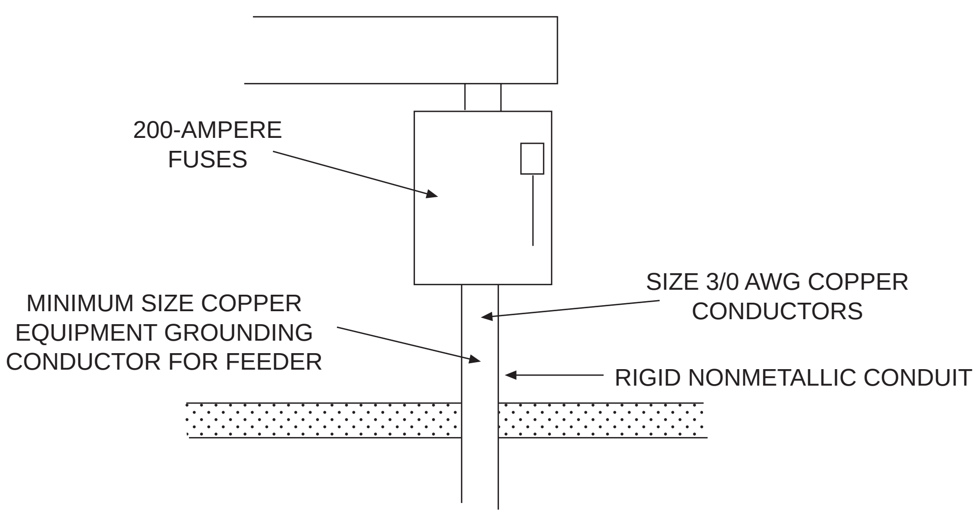


Figure 5.27 Determine the minimum size copper equipment grounding conductor permitted for a 200-ampere rated feeder run in Rigid Nonmetallic Conduit.

10. An ac electrical system not required to be grounded is a:
    - A. 120/240-volt, 3-wire, single-phase system.
    - B. 208Y/120-volt, 4-wire, 3-phase system.
    - C. 480Y/277-volt, 4-wire, 3-phase system serving 277-volt lighting loads.
    - D. 240/120-volt, 4-wire, 3-phase delta system.
    - E. 240-volt, 3-wire, 3-phase delta system.

Code reference ___________________

11. At least one receptacle on a general purpose 125-volt, 15- or 20-ampere branch-circuit is required to be installed at a dwelling not more than 20 ft (6 m) from the inside edge of a permanent swimming pool as shown in Figure 5.28. That receptacle is not permitted to be located closer to the inside edge of the swimming pool than:
    - A. 3 ft (750 mm).
    - B. 4 ft (1.2 m).
    - C. 5 ft (1.5 m).
    - D. 6 ft (1.83 m).
    - E. 10 ft (3 m).

Code reference ___________________

12. Equipotential bonding for a permanent swimming pool is accomplished by connecting together with a bonding conductor all metal parts associated with the pool including the reinforcing steel in the pool floor, walls, and deck. These include metallic parts of the pool structure, forming shells and mounting brackets of luminaires, metal ladders and other metal fixtures attached to the pool, metal equipment associated with the water circulating system, pool covers, and similar metal parts. The conductor used for this bonding is:
    - A. required to be solid copper not smaller than size 8 AWG.
    - B. permitted to be solid aluminum if insulated and not smaller than size 8 AWG.
    - C. required to be insulated copper, stranded, and not smaller than size 8 AWG.
    - D. permitted to be bare, insulated, or covered copper if not smaller than size 6 AWG.
    - E. required to be copper not smaller than size 2 AWG.

Code reference ___________________

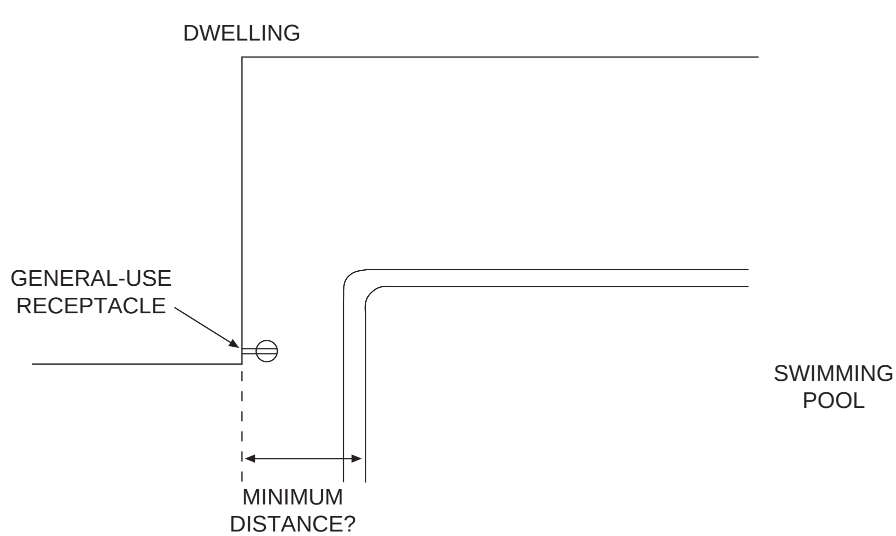


Figure 5.28 Determine the minimum distance a general-use receptacle installed on the side of a dwelling is permitted to be from the inside edge of a permanent swimming pool.

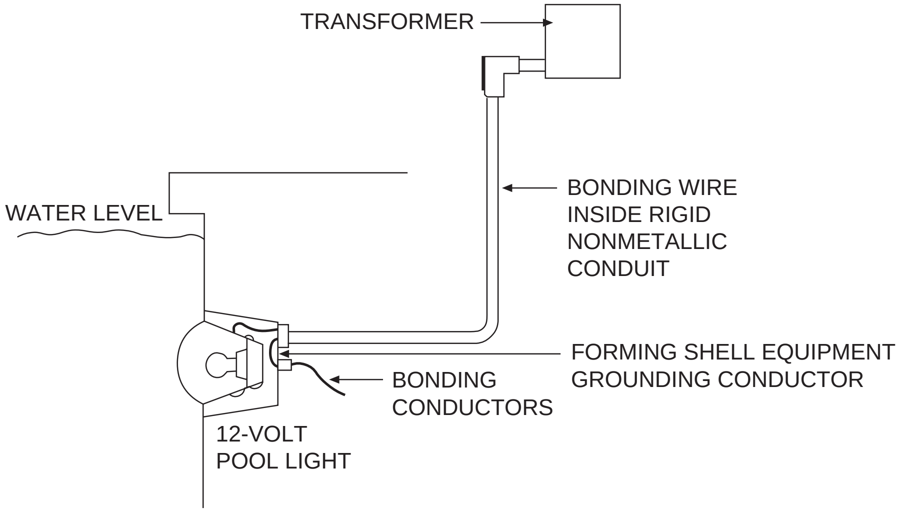


Figure 5.29 The conductors from a transformer enclosure to the forming shell of a wet-niche luminaire (lighting fixture) in a permanent swimming pool are run in Rigid Nonmetallic Conduit.

13. Rigid Nonmetallic Conduit is used to connect the forming shell of a wet-niche, low-voltage swimming pool light to a transformer enclosure as shown in Figure 5.29. This is not a listed low-voltage luminaire (lighting fixture) not requiring grounding. The minimum size copper forming shell equipment grounding conductor permitted to be run inside the conduit to the forming shell is 8 AWG:
    A. insulated solid only.
    B. insulated stranded only.
    C. insulated solid or stranded.
    D. bare, insulated, covered, and solid or stranded.
    E. bare solid or stranded.

Code reference ___________________

14. A Type 1 Surge-Protective Device is:
    A. only permitted to be installed outside of a building.
    B. only permitted to be installed inside of a building.
    C. permitted to be installed inside or outside of a building and on the supply side of the service overcurrent device.
    D. only permitted to be installed by a utility worker with training in high-voltage installations.
    E. installed between an ungrounded conductor of the electrical system and a lightning rod.

Code reference ___________________

15. A Nonmetallic-Sheathed Cable, Type NM-B, enters a metallic device box containing a duplex receptacle that has a device to maintain continuity between the mounting screw and the metal device yoke. There is also a grounding screw in the box. The equipment grounding conductor in the supply cable is:
    A. required to be terminated to the grounding screw on the duplex receptacle.
    B. required to be terminated both to the grounding screw on the duplex receptacle and the grounding screw of the box.
    C. permitted to be terminated to either the grounding screw of the duplex receptacle or the grounding screw of the box.
    D. not required to be terminated in the box if grounded metal objects or masonry surfaces are located not closer than 6 ft (1.8 m) from the box.
    E. required to be terminated to the grounding screw of the box.

Code reference ___________________

WORKSHEET NO. 5—ADVANCED GROUNDING AND BONDING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A 480Y/277-volt service entrance with a 400-ampere main circuit breaker and size 500-kcmil copper ungrounded service conductors is shown in Figure 5.30. A metal underground water pipe entering the building is used as a grounding electrode for the service. The minimum size of a copper grounding electrode conductor permitted to be run to the water pipe is:
   A. 3 AWG.
   B. 2 AWG.
   C. 1 AWG.
   D. 1/0 AWG.
   E. 2/0 AWG.

   Code reference ___________________

2. A commercial building service is 208Y/120-volt, 3-phase, 4-wire wye with a 400-ampere rated main circuit breaker, and size 500-kcmil copper ungrounded conductors. Galvanized steel, 1/2 in. (13 mm) diameter reinforcing bars, a minimum of 20 ft (6 m) long, are installed in the bottom of the foundation which has direct contact with earth. The minimum size copper grounding electrode conductor permitted to be run to the reinforcing bars is size:
   A. 4 AWG.
   B. 2 AWG.
   C. 1 AWG.
   D. 1/0 AWG.
   E. 2/0 AWG.

   Code reference ___________________

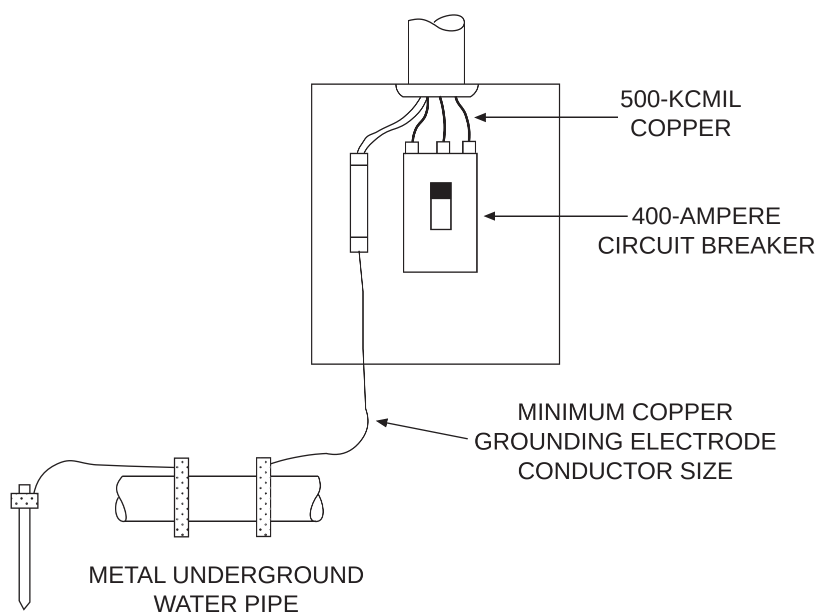


Figure 5.30 Determine the minimum size copper grounding electrode conductor to a metal underground water pipe for a service consisting of a 400-ampere main circuit breaker supplied with size 500-kcmil copper conductors.

3. An aluminum conductor is permitted to be used as a grounding electrode conductor:
   A. as a bare conductor in dry locations and shall be insulated when in direct contact with masonry or the earth.
   B. the same as a copper conductor if it is copper-clad aluminum.
   C. as an insulated conductor run on a masonry surface but not terminated within 18 in. (450 mm) of the earth when run outside a building.
   D. except within 18 in. (450 mm) of the earth either inside or outside a building.
   E. except when in direct contact with masonry or outside within 18 in. (450 mm) of the earth.

   Code reference ___________________

4. Two parallel sets of size 350-kcmil copper conductors are run to a panelboard from the service equipment through two Rigid Nonmetallic Conduits with one set of the parallel conductors in each conduit as shown in Figure 5.31. The feeder to the panelboard is protected with 600-ampere fuses located in the service panel. A copper equipment grounding conductor is routed in each conduit with each set of parallel conductors. The minimum size equipment grounding conductor permitted to be run in each conduit is:
   A. 4 AWG.　　C. 1 AWG.　　E. 2/0 AWG.
   B. 2 AWG.　　D. 1/0 AWG.

   Code reference ___________________

5. Two separate circuits are run in the same nonmetallic conduit. One circuit consists of size 8 AWG copper insulated conductors protected at 50 amperes, and the other circuit run with size 3 copper conductors protected at 100 amperes. One copper equipment grounding conductor is run in this conduit to serve both circuits. The minimum size equipment grounding conductor permitted is:
   A. 10 AWG.　　C. 6 AWG.　　E. 3 AWG.
   B. 8 AWG.　　D. 4 AWG.

   Code reference ___________________

6. A 480-volt delta service entrance has two parallel sets of size 900-kcmil copper Type THWN ungrounded service conductors with each set in a separate service conduit as shown in Figure 5.32. The metal water line is used as a grounding electrode and is

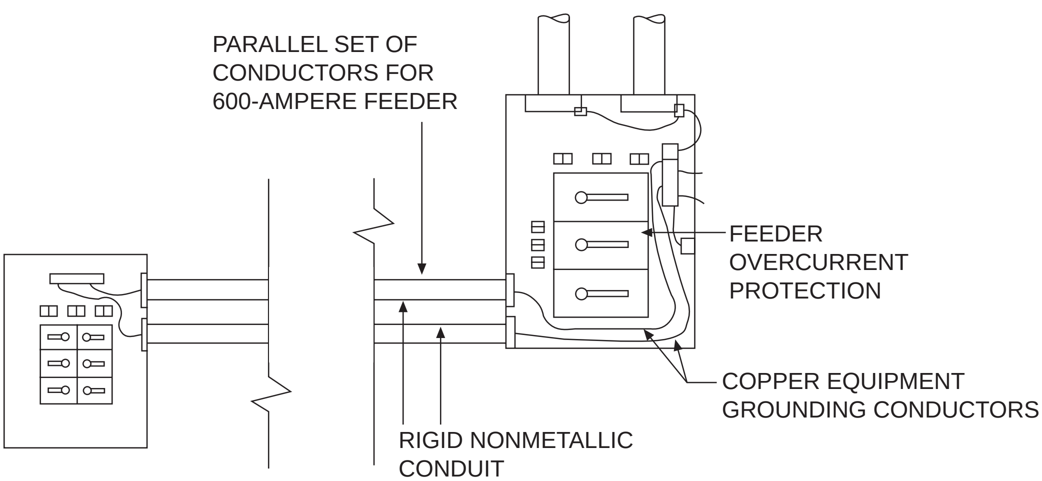


Figure 5.31 Determine the minimum size copper equipment grounding conductor permitted to be run in each conduit where a feeder protected with 600-ampere fuses is run as two parallel sets of conductors in Rigid Nonmetallic Conduit.

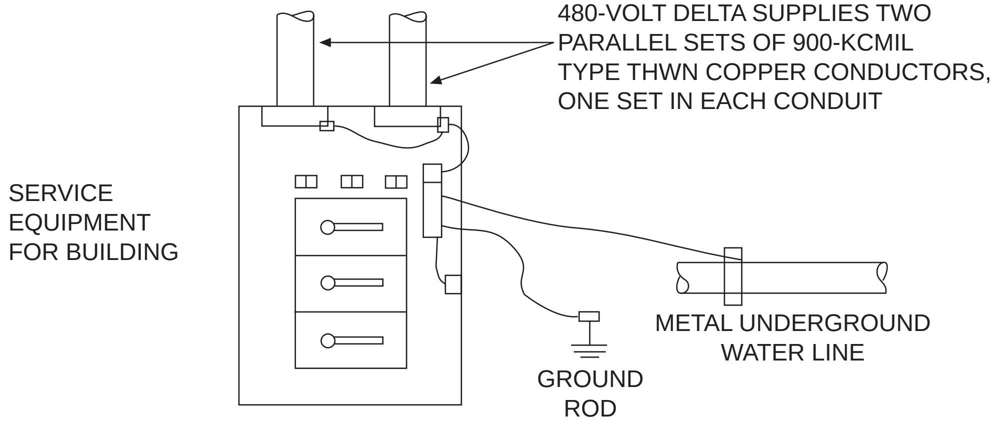


Figure 5.32 Determine the minimum size grounding electrode conductor to a metal water pipe for a service entrance consisting of two parallel sets of copper size 900-kcmil conductors.

supplemented with a driven ground rod. The copper grounding electrode conductor to the ground rods is size 6 AWG. The copper main bonding jumper to the service enclosure is size 250 kcmil, and the copper bonding jumper to the metal service conduits is size 2/0 AWG. The minimum permitted size of copper grounding electrode conductor to the metal water pipe is:

A. 1/0 AWG.
B. 2/0 AWG.
C. 3/0 AWG.
D. 4/0 AWG.
E. 250 kcmil.

Code reference ___________________

7. Two panelboards rated as suitable for use as service equipment make up a service for a building as shown in Figure 5.33. One panelboard has a 200-ampere main circuit breaker and the other has a 100-ampere main circuit breaker. The ungrounded service conductors are size 350-kcmil copper. Ungrounded tap conductors to the 200-ampere panelboard are size 3/0 AWG copper and to the 100-ampere panelboard are size

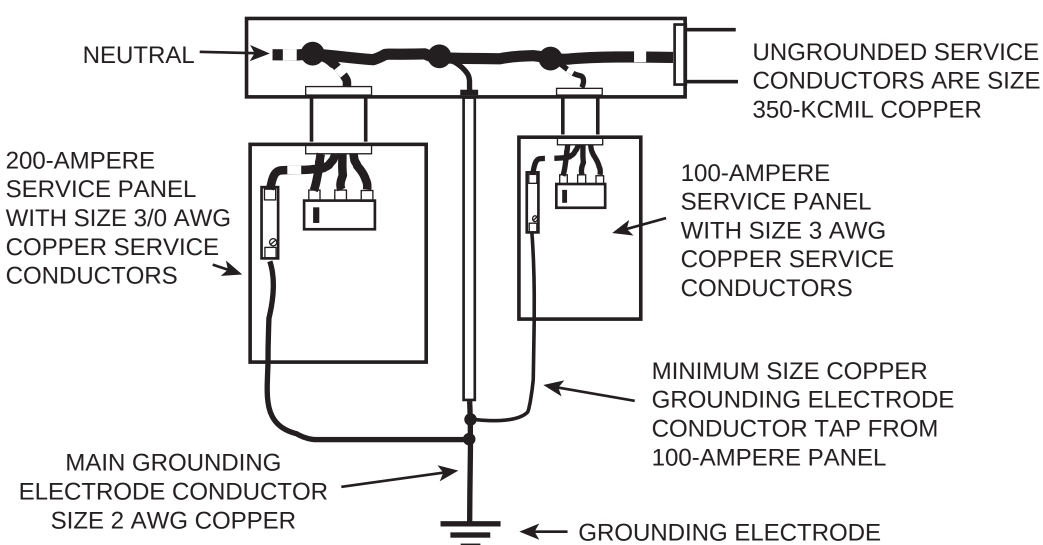


Figure 5.33 Determine the minimum size grounding electrode conductor tap from the 100-ampere panelboard grounded conductor termination point to the main grounding electrode conductor.

3 AWG copper. The grounded circuit conductor is run to each service enclosure. The grounding electrode conductor is run from the neutral in the wireway to the grounding electrode. Grounding electrode conductor taps are run from the grounding bus in the 100-ampere panelboards to the grounding electrode conductor. The minimum permitted size grounding electrode conductor tap for the 100-ampere panelboard is:

A. 8 AWG.
B. 6 AWG.
C. 4 AWG.
D. 3 AWG.
E. 2 AWG.

Code reference ___________________

8. The copper Type THWN conductors for a 480-volt, 3-phase feeder protected by 150-ampere fuses is increased from a size 1/0 AWG to a size 3/0 AWG to compensate for voltage drop. If the feeder is run in Rigid Nonmetallic Conduit, the minimum size copper equipment grounding conductor permitted to be run for this feeder is:

A. 8 AWG.
B. 6 AWG.
C. 4 AWG.
D. 3 AWG.
E. 2 AWG.

Code reference ___________________

9. One building on the same property is supplied 120/240-volt, single-phase power from another building as shown in Figure 5.34. There is no metallic water pipe or other metal equipment connecting the buildings. The second existing building is supplied from a 3-wire feeder with two ungrounded conductors and a neutral. The neutral conductor is:

A. required to be bonded to the disconnect enclosure in the second existing building and connected to a grounding electrode.
B. not permitted to be bonded to the disconnect enclosure or connected to a grounding electrode in the second building.
C. only permitted to be connected to a grounding electrode at the supply end of the feeder in the first building.
D. only permitted to be connected to a grounding electrode at the second building.
E. not permitted to be connected to a grounding electrode at either building.

Code reference ___________________

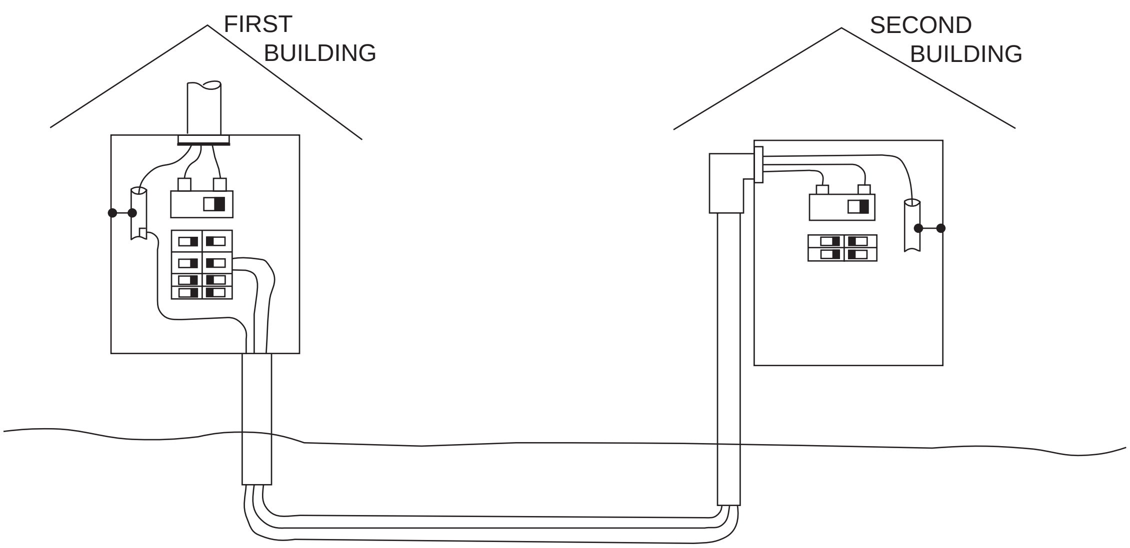


Figure 5.34 Electrical power in one existing building is supplied from another building on the same property with a 120/240-volt, 3-wire, single-phase feeder consisting of two ungrounded conductors and a neutral conductor.

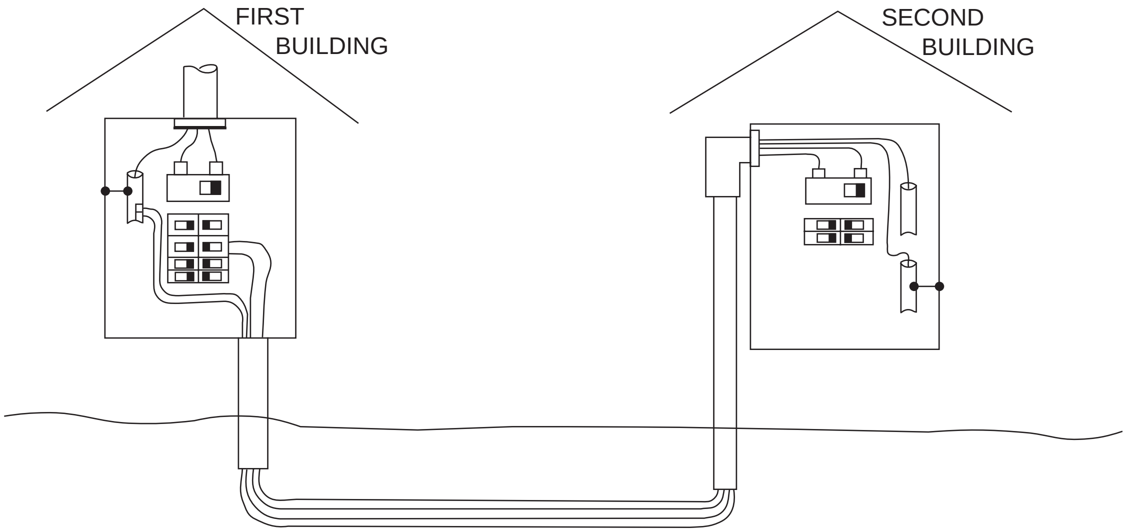


Figure 5.35 Electrical power in one building is supplied from another building on the same property with a 120/240-volt, 3-wire, single-phase feeder consisting of two ungrounded conductors, a neutral conductor, and a separate equipment grounding conductor.

10. One building on the same property is supplied 120/240-volt single-phase power from another building. The second building is supplied from a 4-wire feeder with two ungrounded conductors, a neutral conductor, and an equipment grounding conductor as shown in Figure 5.35. The neutral conductor at the second building is:
    A. not permitted to be connected to a grounding electrode at either building.
    B. required to be bonded to the equipment grounding conductor at the load end in the second building.
    C. required to be bonded to the disconnect enclosure in the second building and connected to a grounding electrode.
    D. only permitted to be connected to a grounding electrode at the second building.
    E. only permitted to be connected to a grounding electrode and bonded to the disconnect enclosure at the supply end of the feeder in the first building.

Code reference ___________________

11. A 15- or 20-ampere, 125-volt receptacle used for the reduction of electrical noise where the grounding terminal is isolated from the receptacle mounting yoke is required to be identified by:
    A. a green grounding symbol.
    B. the words "isolated ground."
    C. being completely orange in color.
    D. having an orange triangle on the face of the receptacle.
    E. having a triangle and a grounding symbol on the face of the receptacle.

Code reference ___________________

12. A duplex receptacle is installed in a commercial building that is wired with Electrical Metallic Tubing and metal device boxes. The receptacle is an isolated ground type with the grounding terminal insulated from the metal mounting yoke as shown in Figure 5.36. The receptacle is identified on the front with an orange triangle. The receptacle grounding terminal is required to be:
    A. bonded to the metal box.
    B. grounded with an insulated grounding wire run all the way back to the grounding bus at the service panel.

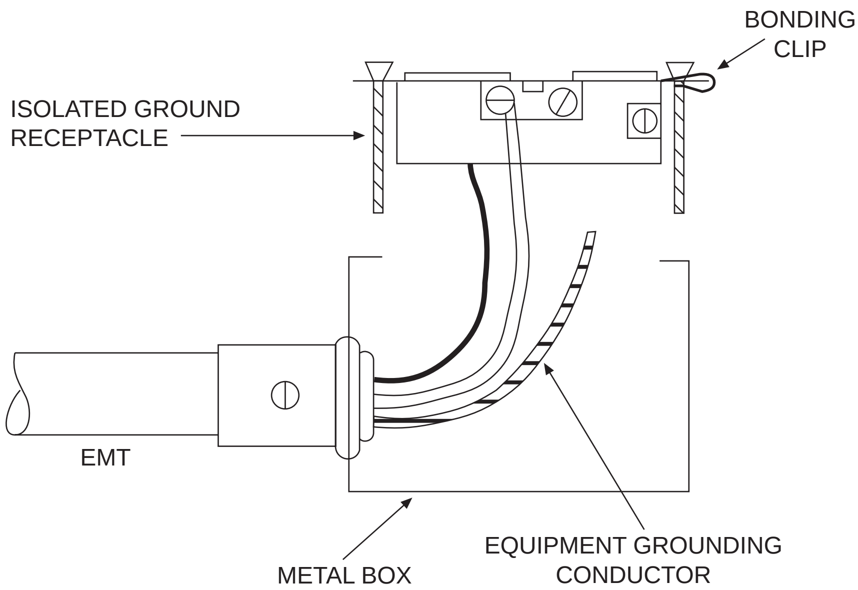


Figure 5.36 An insulated ground receptacle marked with an orange triangle on the front is installed in a metal surface mounted device box supplied by conductors run in Electrical Metallic Tubing.

C. grounded with a bare grounding wire run all the way back to the grounding bus at the service panel.
D. left open with no conductor connected to the grounding terminal.
E. bonded with a short jumper to the neutral terminal on the receptacle.

Code reference ___________________

13. A hot tub installed outdoors at a single-family dwelling is required to have at least one receptacle on a general purpose 125-volt, 15- or 20-ampere branch-circuit installed not closer to the hot tub than 6 ft (1.83 m) nor a distance of more than:
A. 15 ft (4.5 m).
B. 20 ft (6 m).
C. 25 ft (7.5 m).
D. 30 ft (9 m).
E. 50 ft (15 m).

Code reference ___________________

14. A building is supplied electrical power from another building by means of a 208Y/120-volt, 4-wire overhead feeder where the grounded-circuit conductor acts as the equipment grounding conductor for the existing building as permitted in *250.32(B) Exception.* A Type 2 Surge-Protective Device (SPD) installed at the electrical supply to the building is:
A. required to be installed on the supply side of the disconnecting means to the building.
B. permitted to be installed on the supply side of the disconnecting means to the building.
C. required to be installed outside the building and preferably at the drip loop.
D. only permitted to be installed on individual circuit requiring protection from transient surges.
E. required to be installed on the load side of the first overcurrent device in the building.

Code reference ___________________

15. A transformer supplies a 120/240-volt, single-phase, 200-ampere panelboard from a 480-volt, 3-phase supply. The secondary ungrounded conductors from the transformer to the panelboard are size 3/0 AWG copper. This separately derived system installation is shown in Figure 5.37. This transformer is near the service disconnect to the building and it is grounded to the metal underground water pipe. The minimum size copper grounding electrode conductor permitted for this transformer installation is:

    A. 10 AWG.
    B. 8 AWG.
    C. 6 AWG.
    D. 4 AWG.
    E. 2 AWG.

    Code reference ___________________

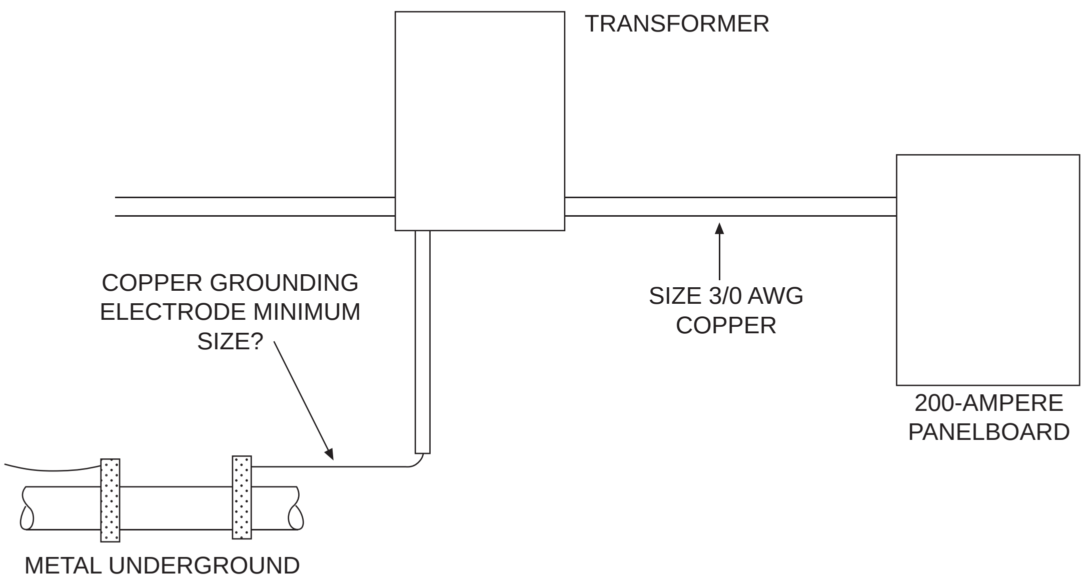


Figure 5.37 Determine the minimum size grounding electrode conductor to the metal underground water pipe for a transformer supplying a panelboard with a 200-ampere main circuit breaker with size 3/0 AWG copper conductors.

UNIT 6

Overcurrent Protection

OBJECTIVES

After completion of this unit, the student should be able to:

- name two types of overcurrent conditions.
- explain two ways in which conductors and equipment are damaged during overcurrent conditions.
- name two types of electrical fault conditions.
- explain interrupting rating as related to electrical equipment.
- name the two types of overcurrent conditions from which an overcurrent device protects.
- determine the voltage drop along a length of conductor.
- determine the minimum size wire that will limit voltage drop to a specific value for a given length of run and load.
- answer wiring installation questions relating to *Articles 240, 408, 550, 551,* and *552.*
- state at least five significant changes that occurred from the 2005 to the 2008 Code for *Articles 240, 408, 550, 551,* and *552.*

CODE DISCUSSION

The main emphasis of this unit is overcurrent protection. Several other articles are covered in which overcurrent protection is of particular importance. These additional topics are switchboards, panelboards, mobile homes, recreational vehicles, and park trailers.

Article 240 is the subject of overcurrent protection. The FPN to *240.1* describes the purpose of overcurrent protection. Rules on overcurrent protection for specific equipment are placed in the articles covering that specific equipment. Those articles and subjects are listed in *Table 240.3.* Some of those other rules will be discussed in other units of this text. The Code lists standard ratings of fuses and fixed-trip circuit breakers in *240.6(A).* In this and other articles of the Code, reference is sometimes made to rounding up, or rounding down to the next standard rating of overcurrent device. Fuses or circuit breakers are not necessarily available at all of these standard ratings. Manufacturers also have overcurrent protective devices available in other rated sizes. Common ratings of time-delay fuses from 1/10 to 30 amperes are listed in Table 7.2 in Unit 7.

NEC® 240.20(A) is fundamentally important in that a fuse, overload trip unit, or a circuit breaker is required to be installed in series with each ungrounded conductor. *NEC® 240.21* requires that the location of the overcurrent protective device be at the point where the conductors receive their supply. The cases where this is not true are for service conductors, sometimes conductors from generators, and for a special type of conductor called a tap. The definition of a tap is found in *240.2*, and an example of a tap is shown in Figure 6.1. The rules for sizing and installing feeder and transformer tap conductors are found in *240.21.* The tap rules for services are found in *230.46*, for motors circuits tap rules are found in *430.28* and *430.53.* A tap is permitted to be made to a branch-circuit to serve specific loads, but not to serve general use receptacles. This rule is in *210.19(A)*, which also gives rules for taps from range circuits to serve a counter-mounted cooking unit or a wall-mounted oven.

NEC® 240.4 requires that conductors be protected from overcurrent in accordance with the conductor ampacity as determined in *310.15.* This was discussed in several of the earlier units of this text. There are several specific situations where this rule does not apply, and those situations are listed in *Table 240.4(G).* According to *240.4(B),* if the overcurrent device protecting the conductors is not rated more than 800 amperes,

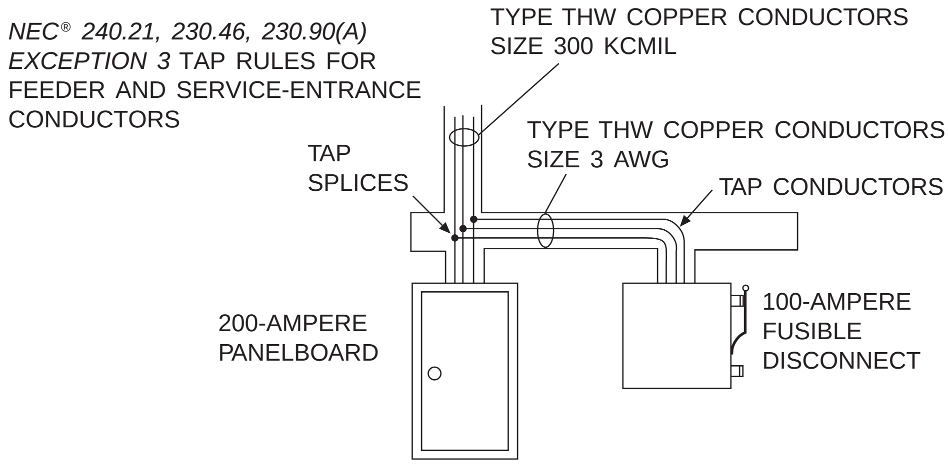


Figure 6.1 A conductor of a smaller size is permitted to be tapped from a conductor that is larger provided the tap conductor ends at an overcurrent device sized not larger than the allowable ampacity of the tap conductor.

and the allowable ampacity of the conductor does not correspond with a standard rating of overcurrent device, then it is permitted to protect that set of conductors with the next higher rating of standard overcurrent device. Assume for example a set of feeder conductors adequate to supply the intended load is size 300-kcmil copper. According to *Table 310.16*, this conductor is good for 285 amperes if there are no adjustments or corrections. It is permitted to protect this conductor with a 300-ampere-rated set of fuses or a circuit breaker. This rule is not permitted to be used in the case of branch-circuits serving multiple receptacles intended for plug-connected portable loads. According to *240.4(C)*, a conductor is required to have an allowable ampacity not less than the rating of an overcurrent device rated more than 800 amperes.

NEC® 240.4(D) is a special rule that applies to conductor sizes 10 AWG copper and smaller. This rule sets a maximum rating of overcurrent device that is permitted to protect circuits using sizes 14, 12, and 10 AWG copper wires, and sizes 12 and 10 AWG aluminum wires. There are some special cases like motor circuits where this rule does not apply.

Part V of *Article 240* deals with screw shell or plug fuses, which are rated 125 volts and up to 30 amperes. These fuses are permitted to be used to protect a circuit or equipment operating at 120 volts or 208 volts line-to-line where the voltage from either conductor is not more than 150 volts. This is permitted by *240.50(A)(2)* because two fuses are working together in series for a line-to-line short circuit, and they are rated to handle up to 150 volts on a ground fault. They are of the Edison-base type, which is the same as a standard medium-base incandescent lamp. They are also available as Type S noninterchangeable fuses where an adapter is inserted into the standard Edison-base fuse holder. The internal threads of the adapter will only fit the threads on a specific ampere range. The Code recognizes Type S fuses with adapters in the range of up to 15 amperes, 16 to 20 amperes, and 21 to 30 amperes. The adapter is required to be nonremovable. Figure 6.2 shows a Type S fuse and adapter being inserted into an Edison-base fuse screw shell fuse holder.

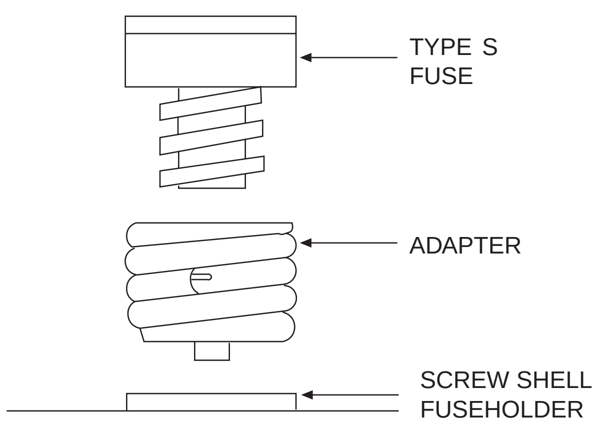


Figure 6.2 A Type S screw shell fuse with an adapter prevents replacing a fuse with one with a much higher rating.

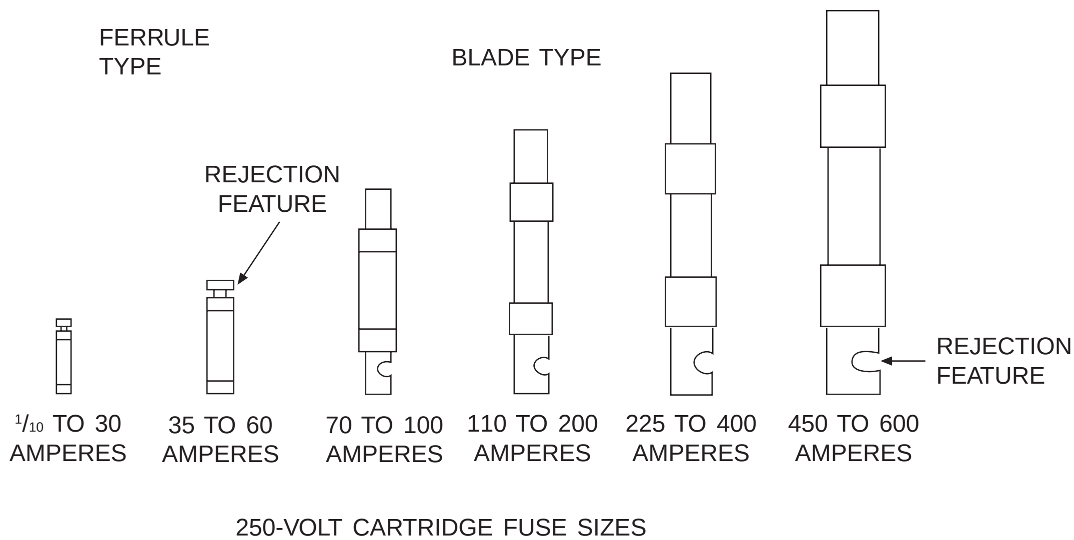


Figure 6.3 Cartridge fuses are grouped into ranges of ratings that prevent replacement by a fuse with a rating from a higher range.

NEC® 240.52 requires that when fuse holders of the Edison base are installed, they are to be fitted with a Type S fuse adapter. This prevents 20- or 30-ampere fuses from being used on a circuit that requires not larger than a 15-ampere fuse. A 30-ampere fuse will not fit into an adapter that is rated for 20-ampere fuses.

Part VI of *Article 240* deals with cartridge fuses. Low-voltage cartridge fuses are rated either at 250 volts, 300 volts, or 600 volts. Fuses rated at 300 volts are considered to be Class G, and they are commonly used inside equipment. Fuses rated at 250 volts and at 600 volts are generally used for circuit protection. They are physically different in size so they cannot be interchanged. Fuses are grouped into sizes to limit the ratings that can be interchanged, and to be capable of handling the intended current as well as interrupting the current during an overload or fault. Relative sizes of cartridge fuses and the ratings are shown in Figure 6.3 for ratings up to 600 amperes. The physical size and rating of disconnect enclosure will change as the physical size of the fuses changes.

Fuses are made as one-time blow, or as time-delay. Figure 6.4 shows the internal arrangement of a time-delay fuse. There is a time-delay section and one or two short-circuit sections. There are several different methods of obtaining a time delay. With the type shown in Figure 6.4, solder holds contacts together. An overload that persists long enough will melt the solder and the spring will pull the contacts apart. The short-circuit section may consist of one conducting ribbon or several in parallel. Frequently there is one or

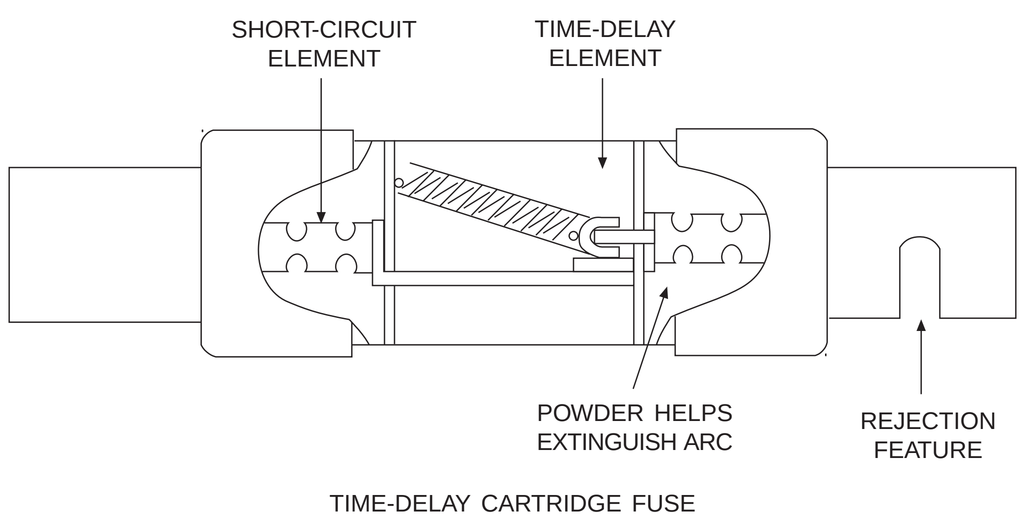


Figure 6.4 A time-delay cartridge fuse has a time-delay element and one or more short-circuit elements.

more narrow points on the metal ribbon that will burn apart when a high current flow occurs. It usually takes more than six times the fuse rating to heat the short-circuit elements enough to burn them apart. There are frequently multiple narrow sections on the short-circuit element in series to increase the gap quickly during a short circuit to stop the arcing. On some fuses, the short-circuit elements are surrounded by a powder that also helps stop the arc quickly. Overcurrent devices that are capable of opening very quickly have the ability to limit the amount of current that is allowed to flow during a short circuit. These overcurrent devices have a high interrupting rating, and are often considered to be current limiting. *NEC® 240.60(C)* requires cartridge fuses to have a minimum interrupting rating of 10,000 amperes, and many are rated as high as 200,000 amperes. Circuit breakers are required to have an interrupting rating of 5000 amperes; however, most are rated at least 10,000 amperes. Other typical circuit-breaker interrupting ratings are 22,000, 42,000, and 65,000 amperes.

Circuit breakers are sometimes used as switches for lighting in a building. Electric discharge lighting such as fluorescent luminaires (lighting fixtures) or high-intensity discharge luminaires (lighting fixtures) have a ballast that contains inductors and capacitors. These components can store energy that gets released when the circuit is opened. To deal with this extra energy that may be present, a circuit breaker that is used frequently as a switch to interrupt current flow needs to be rated to handle the extra energy that must be interrupted. *NEC® 240.83(D)* requires circuit breakers that are intended to be used as switches for fluorescent luminaires (lighting fixtures) to be marked SWD, and if used as a switch for high-intensity discharge luminaires (lighting fixtures) to be marked HID. A circuit breaker marked HID is permitted to be used as a switch for both fluorescent and high-intensity discharge luminaires (lighting fixtures).

NEC® 210.12 requires receptacles in dwelling bedrooms, family room, dining room, living room, parlor, library, den, sun room, recreation room, closets, hallways, and similar areas on 15- or 20-ampere, 120-volt-rated branch-circuit to be protected by an arc-fault interrupter of the combination type. Arcing faults can develop at outlets, in appliance cords, or in the circuit wiring that persist for long periods of time at levels too low for a fuse or circuit breaker to detect. These arcing faults over time can build up enough heat to start a fire. Arcing faults have an intermittent current-flow pattern similar to the current shown in Figure 6.5. The arc-fault interrupter is a circuit breaker that contains an electronic device to identify the current flow pattern of an arcing fault and trip off power to the circuit. Arc-fault interrupters are larger than a standard circuit breaker, but generally will fit in the space of a single-pole circuit breaker. They have a factory installed white insulated wire that is to be connected to the neutral bus. The circuit ungrounded and neutral wire are connected directly to the arc-fault interrupter as shown in Figure 6.6. A combination-type arc-fault circuit-interrupter (AFCI) is also built into a receptacle similar to that of a GFCI receptacle. This type of AFCI is permitted to be installed remote from the service panel if certain requirements are met. The combination type is more sensitive to what is known as a series-arcing condition and provides a higher level of protection than the branch/feeder type AFCI.

NEC® 240.85 lists important voltage ratings of circuit breakers that are necessary to understand in order to avoid potentially dangerous installations. The voltage rating of the circuit breaker may be marked on the side of the circuit breaker, or it may be printed on a small label on the end next to the wire terminal. For low-voltage molded-case circuit breakers, voltages are listed as either a single voltage such as 240 Vac or two voltages such as 120/240 Vac. A circuit breaker may be called upon to clear a line-to-line short circuit, or a line-to-ground fault. A circuit breaker with a single voltage, such as 240 Vac, means the circuit breaker is able to withstand a line-to-line short circuit at 240 volts nominal. The circuit breaker is also able to withstand a line-to-ground fault of up to 240 volts nominal. This type of circuit breaker would be required

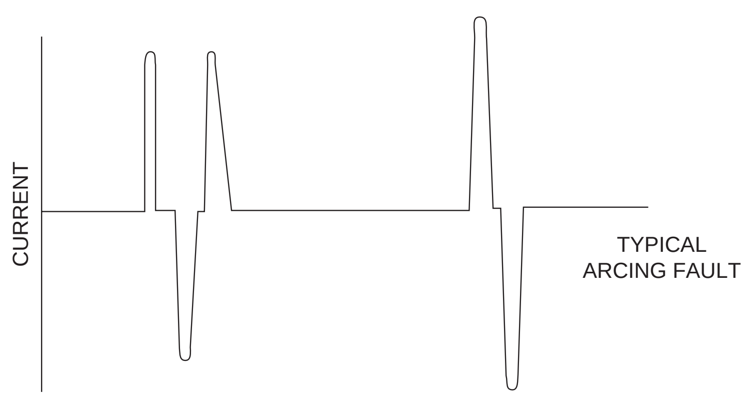


Figure 6.5 An arcing fault in a circuit such as caused by a loose terminal or a fastener piercing a cable is characterized by an intermittent current flow.

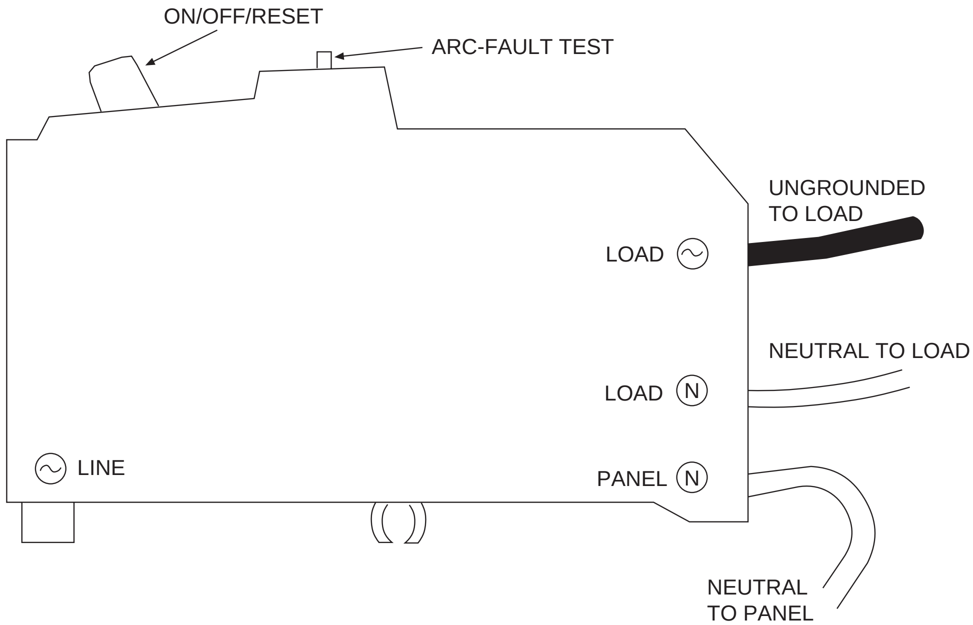


Figure 6.6 An arc-fault interrupter is a circuit breaker with an internal electronic circuit that can detect an arcing-fault current pattern and disconnect power to the circuit.

on a 240-volt, 3-phase, 3-wire ungrounded electrical system. If one phase becomes faulted to ground, the other two phases will be operating at 240 volts-to-ground.

When a circuit breaker lists two voltages, the higher is the voltage line-to-line. A 120/240-volt rated circuit breaker is able to withstand a line-to-line short circuit at up to 240 volts nominal. The lower voltage is the maximum permitted line-to-ground voltage the circuit breaker can handle during a ground fault. Table 6.1 lists the different types of electrical systems and the typical circuit breaker voltage ratings available that can

Table 6.1 Circuit breaker voltage ratings permitted for various circuits and different types of low voltage electrical systems.

Electrical System	1-pole circuit breaker	2-pole circuit breaker	3-pole circuit breaker
1-phase, 120/240 Vac 3-wire	120/240 Vac	120/240 Vac or 240 Vac	
1-phase, 120/208 Vac 3-wire	120/240 Vac	120/240 Vac or 240 Vac	
3-phase, 208Y/120 Vac 4-wire		120/240 Vac or 240 Vac	240 Vac
3-phase, 480Y/277 Vac 4-wire		480Y/277 Vac or 480 Vac	480 Vac
3-phase, 600Y/347 Vac 4-wire		600 Y/347 Vac or 600 Vac	600 Vac
3-phase, 240 Vac 3-wire ungrounded		240 Vac	240 Vac
3-phase, 480 Vac 3-wire, ungrounded		480 Vac	480 Vac
3-phase, 600 Vac 3-wire, ungrounded		600 Vac	600 Vac
3-phase, 240 Vac 3-wire, corner grounded		240 Vac	240 Vac
3-phase, 480 Vac 3-wire, corner grounded		480 Vac	480 Vac
3-phase, 240/120 Vac 4-wire, delta	120/240 Vac	120/240 Vac or 240 Vac	240 Vac
(using B-phase)	(Do not use)	240 Vac	
3-phase, 480Y/277 Vac 3-wire, high impedance grounded	(Do not use)	480 Vac	480 Vac

be used for various circuits. Two-pole circuit breakers with a rating of 120/240 volts are not permitted to be installed in a 240/120-volt, 3-phase, 4-wire electrical system for a single-phase 240-volt load except between the A and C phases. The voltage from the B phase to ground is approximately 208 volts, which exceeds the line-to-ground voltage rating of the circuit breaker. A two-pole circuit breaker used in this panel for a 240-volt load connected to the B phase is required to have a single voltage rating of 240 volts.

Part VIII of *Article 240* gives some special rules for what is called a supervised industrial installation. *NEC® 240.92* gives some special rules for outside taps from feeders and taps from transformers that are different than for normal tap installations. The definition of a supervised industrial installation is found in *240.2.* There must be at least one service operating at more than 150 volts-to-ground and over 300 volts between conductors. And, the minimum load is required to be 2500 kVA, which at 480 volts would be more than 3000 amperes. The installation is also required to have a qualified electrical maintenance staff on duty. A key difference in the tap rule for a set of conductors from the secondary of a transformer is that conductors are permitted to be up to 100 ft (30 m) in length, and are permitted to terminate in up to six overcurrent devices grouped together with a combined rating not exceeding the ampacity of the tap conductor. Taps that are run outside buildings are permitted to be of any length and terminate in up to six overcurrent devices grouped together with a combined rating not exceeding the ampacity of the tap conductors.

Article 408 covers the use, installation, and protection of switchboards and panelboards. A switchboard is defined in *Article 100,* and it is a large panel, frame, or assembly of panels in which are mounted switches, buses, overcurrent devices, and other protective equipment. Measurement instruments are also frequently included. This equipment is generally accessible from both the front and from the rear. A panelboard is defined in *Article 100,* and it is an assembly of electrical buses, overcurrent devices, and sometimes switches. It is used for the control of light, heat, and power circuits. The parts are usually installed in a cabinet accessible only from the front.

In the past, panelboards were classified as lighting and appliance branch-circuit panelboards and as power panelboards. Those designations are no longer used in the Code. Panelboards are used as service equipment, and they are used for power distribution at the termination of a feeder. Whenever the panelboard is installed for distribution purposes at the end of a feeder or tapped from a feeder, it is required to be provided with overcurrent protection with a rating not exceeding the rating of the panelboard, *408.36.* This overcurrent protection can be in the form of a main overcurrent device at the panelboard, or it can be the overcurrent device protecting the feeder conductors, provided that overcurrent device does not have a rating exceeding that of the panelboard. This is illustrated in Figure 6.7. *Exception 2* of *408.36* does permit the installation of panelboards with two main overcurrent devices if the sum of the overcurrent device ratings does not exceed the rating of the panelboard.

When used as service equipment, a panelboard typically will have a single main overcurrent device with a rating not exceeding the rating of the panelboard. *Exception 1* of *408.36* permits a panelboard to be used as service equipment without a single main overcurrent device. The rules of *230.71(A)* must then be followed which permit up to six separate overcurrent devices. In this case, the service conductors are sized to the load in accordance with *Exception 3* of *230.90(A).* It should be noted in *Exception 3* that the sum of the ratings of the overcurrent devices is permitted to exceed the rating of the panelboard for this application. In the past, none of the circuit breakers used as a main could be rated 30 amperes or less where the neutral conductor was used as a part of the circuit or feeder. That restriction no longer exists. A panelboard used as

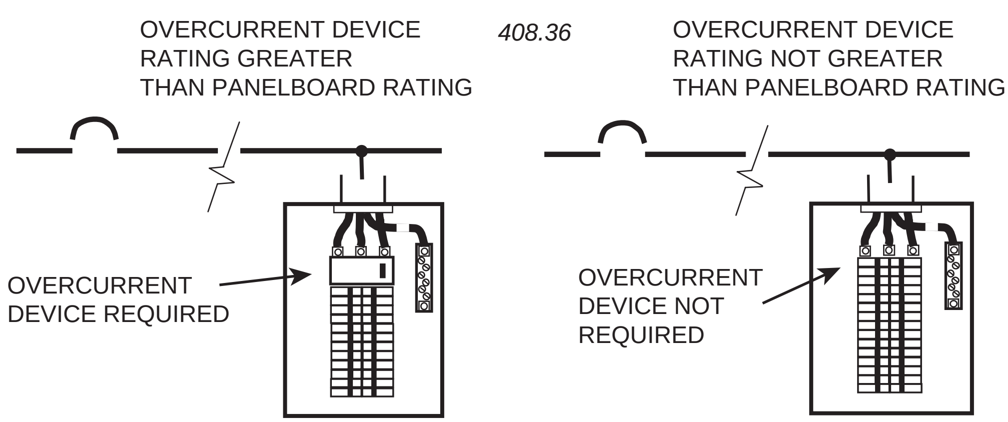


Figure 6.7 Panelboards supplied by feeders are required to be provided with overcurrent protection not exceeding the rating of the panelboard. This overcurrent protection can be provided in the panelboard or at some point ahead of the panelboard.

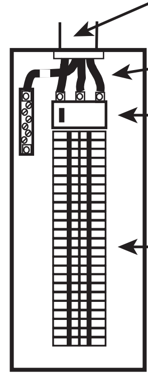


Figure 6.8 A panelboard provided with individual overcurrent protection either in the panelboard or ahead of the panelboard and meeting the wire bending space requirements of *408.55* is permitted to be listed for more than 42 overcurrent devices.

service equipment with up to six main overcurrent devices is shown in Figure 6.8. Since *230.71(A)* limits the maximum number of overcurrent devices to six, the panelboard may be limited to the number of spaces necessary to meet this requirement and may not be permitted to have spare spaces available. This will most likely be a judgment call on the part of the inspector or plan reviewer. For example, in the case of a single-phase panelboard used as service equipment with six 2-pole circuit breakers, the panelboard may be limited to 12 total spaces. In the case of a 3-phase panelboard, the limit on spaces may be 18.

Panelboards are not necessarily limited to a maximum of 42 overcurrent devices. The number of overcurrent devices is counted as the maximum number of standard single-pole devices that can fit into the panelboard. If the panelboard is of the type that has two separate bus sections, each with an individual main overcurrent device, then the limit is 42 maximum overcurrent devices in the panelboard, *408.36 Exception 2*. The other case where there is a 42 overcurrent device limitation is for a panelboard rated 225 amperes or less and either the top or bottom wire bending space is sized according to *Table 312.6(A)* with the other sized according to *Table 312.6(B)*. If both the top and bottom wire bending space is sized according to *Table 312.6(B)*, then there is no maximum 42 overcurrent device limitation. Only panelboards that are listed for more than 42 overcurrent devices are permitted to have the 42 overcurrent device limit exceeded.

Only one neutral conductor is permitted to be connected to a terminal of the neutral bus in a panelboard unless the terminal is specifically listed for more than one wire. This rule is in 408.41 and is illustrated in Figure 6.9. There is usually a label located on the inside of a panelboard enclosure that states the maximum number of equipment grounding wires of various sizes that are permitted to be installed at a single terminal.

Article 550 begins with some definitions in *550.2* that are important for understanding the intent of the provisions of this article. *Part II* applied to wiring within the mobile home or manufactured home, the electrical disconnecting means, and the distribution equipment for the mobile home. It is important to understand that a mobile home is movable; therefore, the service drop or service lateral would logically connect to service equipment that is not mobile. The service equipment or disconnecting means for a mobile home is required by *550.32(A)* to be located adjacent to the mobile home, and not on or within the mobile home. This is illustrated in Figure 6.10. *NEC*® *550.18* gives a method to determine the minimum permitted rating of the electrical power supply to the mobile home. The minimum permitted size of power supply cord or feeder to the mobile home is given in *550.10*. *Part III* covers services for mobile homes and feeders in a mobile home park. The service for a mobile home in a mobile home park is permitted to be remote from the mobile home, but a disconnecting means for the mobile home is required to be installed according to the rules of *550.32(A)*. For all new feeder installations, the neutral is required to be insulated, and a separate equipment grounding wire is required according to *550.33(A)*.

The minimum rating of service equipment for a mobile home is 100 amperes. The mobile home is permitted to be supplied power with permanent wiring or with a cord. Cords rated 50 amperes are most common, although in some cases, a 40-ampere cord is permitted. After installation, there is to be a minimum length of 20 ft (6 m) of cord from the point of attachment to the mobile home to the end of the plug. *NEC*® *550.11(A)* requires a single main disconnect in the mobile home near the point of entrance of the service conductors. This is generally in the distribution panel. The rating of a circuit breaker acting as the disconnect is 50 amperes for a 50-ampere supply cord, and 40 amperes for a 40-ampere supply cord. Whether the supply conductors are by means of permanent wiring or a supply

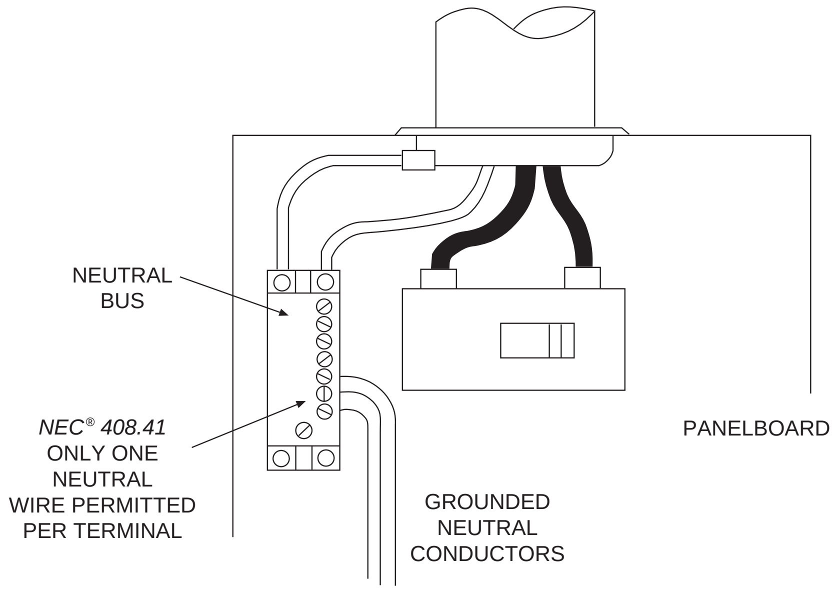


Figure 6.9 Only a single neutral conductor is permitted to be attached to a terminal in a panelboard.

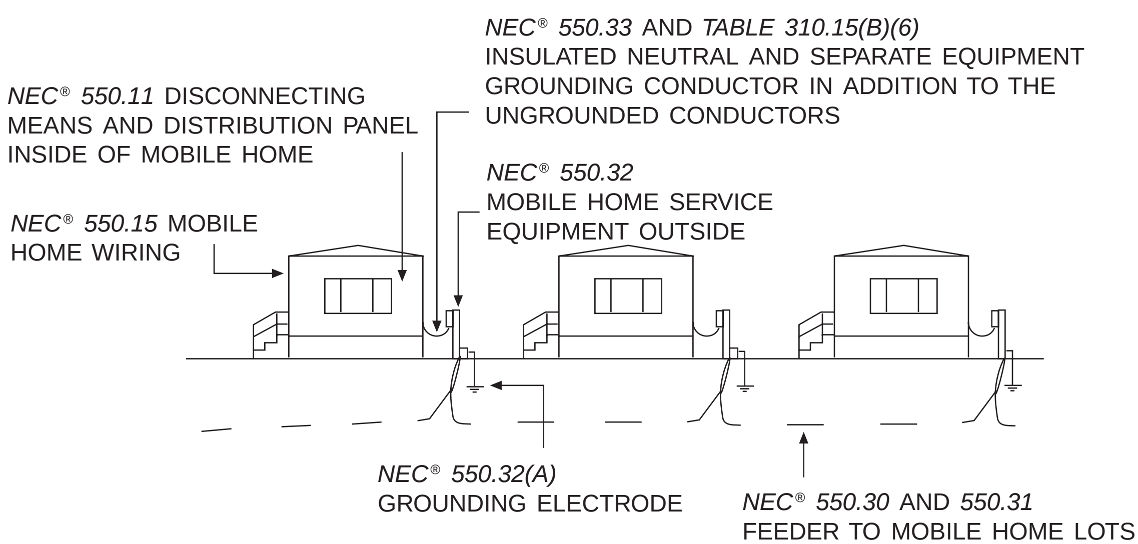


Figure 6.10 Service equipment for a mobile home is required to be located adjacent to the mobile home and not on or within the mobile home.

cord, the neutral and equipment ground are separated in the distribution panel. The neutral bus is insulated from the enclosure, and the equipment grounding bus is required to be bonded to the enclosure. The supply conductors from the service equipment located adjacent to the mobile home to the distribution panel in the mobile home is required to have an insulated green equipment grounding conductor and an insulated white neutral conductor. These rules are summarized in Figure 6.11 along with the minimum circuit requirements for a mobile home.

Article 551 contains definitions in *551.2* that are important for understanding wiring requirements for recreational vehicles and recreational vehicle parks. Low voltage for recreational vehicle applications is defined in *551.2* as 24 volts or less either ac or dc. Low-voltage wire types used in recreational vehicles are specified by the Society of Automotive Engineers (SAE). It is important that a separation be maintained between conductors carrying direct current and those carrying alternating current. *Part III* of *Article 551* deals with the installation of wiring intended to operate from a combination of power

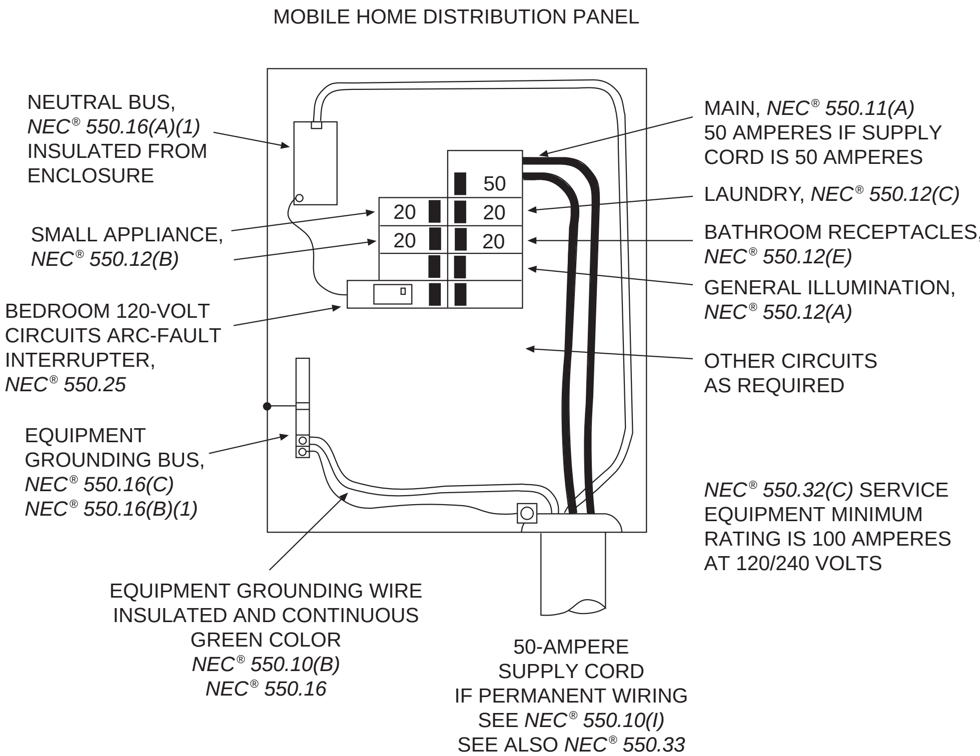


Figure 6.11 A distribution panel in a mobile home is supplied with a feeder consisting of all insulated conductors, two ungrounded, one neutral, and one equipment grounding conductor where the neutral terminal block is not bonded to the panel enclosure.

sources. For example, the circuits may be supplied from a battery, or from a 120-volt alternating current source. *Part IV* applies to the installation of power sources, such as an engine-driven generator or batteries. When there are multiple power sources, such as a generator and a power supply cord, a transfer switch shall be installed to prevent interconnection of the power sources if such a transfer device is not supplied as part of the generator.

Part V of *Article 551* covers the installation of wiring to be supplied from a nominal 120-volt or 120/240-volt electrical system. *NEC® 551.41* provides the requirements for the spacing and type of receptacle outlets. The receptacle outlet next to a lavatory in the bath is required to be ground-fault circuit-interrupter protected. Also, all receptacle outlets installed to serve a counter space that are within 6 ft (1.8 m) of a lavatory or sink are required to be ground-fault circuit-interrupter protected. This provision primarily applies to kitchen counters. *NEC® 551.41(C)(2)* does not apply to receptacles located within 6 ft (1.8 m) of a bathroom lavatory and not intended to serve a counter space as shown in Figure 6.12. *NEC® 551.42* covers the minimum branch-circuit requirements for a recreational vehicle. The type and installation of the distribution panelboard including working clearances are covered in *551.45*. The means of connecting the recreational vehicle to an external power supply are covered in *551.46. NEC® 551.47* describes the wiring methods permitted to be used in a recreational vehicle for 120-volt or 120/240-volt electrical systems. The methods of grounding equipment are covered in *551.55.*

Part VII provides requirements for determining the minimum size and installation of equipment at each recreational vehicle site and the feeders supplying the sites. Recreational vehicle parks are only permitted to be supplied power by a single-phase, 120/240-volt, 3-wire electrical system according to *551.72.* A fourth wire for equipment grounding is required to be run with the supply conductors to each RV site. *551.76.* Of the recreational vehicle sites with electrical power, every one is required to provide a 20-ampere, 125-volt receptacle, according to *551.71.* A minimum of 70% are required to be equipped with a 30-ampere, 125-volt receptacle, and a minimum of 20% of the sites are required to be equipped with a 120/240-volt, 50-ampere receptacle. Other receptacle

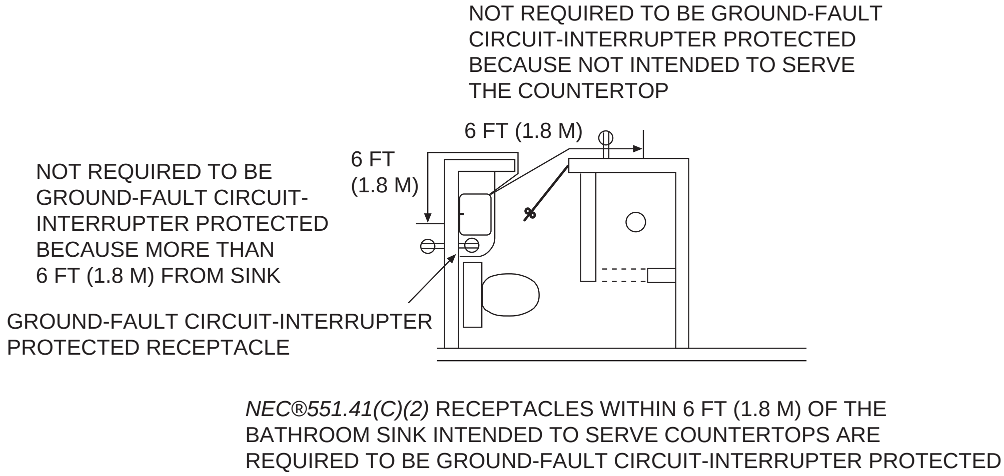


Figure 6.12 Receptacle outlets installed within 6 ft (1.8 m) of the lavatory in the bathroom of a recreational vehicle are not required to be ground-fault circuit-interrupter protected unless intended to serve the counter tops.

configurations are permitted to be provided. All 15- or 20-ampere, 125-volt recreational vehicle site receptacles are required to be ground-fault circuit-interrupter protected. The recreational vehicle site supply equipment is required to contain a disconnect for the power and one or more receptacles as required for the park. The location where the recreational vehicle can be parked is called the stand. The receptacle and disconnect are to be located at the side of the stand with the dimensions described in *551.77.* The equipment is to be located at least 2 ft (600 mm) above ground, but not more than $6^1/_2$ ft (2 m). The location of the power supply pedestal for a back-in recreational vehicle site is on the driver's side of the vehicle as shown in Figure 6.13. For a drive-through recreational vehicle site, the power supply pedestal is to be located from the centerline of the stand as shown in Figure 6.14.

Article 552 specifies the rules for wiring on park trailers. A park trailer is defined in *552.2* as a unit that is built on a single chassis which is mounted on wheels, and the unit gross area does not exceed 400 sq. ft (37 m^2) when set up for occupancy. These units are ones that are intended for seasonal use, and they are not intended to have commercial uses or to be occupied as a permanent dwelling. A park trailer has differences that are not addressed in *Article 550* on mobile homes or in *Article 551* on recreational vehicles. This article does cover the wiring of lighting required to transport the trailer on public roads and highways. Electrical wiring operating from an alternating current source of 120 volts or 120/240 volts is specified in *Part IV.* The minimum permitted size of distribution panelboard and power supply cord or feeder for the park trailer can be determined by using the method of *Article 220, Part III,* or the size determination can be made by using *552.47*.

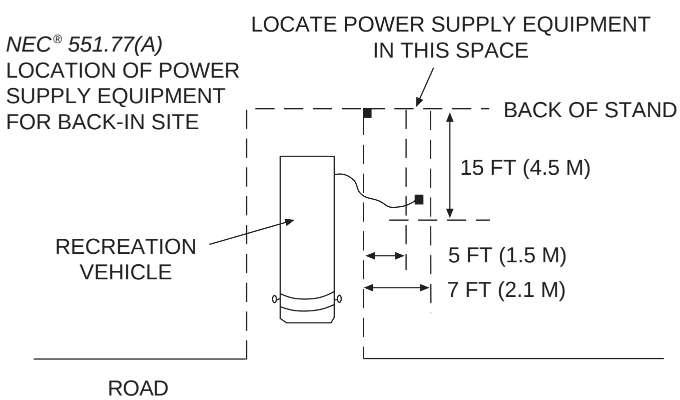


Figure 6.13 The power supply pedestal for a back-in recreational vehicle site is located on the driver's side of the vehicle and distances are measured from the back corner of the stand.

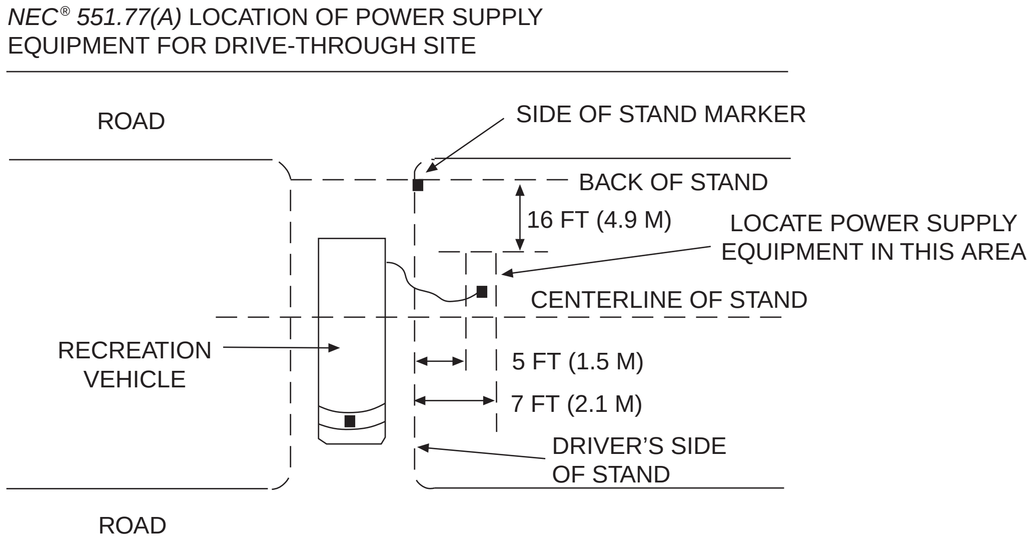


Figure 6.14 The power supply pedestal for a pull-through recreational vehicle site is located on the driver's side of the vehicle, and distances are measured from the centerline of the stand.

OVERCURRENT PROTECTION FUNDAMENTALS

The purpose of overcurrent protection is to open a circuit if the temperature in the wiring or equipment rises to an excessive or dangerous level. This is discussed in the FPN to *240.1*.

Every circuit shall be protected by two levels of overcurrent protection: overload and short circuits or ground faults. Usually one overcurrent device provides both levels of protection, but in the case of a motor circuit, this protection is often provided at two locations. In a typical motor branch-circuit, short-circuit and ground-fault protection is provided by the fuse or circuit breaker, while overload protection is provided by the thermal unit in the motor starter.

Overloads

An overload is a gradual rise in current level above the current rating of the wires in the circuit or in the equipment. Heat is produced as the current flows through the wires. The two important variables for conductor heating are current level and time, in addition to resistance. Equation 1.16 discussed in *Unit 1* may be used to determine the heat produced as electrical current flows in a conductor for a given length of time.

$$\text{Heat} = \text{Current}^2 \times \text{Resistance} \times \text{Time}$$

Heat is in joules
Current is in amperes
Resistance is in ohms
Time is in seconds

Faults

A high level of current generally flows during a fault. Common faults are short circuits between wires and faults from an ungrounded wire to ground. This condition is called a **ground fault.** If arcing occurs, then the fault is also referred to as an **arcing fault,** such as the case when a wire touches the conduit causing an **arcing ground-fault.** If two conductors with voltage between them are accidentally connected together, arcing generally will not occur. If the conductors are connected together so that arcing does not occur, this is termed a **bolted fault.**

Symmetrical and Asymmetrical Current

Understanding overcurrent protection requires an understanding of the behavior of electrical current during a ground fault or a short circuit. The current that flows generally is many times higher than the rating of the overcurrent device. When a graph of the current is made over time, it draws out the shape of a sine wave as shown in Figure 6.15. If the current wave is centered about the zero axis, then it is called symmetrical current. If a direct current is added to the voltage supply, then the current wave will be offset either positively or negatively as shown

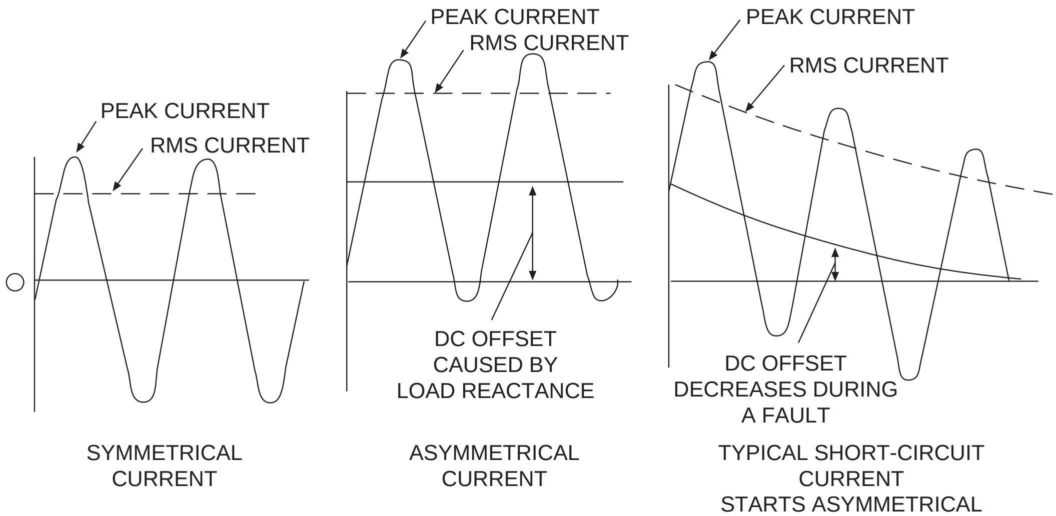


Figure 6.15 A symmetrical current is centered around the zero line while an asymmetrical current is off-set either positively or negatively from the zero line resulting in a higher than normal peak and rms current.

in Figure 6.15. During a fault, reactive loads supplied by the electrical system such as motors, can cause a dc offset. This is called asymmetrical current. The effect of this offset is that the peak current can be considerably higher than if the offset is not present. During an actual fault in the circuit, there is often a dc offset, but it generally only lasts for a few cycles. The fault current may start out asymmetrical and quickly become symmetrical as shown in Figure 6.15. Even though the offset lasts only for a very short time, the peak current will occur in just one quarter cycle or about 0.004 seconds (4 ms). Another important number is the rms current. For a steady current flow, this is 0.707 times the peak current. The rms current is represented by the dashed line in Figure 6.15. During an actual fault, the rms current starts out high and quickly decreases to a steady value.

How Damage Occurs

When a fault occurs, the amount of current that flows depends on the impedance (resistance) of the fault—the impedance of the wires, transformer, and electrical system feeding the fault. The circuit voltage between the faulted wires is also important in determining the amount of fault current that will flow. The current flow during a fault is often in the thousands of amperes.

High current flow during a fault will cause strong magnetic forces that can move wires and deform electrical parts if the parts are not adequately secured and braced to withstand these forces. This mechanical force is proportional to the square of the peak current (I_{peak}^2). Arcing will occur when parts with a voltage between them touch together. This may be a secondary effect after the magnetic forces deform the parts. Heating will occur in conductors and components of the electrical system. Contacts may be welded together from heat produced by the rms current flow. Heating during a fault is proportional to the square of the rms current times time ($I_{rms}^2 \times t$).

If an electrical conductor is overloaded with current for a long enough period of time, the conductor will get hot. The conductor insulation will begin to sustain damage when the temperature rating of the conductor is exceeded, such as 75°C (167°F). Short circuits only last for a brief time, but the heating of the conductor is controlled by the length of time and the square of the rms current. Testing by the Insulated Cable Engineers Association[1] has revealed that a size 8 AWG copper conductor with thermoplastic insulation can withstand up to 6800 amperes for one cycle (0.017 sec.) without damage. For one full second (60 cycles) the same conductor can withstand only 850 amperes without damage. A size 3/0 AWG copper conductor with thermoplastic insulation can withstand up to approximately 68,000 amperes for one cycle and 8800 amperes for one second. The goal of an overcurrent device is to cut off current in time to prevent damage to conductors and equipment.

[1]Insulated Cable Engineers Association, P.O. Box 1568, Carrollton, GA 30112.

Interrupting Ratings of Fuses and Circuit Breakers

NEC® 110.9 requires that equipment intended to interrupt current at fault levels must have an interrupting rating sufficient for the circuit voltage and the current that is available at the supply terminals of the equipment. Circuit breakers, fuses, knife switches, and contactors are examples of components that are required to interrupt circuits at fault-current levels. An interrupting rating is the highest current a device is intended to interrupt at rated voltage under standard test conditions. *NEC® 110.10* requires overcurrent devices to be capable of opening the circuit during a fault so as to prevent extensive damage to electrical components of the circuit. The component of the electrical system that is most frequently exposed to the highest available current during a short circuit or a fault is the service equipment. This is why in *230.66* the service equipment is required to be marked as suitable for use as service equipment. The withstand rating of equipment is the maximum current equipment can safely handle at the system voltage.

The responsibility of the electrician is to know when excessive short-circuit currents can occur. Standard circuit breakers are only required to withstand 5000 amperes of short-circuit current. However, most are rated at 10,000 amperes as stamped on the circuit breaker. Fuses are required to have an interrupting rating of at least 10,000 amperes. Fuses are commonly available having interrupting ratings up to 200,000 amperes. Some fuses have an interrupting rating as high as 300,000 amperes.

Fuses that have an interrupting rating higher than the minimum 10,000 amperes are manufactured with a rejection feature as shown in Figure 6.3 and Figure 6.4. A pin can be installed into the fuse holder that will accept only fuses with the rejection feature. This prevents fuses that only have a 10,000-ampere interrupting rating from being installed in rejection fuse holders where short-circuit currents higher than 10,000 amperes are available.

Current Limiting

The amount of short-circuit current that will flow if there is a short circuit or a ground fault near service equipment may be higher than the interrupting rating of the overcurrent device at the service equipment. In this case the overcurrent device can be replaced with one that has an interrupting rating greater than the available short-circuit current. The dashed sine wave in Figure 6.16 shows the level of current that would flow if the overcurrent device was incapable of limiting the flow. If a circuit-breaker panelboard is installed adjacent to this main overcurrent device then all of the circuit breakers must have an interrupting rating not less than this current. Many fuses, and some circuit breakers open the circuit so rapidly the peak current of the first half cycle never gets through to load side equipment. This type of overcurrent device is called current limiting. The solid line in Figure 6.16 represents the short-circuit current during a fault. For a fuse, the current increases until the short-circuit element melts. Then there is a short period of arcing within the fuse as the current flow is terminated. The peak let-thru current of the fuse is much less than the original peak current. And the rms let-thru current is much less than the previous rms current.

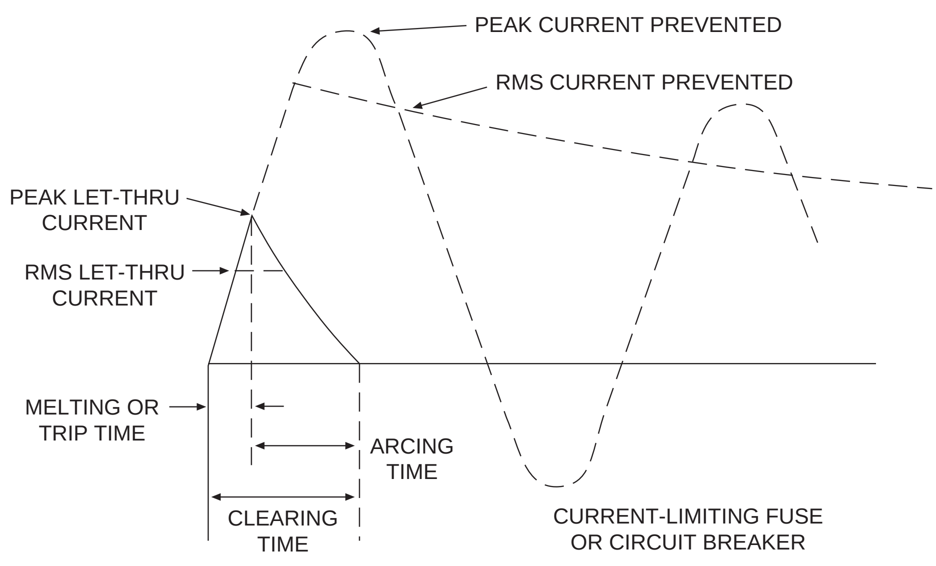


Figure 6.16 An overcurrent device that is current limiting is able to open the circuit within the first half-cycle of fault-current flow, which limits the peak and rms current that are let-thru the device.

Series Rating

In the case where a fusible switch acts as the service disconnect and it is followed immediately by a circuit-breaker panelboard, the two overcurrent devices may operate at the same time to open when there is a short circuit or a ground fault. If the circuit breaker immediately follows the fuse as shown in Figure 6.17, and they both act at the same time to clear a fault, they are considered to be a series-rated system. The same would be true for a circuit-breaker panelboard with a main circuit breaker acting as the service disconnect. The main circuit breaker immediately followed by a branch-circuit or feeder circuit breakers are considered to be a series-rated system. If both overcurrent devices have an interrupting rating not less than the available short-circuit current, then this is considered to be a fully-rated system. Each overcurrent device is capable of opening the circuit during a ground fault or short circuit without the help of the other circuit breaker.

With a series-rated system, the first circuit breaker or fuse must have an interrupting rating not less than the available short-circuit current. The circuit breaker that immediately follows is permitted to have an interrupting rating less than the available short-circuit current if the two overcurrent devices acting at the same time have a listed series interrupting rating greater than the available short-circuit current. Example interrupting ratings are shown in Figure 6.17. In each case, the first overcurrent device has an interrupting rating greater than the available short-circuit current. The circuit breakers in the panelboard have an interrupting rating less than the available short-circuit current. Note in both cases in Figure 6.17, the circuit breakers in the panelboard acting in series with the first overcurrent device each have a series-interrupting rating that is greater than the available short-circuit current. These are acceptable installations provided the equipment is labeled as a series-rated system, *240.86(A)* and *110.22*. Suggested wording for the series rated-label is given in *110.22*. Specific replacement parts required are listed as manufacturer and model number of fuses and circuit breakers.

Feeder Taps

A conductor is permitted to be tapped from a feeder where the feeder overcurrent device has a higher rating than the allowable ampacity of the tap conductor. This is permitted where the tap conductor terminates at an overcurrent device with a rating not higher than the allowable ampacity of the tap conductor. This practice, illustrated in Figure 6.18, is permitted by *240.4(E)*. The overload protection is provided by the fuse or circuit breaker at the tap termination. The short-circuit and ground-fault protection is provided by the fuses or circuit breaker protecting the feeder. There are several rules for determining the size of tap conductor with respect to the rating of the feeder overcurrent protection. These rules are found in *240.21* and are based upon the distance from the tap point to the tap overcurrent device and the degree of hazard due to location. A transformer is

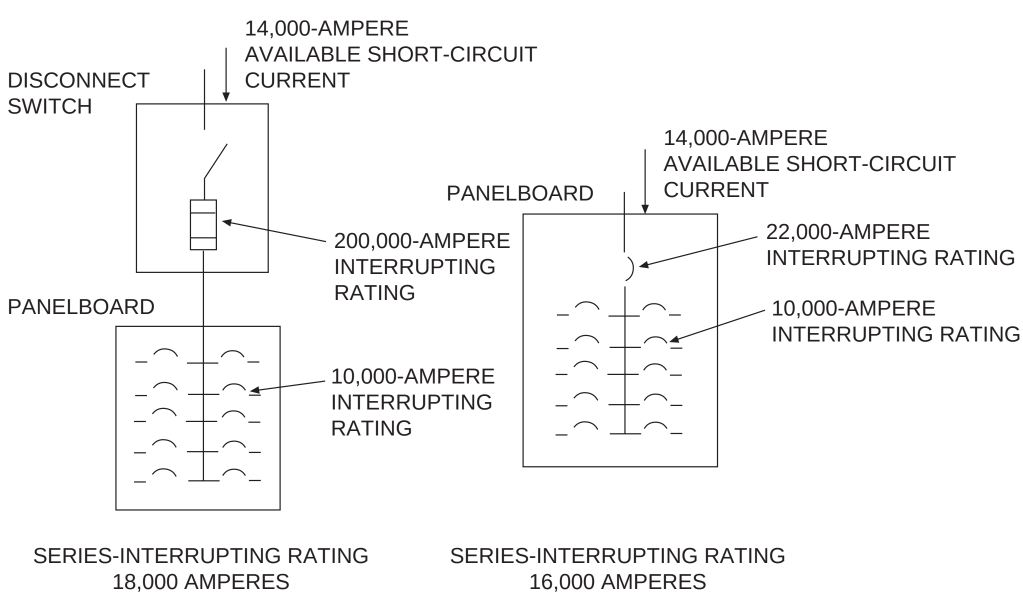


Figure 6.17 Two overcurrent devices in series such as a fuse and circuit breaker or two circuit breakers opening at the same time can act to limit the let-thru current during a short circuit or ground fault to protect load side equipment from excessive current. This arrangement is called a series-rated system.

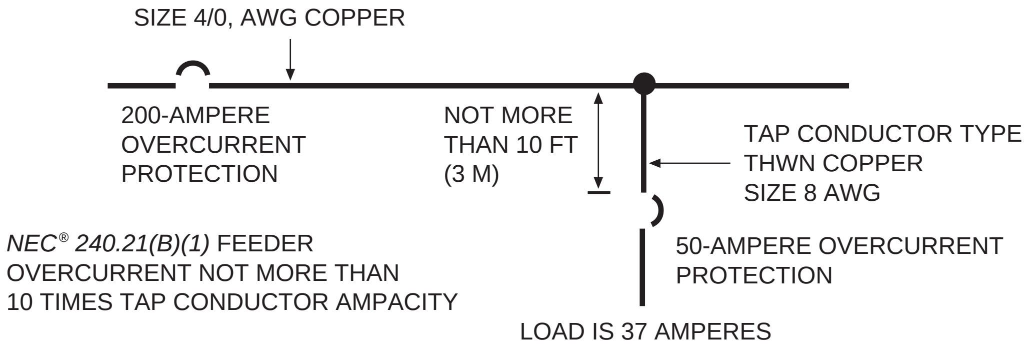


Figure 6.18 A tap is a conductor of lower ampacity connected to a feeder conductor and ending at a single overcurrent device that has a rating not greater than the ampacity of the tap conductor. If the distance from the tap point to the overcurrent device is not more than 10 ft (3 m), the tap conductor is permitted to have an ampacity as low as 10% of the feeder overcurrent device rating.

permitted to be installed along a tap, but that case will be discussed in *Unit 8*. The secondary conductors leaving a transformer are also considered to be tap conductors and those cases will be discussed in *Unit 8*.

The rules for a 10 ft (3 m) tap are covered in *240.21(B)(1)*. The distance from the tap point to the tap overcurrent device is not permitted to be more than 10 ft (3 m). The tap conductor is required to be enclosed in raceway. The tap conductor is required to have an allowable ampacity not less than the load to be served and not less than the rating of the fuse or circuit breaker at its termination. And finally, the tap conductor must have an allowable ampacity not less than 10% of the rating of the overcurrent device protecting the feeder. These rules are illustrated in Example 6.1.

Example 6.1 A feeder protected by a 200-ampere circuit breaker consists of size 4/0 AWG copper Type THW conductors run in Rigid Metal Conduit with several pull boxes located along the length of the feeder. The feeder is tapped at one of the pull boxes to supply an electrical resistance heater with a full-load current of 37 amperes. The distance from the tap point to a 50-ampere rated overcurrent device is just under 10 ft (3 m) as shown in Figure 6.18. The copper Type THWN tap conductors are run in EMT with all terminations rated 75°C. Determine the minimum size tap conductor.

Answer: For this situation there are two points to be considered. First, meet the conditions of *240.21(B)(1)(1)b*. The tap conductor must have an allowable ampacity not less than the overcurrent device at its termination. The overcurrent device has a 50-ampere rating. Therefore, find a copper conductor size that has an allowable ampacity of not less than 50 amperes in the 75°C column of *Table 310.16*. The minimum size permitted is 8 AWG. The other condition is that of *240.21(B)(1)(4)*. The rating of the overcurrent device protecting the feeder is not permitted to have a rating higher than 10 times the allowable ampacity of the tap conductor, which in this case is 500 amperes ($50\text{ A} \times 10 = 500\text{ A}$). Another approach is to divide the feeder overcurrent device rating by 10 to determine the minimum allowable tap conductor ampacity which is 20 amperes ($200\text{ A} / 10 = 20\text{ A}$). The size 8 AWG copper conductor required to supply the load is adequate to also meet this rule. The minimum size tap conductor for this installation is 8 AWG copper.

The tap is permitted to have a total length of 25 ft (7.5 m) from the tap point to the overcurrent device in cases where it is not practical to limit the length of the tap to 10 ft (3 m). The rules for a 25 ft (7.5 m) tap are found in *240.21(B)(2)*. The tap conductor is required to be suitably protected or run in raceway. The tap conductor is required to terminate at a single set of fuses or a circuit breaker with a rating not higher than the allowable ampacity of the tap conductor. And finally, the allowable ampacity of tap conductor is not permitted to be less than one-third the rating of the feeder overcurrent device. Determining the size of a tap conductor for a load using the 25 ft (7.5 m) tap rule is demonstrated by Example 6.2.

Example 6.2 A feeder protected by a set of 400-ampere fuses consists of size 500-kcmil copper Type THWN conductors run in Electrical Metallic Tubing with several pull boxes located along the length of the feeder. The feeder is tapped at one of the pull boxes to supply a load that draws 46 amperes, with the tap terminating at a switch containing 60-ampere fuses. The distance from the tap point to the

60-ampere fuses is just under 25 ft (7.5 m) as shown in Figure 6.19. The tap conductors are copper, Type THWN, all terminations are rated 75°C, and the tap conductors are suitably protected from physical damage. Determine the minimum size tap conductor.

Answer: For this situation there are two points to be considered. First, meet the conditions of *240.21(B)(2)(2)*. The tap conductor must have an allowable ampacity not less than the overcurrent device at its termination. The fuses have a rating of 60 ampere. Therefore, find a copper conductor size that has an allowable ampacity of not less than 60 amperes in the 75°C column of *Table 310.16*. The minimum size copper tap conductor permitted is 6 AWG. The other condition is that of *240.21(B)(2)(1)*. The rating of the overcurrent device protecting the feeder is not permitted to be less than one-third the rating of the overcurrent device protecting the feeder which would be 133 amperes (400 A / 3 = 133A). The tap conductor is required to have an allowable ampacity of not less than 133 amperes even if the load served is much smaller. This rule requires a size 1/0 AWG copper conductor from the tap point to the disconnect switch. The conductors on the load side of the 60-ampere fuses is permitted to be size 6 AWG. The minimum tap conductor size permitted for this installation is 1/0 AWG copper.

In the case of a manufacturing building with a room that is not less than 35 ft (11 m) above the floor at the walls, it would be impractical to tap a feeder run along the underside of the roof. It would not be possible to get to an overcurrent device accessible from the floor within the 25 ft (7.5 m) limit. *NEC® 240.21(B)(4)* permits the tap to be up to 100 ft (30 m) in length in the high ceiling area of a manufacturing building where the tap is actually made not less than 30 ft (9 m) above the floor. The tap is not required to be directly below the tap point. The single overcurrent device at the tap termination is permitted to be located anywhere within 25 ft (7.5 m) measured horizontally of a point directly below the tap to the feeder as illustrated in Figure 6.20. This conductor is required to be not smaller than size 6 AWG copper or size 4 AWG aluminum and they are not permitted to penetrate any walls, floors, or ceilings. The remaining rules are the same as for 25 ft (7.5 m) feeder taps. Example 6.3 is a case in point of a feeder supplying two panelboards in a high ceiling manufacturing building.

Example 6.3 A feeder protected by a 400-ampere circuit breaker consists of size 600-kcmil copper Type THWN conductors run in Electrical Metallic Tubing across the ceiling of a manufacturing building to supply two panelboards each with a 200-ampere main overcurrent device. The feeder is run 40 ft above the floor with the tap points also 40 ft above the floor. The tap conductors are run in Rigid Metal Conduit down a structural support to the panelboard mounted with the top 6 ft (1.83 m) above the floor. The tap conductors are copper, Type THWN, and all terminations are rated 75°C. Determine the minimum size tap conductor.

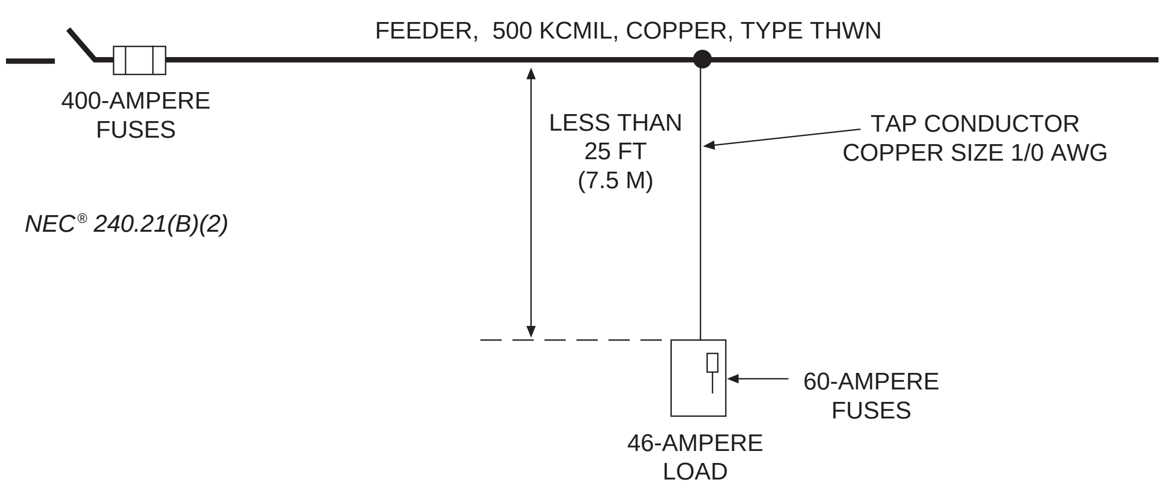


Figure 6.19 If the distance from the tap point to the overcurrent device is not more than 25 ft (7.5 m) and more than 10 ft (3 m), the minimum ampacity of the tap conductor is not permitted to be less than the single overcurrent device at its termination or one-third the rating of the feeder overcurrent device, whichever is higher.

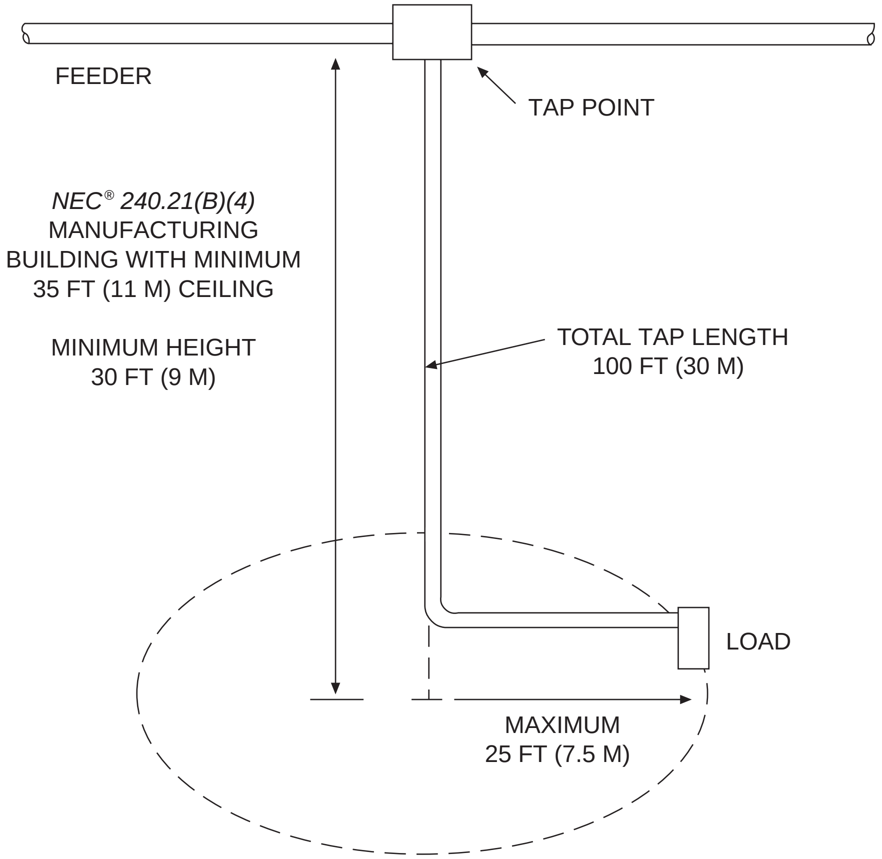


Figure 6.20 In a manufacturing building with a ceiling not less than 35 ft above the floor at the walls, a tap to a feeder made at least 30 ft above the floor is permitted to have a total length of not more than 100 ft and terminate at a single overcurrent device rated not greater than the ampacity of the conductor. The tap conductor ampacity is also not permitted to be less than one-third the rating of the feeder overcurrent device.

Answer: For this situation there are two points to be considered. First, meet the conditions of *240.21(B)(4)(4).* The tap conductor must have an allowable ampacity not less than the overcurrent device at its termination. The overcurrent device has a 200-ampere rating, therefore, find a copper conductor size that has an allowable ampacity of not less than 200 amperes in the 75°C column of *Table 310.16.* The minimum size permitted is 3/0 AWG. The other condition is that of *240.21(B)(4)(3).* The tap conductor ampacity is not permitted to be less than one-third the rating of the feeder overcurrent device. According to this rule, the tap conductor is required to have an ampacity not less than 133 amperes (400 A / 3 = 133 A). The load requires size 3/0 AWG. Therefore, the ampacity required by this rule is easily exceeded. The minimum size tap conductor for this installation is 3/0 AWG copper with a total length of approximately 34 ft (10.36 m).

Tap conductors, either run overhead or underground, are frequently outdoors except at the point of entry to a building. *NEC® 240.21(B)(5)* permits a feeder conductor that is run outside a building to be tapped, outside the building, to supply another load provided the feeder has an adequate ampacity, as determined by *215.2,* to supply all loads. The tap conductor is permitted to be of any length provided it is run completely outside except at the point of entry to the building supplied. The tap conductor is required to be sized to the load served, but it is not required to be limited by the rating of the feeder overcurrent device. Example 6.4 will show an application of the outside tap rule.

Example 6.4 A group of several buildings are supplied power from a central distribution point consisting of a 400-ampere fusible switch rated as suitable for use as service equipment, and located outdoors near the utility transformer pole. A tap box is installed at this location and the buildings are supplied using underground aluminum Type USE single-conductor direct burial cable. A tap box is installed beside the service disconnect and no overcurrent protection other than the 400-amperes fuses

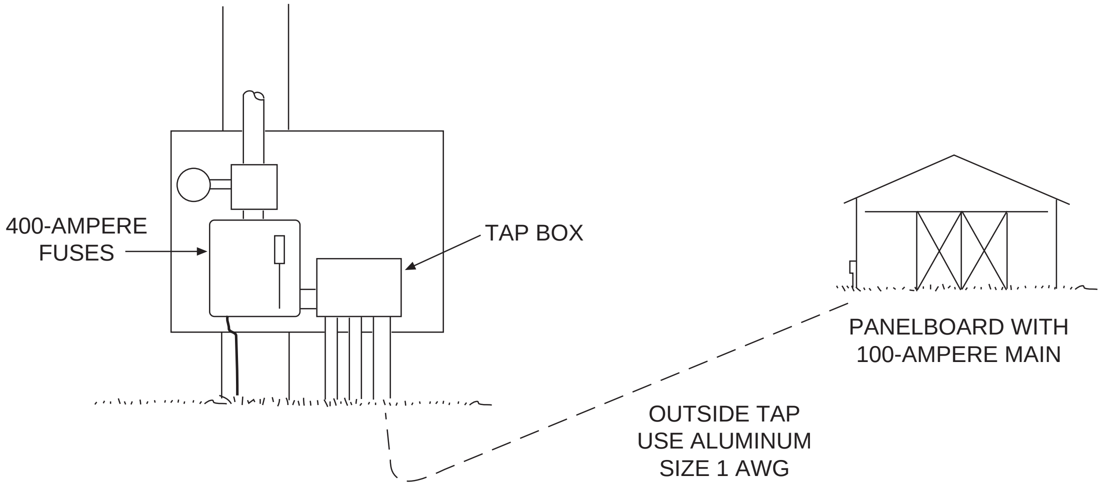


Figure 6.21 A tap to a feeder that is completely outside a building except at the point of termination to the building is permitted to be of any length and is only required to have an ampacity not less than the single overcurrent device at its termination.

in the service disconnect protects the taps to the buildings. One of the taps is 150 ft in length and terminates at a panelboard with a 100-ampere main circuit breaker. The tap is illustrated in Figure 6.21. All terminations are 75°C rated. Determine the minimum size aluminum tap conductor.

Answer: There is only one condition that must be met to size the conductor—provided this qualifies as an outside tap. The allowable ampacity of the conductor is not permitted to be less than the rating of the 100-ampere overcurrent device at its termination. Look up the minimum conductor size in the 75°C column of *Table 310.16*. The minimum tap conductor size for this situation is 1 AWG aluminum, Type USE.

VOLTAGE DROP

The minimum size conductor for a branch-circuit or feeder may not be adequate if the circuit or feeder length causes an excessive voltage drop. Excessive voltage drop results in inefficient operation of electrical equipment, sometimes malfunctioning of control systems, and premature motor failure. Voltage drop is caused by the current experiencing the resistance of the circuit. The more current, the more voltage drop caused by the circuit conductors. This is simple Ohm's law such as described in Equation 1.4 in *Unit 1*. The solution is to reduce the resistance of the conductors which is described by Equation 1.2 in *Unit 1*. An actual circuit is two wires for single-phase and three wires for 3-phase. Therefore, Equation 1.4 must be modified to account for all circuit conductors. Equation 6.1 can be used to determine voltage drop in a single-phase circuit. Equation 6.2 accounts for the current flowing on all three conductors and gives the voltage drop for a 3-phase circuit.

$$\textbf{Voltage} = \textbf{Current} \times \textbf{Resistance} \qquad \textbf{Eq. 1.4}$$

$$\textbf{Resistance of Wire} = \frac{\textbf{Resistivity (K)} \times \textbf{Length (L)}}{\textbf{Area (A)}} \qquad \textbf{Eq. 1.2}$$

Single-phase circuit

$$\textbf{Voltage Drop} = \textbf{2} \times \textbf{Current} \times \textbf{Resistance} \qquad \textbf{Eq. 6.1}$$

Three-phase circuit

$$\textbf{Voltage Drop} = \textbf{1.73} \times \textbf{Current} \times \textbf{Resistance} \qquad \textbf{Eq. 6.2}$$

The Code does not have a requirement on the amount of voltage drop permitted on branch-circuits and feeders in general. It is suggested, however, that a maximum of 5% voltage drop be permitted on a feeder plus branch-circuit to the most distant point of power use. This is in the form of a FPN in *215.2* and *210.19(A) FPN 4.* Many tables, charts, and formulas are available to size wires that limit voltage drop to within a specified percentage. Voltage drop is the extent to which the line voltage at the source end of a branch-circuit or feeder is reduced as the load current flows along the conductors. The way to measure voltage drop is to operate the load, then measure the voltage at the source end of the branch-circuit or feeder and at the load end. Equation 6.3 can be used to determine the percent voltage drop when the line-to-line voltage is measured at the source and load ends of a conductor carrying current. Example 6.5 shows how percentage voltage drop can be determined for an actual circuit.

$$\textbf{Percent Voltage Drop} = \frac{\textbf{Voltage}_{\textbf{Source}} - \textbf{Voltage}_{\textbf{Load}}}{\textbf{Voltage}_{\textbf{Source}}} \times \textbf{100} \qquad \textbf{Eq. 6.3}$$

Example 6.5 A single-phase, 5-horsepower, 240-volt electric motor draws 28 amperes and is supplied by size 8 AWG copper conductors that have a one-way length from the panelboard to the motor of 360 ft (109.7 m). During the normal operation within the building and the motor running, there was 240 volts at the panelboard and 225.3 volts at the motor. Determine the percent voltage drop for this circuit.

Answer: Use Equation 6.3 to determine the percentage voltage drop. The 240 volts is at the source and the 225.3 volts is at the load. For this circuit, the voltage drop is 6.1%.

$$\text{Percent Voltage Drop} = \frac{240\text{ V} - 225.3\text{ V}}{240\text{ V}} \times 100 = 6.1\%$$

Calculating the expected voltage drop for a circuit involves looking up the resistance of the conductor in *Table 8, Chapter 9* of the Code for the proper wire size, and making an adjustment for the actual length and operating temperature. A typical operating temperature for branch-circuits and feeders can be assumed to be about 50°C. The values of resistance in *Table 8* are at 75°C. Another way to determine expected voltage drop is to substitute Equation 1.2 into Equation 6.1 or 6.2 and come up with a new equation where all you need to do is remember the typical value of resistivity for the conductor. The result is the following two equations for voltage drop, where Equation 6.4 is for single-phase voltage drop and Equation 6.5 is for 3-phase voltage drop. Values of resistivity **K** for copper and aluminum conductors in both English and metric units are given in Table 1.2 in *Unit 1.* Suggested values for **K** are at approximately 50°C and are listed below:

Single-phase

$$\textbf{Voltage Drop} = \frac{\textbf{2} \times \textbf{K} \times \textbf{Current} \times \textbf{One-way length}}{\textbf{Wire cross-sectional area}} \qquad \textbf{Eq. 6.4}$$

Three-phase

$$\textbf{Voltage Drop} = \frac{\textbf{1.73} \times \textbf{K} \times \textbf{Current} \times \textbf{One-way length}}{\textbf{Wire cross-sectional area}} \qquad \textbf{Eq. 6.5}$$

English Units: K = 12 for copper and 19 for aluminum
One-way length is in ft
Wire cross-sectional area is in circular mils (cmil)

Metric Units: K = 0.02 for copper and 0.032 for aluminum
One-way length is in meters (m)
Wire cross-sectional area is in square millimeters (mm^2)

Example 6.6 A building with a 120/240-volt single-phase, 100-ampere panelboard is supplied with a size 3 AWG overhead aluminum triplex cable, which is 180 ft (54.86 m) in length. If the typical load in the building is evenly balanced with 80 amperes, on each ungrounded conductor, determine if the voltage drop on the overhead conductor is in excess of 2% assuming 240 volts at the supply end of the triplex cable.

Answer: First multiply 240 volts by 0.02 to get 4.8 volts as a 2% voltage drop. Next, use Equation 6.4 to determine the expected voltage drop. It will be assumed the conductor temperature will be approximately 50°C. Use 19 (0.032 metric) as the value of **K** in Equation 6.4. It will be necessary to look up the cross-sectional area of a size 3 AWG conductor in *Table 8, Chapter 9* in the Code and find it to be 52,620 cmil (26.7 mm²). The expected voltage drop is 10.4 volts, which is more than 2%.

$$\text{Voltage Drop} = \frac{2 \times 19 \times 80\text{A} \times 180 \text{ ft}}{52{,}620 \text{ cmil}} = 10.4 \text{ volts}$$

$$\text{Voltage Drop} = \frac{2 \times 0.032 \times 80 \text{ A} \times 54.86 \text{ m}}{26.7 \text{ mm}^2} = 10.5 \text{ volts}$$

If voltage drop was expected to be excessive, then it would be desirable to have an easy way to select a wire size that would limit the voltage drop to the desired percentage. That can easily be accomplished by a slight rearrangement of Equations 6.4 and 6.5. The following Equations 6.6 and 6.7 can be used to determine the wire size required to limit the voltage drop. The result of the calculation will be the cross-sectional area of the wire. The actual wire size is found in *Table 8, Chapter 9* in the Code. The value for voltage drop in the equation is actually in decimal. For example, if the desired voltage drop is 3%, insert 0.03 into the equation.

Single-phase

$$\textbf{Wire cross-sectional area} = \frac{\mathbf{2 \times K \times Current \times One\text{-}way\ length}}{\mathbf{\%\ voltage\ drop \times Voltage_{Supply}}} \qquad \textbf{Eq. 6.6}$$

Three-phase

$$\textbf{Wire cross-sectional area} = \frac{\mathbf{1.73 \times K \times Current \times One\text{-}way\ length}}{\mathbf{\%\ voltage\ drop \times Voltage_{Supply}}} \qquad \textbf{Eq. 6.7}$$

Example 6.7 A building with a 120/240-volt single-phase, 100-ampere panelboard is supplied with an overhead aluminum triplex cable which is 180 ft (54.86 m) in length. If the typical load in the building is evenly balanced with 80 amperes on each ungrounded conductor, determine the minimum size conductor required to limit the voltage drop on the feeder to 2%.

Answer: Use Equation 6.6 to find the cross-sectional area of the conductor required to limit the voltage drop to 2%. Assume the conductor operating temperature is approximately 50°C and the value of **K** for the equation will be 19 (0.032 metric). The cross-sectional area of conductor needed is 114,000 cmil (58.5 mm²). Now look up the conductor size in *Table 8, Chapter 9* of the Code and find size 2/0 AWG.

$$\text{Wire cross-sectional area} = \frac{2 \times 19 \times 80 \text{ A} \times 180 \text{ ft}}{0.02 \times 240 \text{ V}} = 114{,}000 \text{ cmil}$$

$$\text{Wire cross-sectional area} = \frac{2 \times 0.032 \times 80 \text{ A} \times 54.86 \text{ m}}{0.02 \times 240 \text{ V}} = 58.5 \text{ mm}^2$$

For wire sizes larger than AWG number 4/0, skin effect and inductive reactance frequently become significant and must be considered. *Table 9, Chapter 9* of the Code contains impedance values of wires in different types of raceway where the power factor is not unity. If a motor load is being supplied by a branch-circuit or feeder, the voltage drop can be estimated using the impedance values from *Table 9*. If the power factor of the circuit or feeder is approximately 0.85, then impedance values are given in *Table 9*.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the *2008 NEC®* that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 240 **Overcurrent Protection**

240.4(D): For the first time, the Code now permits size 18 AWG copper and size 16 AWG copper wires for use as power circuit wires in applications other than in luminaires and appliances. The conductors are required to be protected from overcurrent rated at not more than 7 amperes for size 18 AWG and 10 amperes for size 16 AWG. If the conductors are supplying continuous loads, the overcurrent devices are not permitted to be loaded to more than 80% of the overcurrent device rating. The previous edition of the Code primarily limited wires of these sizes to control circuit applications. Requirements for type of overcurrent protection are also covered in this section. The minimum size for premises wiring remains as 14 AWG copper according to *310.5*. An application for the new rule is industrial machinery systems wiring.

240.5(B)(1): A new sentence was added that points out that if the branch-circuit rating exceeds the maximum ratings listed in *240.5(B)(2)* for fixture wires, the fixtures wires are required to be provided with overcurrent protection. This is not a change, but points out that luminaires are permitted to be installed on circuits of higher rating provided the wires within the luminaire are provided with overcurrent protection.

240.21(C)(2)(4): This paragraph sets limits on the minimum size of tap conductors that are permitted on the secondary side of a transformer. The overcurrent protection on the primary is not permitted to exceed 10 times the ampere rating of the smallest secondary conductor after adjusting for the voltage change. The change is that this rule only applies to conductors extending outside of the transformer enclosure or outside of the transformer vault. This means that instrumentation and control wires within the transformer enclosure or within the vault room are exempt from this rule and are permitted to be sized according to their respective purpose.

240.21(C)(3): This is a special transformer tap rule that applies only for industrial applications where the secondary conductors from the transformer have an ampere rating not less than that of the transformer secondary and ends in multiple overcurrent devices which have a combined rating not more than the ampere rating of the conductor. The change is that this practice is only permitted where qualified personnel will service the installation.

240.21(H): This is a new paragraph that requires overcurrent protection to be provided in direct current wires from a storage battery to be installed as close to the battery as practical.

240.24(F): Overcurrent devices are not permitted to be located over steps of a stairway, as illustrated in Figure 6.22.

240.86(A): This paragraph permits a licensed professional engineer to select a series rated set of overcurrent devices. A new paragraph was added that points out a caution that the engineer must make sure that the load side overcurrent device does not trip or open faster than the line side overcurrent device.

240.92(B): This is a new paragraph that permits sizing of feeder taps of lengths of 25 ft (7.5 m) as described in *240.21(B)(2), 240.21(B)(3),* and *240.21(B)(4)* using a calculating method as described in a new *Table 240.92(B)*. This is only permitted in supervised industrial installations.

Article 408 **Switchboards and Panelboards**

408.3(F): In the case of a 240/120 volt, 4-wire delta, 3-phase electrical system, the midpoint of one phase is grounded to form a 120/240 volt, 3-wire, single-phase system, and by adding the other ungrounded

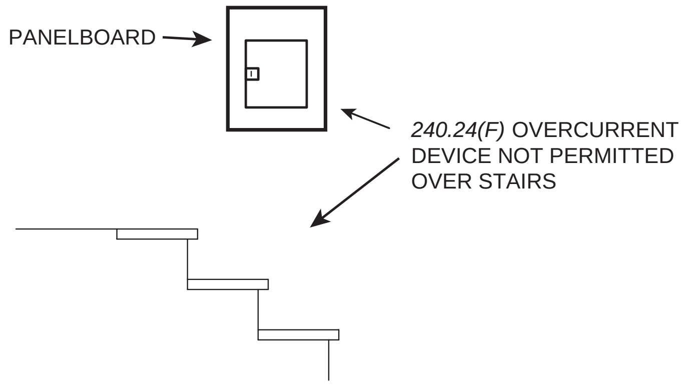


Figure 6.22 Overcurrent devices are not permitted to be located above a stairway; therefore, a panelboard is not permitted to be located above stairs.

conductor a 240 volt 3-phase system is also available. Two of the ungrounded conductors will have a nominal 120 volts to ground, and the third ungrounded conductor will have a nominal 208 volts to ground. In *110.15* and *408.3(E)*, that phase is described as the one with the higher voltage to ground. In *110.15*, that phase is required to be provided at the time of installation with orange markings at points of termination and potential points of connection. In *408.3(E)*, that conductor with the higher voltage to ground is required to be installed such that it is the “B” phase. Apparently, these identifying techniques are not sufficient to prevent problems, and now this new paragraph requires that a warning label be attached to the switchboard or panelboard. The warning label is to read “Caution B Phase has 208 Volts to Ground,” as illustrated in Figure 6.23.

408.4: This section requires labeling of circuits in switchboards and panelboards. Two new points were added to the list of circuit labeling requirements. Unused or spare switches or circuit breakers are to be labeled as spare or unused. The other is that circuits are to be labeled in such a manner that the outlets they supply are identified by a physical characteristic of the structure and not based upon some transient description such as “receptacles in spare office.” That office may not be spare with the next occupant. Examples are shown in Figure 6.24.

408.34: This section that provided a description of a lighting and appliance branch-circuit panelboard and a power panelboard was deleted. The Code makes no distinction between these two types of panelboards.

408.35: This section specified a maximum of 42 overcurrent devices in a lighting and appliance branch circuit panelboard. This section was deleted. The only reference to a maximum of 42 overcurrent devices is now in *408.36 Exception 2* and *408.55 Exception 1*. There is a new section *408.54* that makes reference to the maximum number of overcurrent devices, but there is no set maximum number.

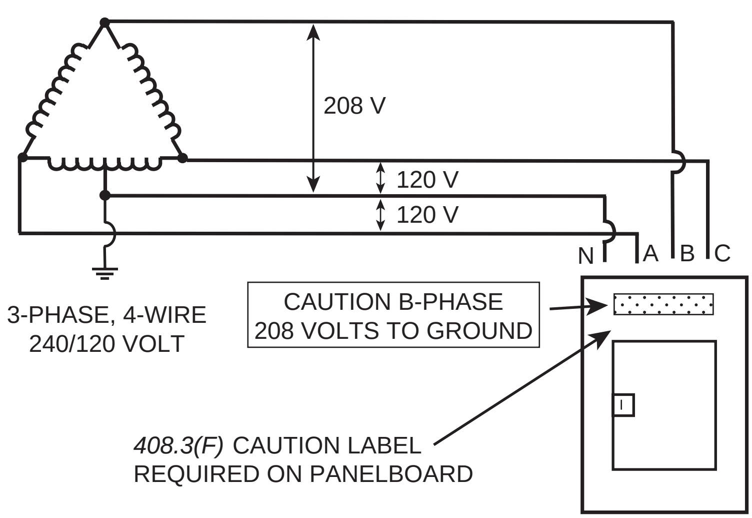


Figure 6.23 When a panelboard is supplied power from a 240/120 volt, 4-wire, 3-phase delta electrical system, one phase conductor has a higher voltage to ground than the other phases; thus, the panelboard is required to be provided with a warning about the phase with the higher voltage to ground.

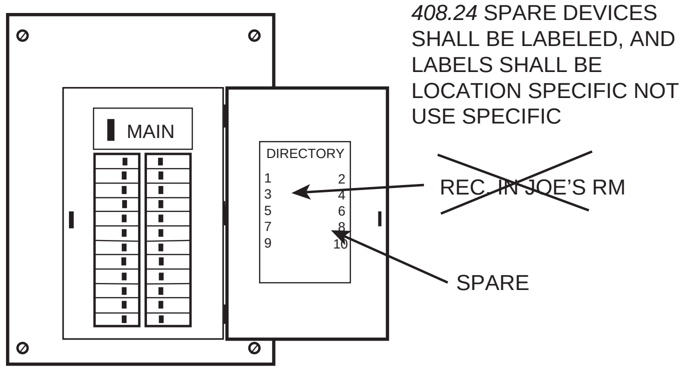


Figure 6.24 The directory in a panelboard must indicate if an overcurrent device is a spare and not used, and circuit descriptions must be unique to the structure and not to their use.

408.36: There is no longer a distinction between a power panelboard and a lighting and appliance branch-circuit panelboard. The section simply states that all panelboards are required to be protected by an overcurrent device with a rating not greater than the rating of the panelboard.

408.36 Exception 1: When used as service equipment, a panelboard is permitted to be protected by multiple circuit breakers or sets of fuses in accordance with *230.71* as shown in Figure 6.25. There are no other limitations other than that in the case of three or more main overcurrent devices the panelboard is only permitted to have a single bus set. An overcurrent device is not permitted to supply a second bus in the panelboard. In the past, this practice was not permitted if there were more than 10% of the overcurrent devices rated 30 amperes or less where a neutral was used as a part of the circuit. That limitation no longer exists.

408.36 Exception 2: A panelboard is permitted to be protected by two circuit breakers or two sets of fuses, provided the total number of other overcurrent devices does not exceed 42.

408.54: This new section simply specifies that a panelboard is not permitted to accept more overcurrent devices than for which it was listed. It is permitted for a panelboard to be listed for more than 42 overcurrent devices.

408.55 Exception 1: The section requires both a top and bottom wire bending space to be sized in accordance with *Table 312.6(B).* This exception only requires the top or the bottom wire bending space to be sized in accordance with *Table 312.6(B)* with the other sized according to *Table 312.6(A),* and where the rating of the panelboard is 225 amperes or less. An additional restriction was added that the panelboard is to be designed to contain not more than 42 overcurrent devices. These rules are illustrated in Figure 6.26.

Article 550 Mobile Homes, Manufactured Homes, and Mobile Home Parks

550.25(B): This section specifies that all 15- or 20-ampere, 120-volt outlets installed in bedrooms of a mobile home or manufactured home are to be arc-fault circuit-interrupter protected in accordance with *210.12(B).* For permanent homes, rooms other than bedrooms are covered by this rule, but not for

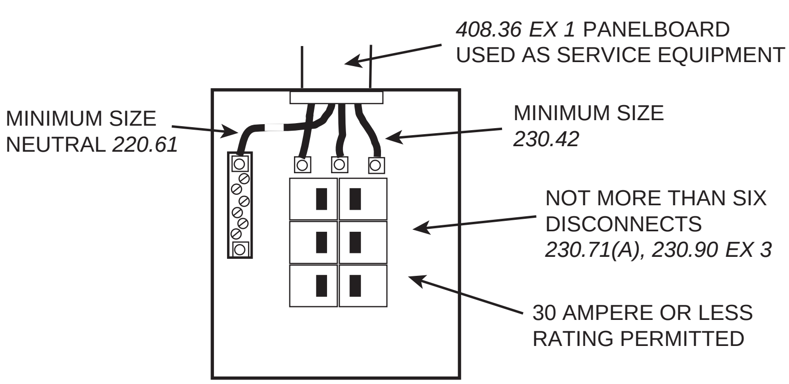


Figure 6.25 A panelboard used as service equipment is permitted to contain up to six overcurrent devices as mains, and there is no limitation on the rating or use of these six overcurrent devices.

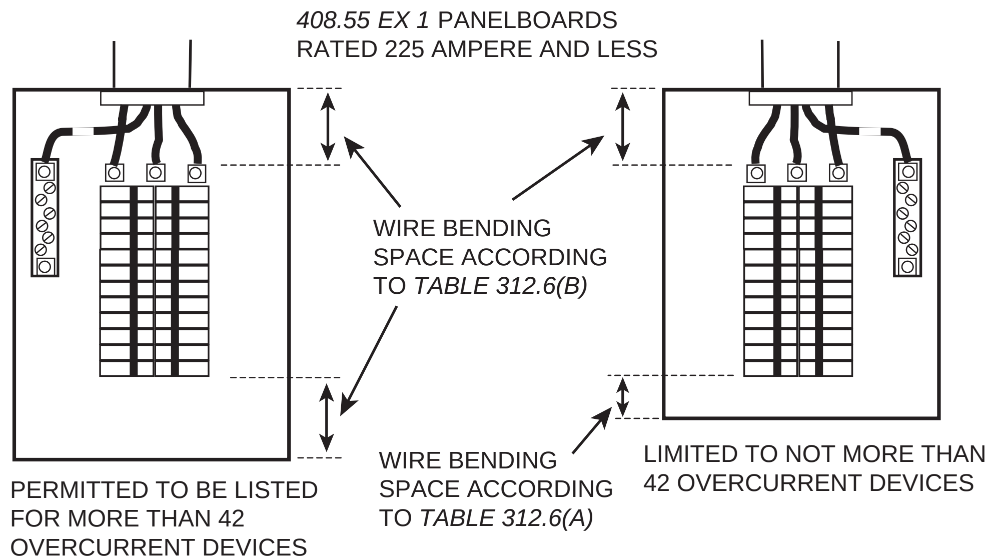


Figure 6.26 A panelboard rated 225 amperes or less with the top or bottom wire bending space meeting the requirements of *Table 312.6(B)* and the other meeting the requirements of *Table 312.6(A)* is limited to a maximum of 42 overcurrent devices.

mobile homes and manufactured homes. After January 1, 2008 the arc-fault circuit-interrupter (AFCI) will be required to be of the combination type. Also the AFCI will be permitted to be of the receptacle type if installed according to the rules of *210.12(B) Exception 1*.

550.33(A)(2): The service for a mobile home is permitted to be located elsewhere on the property with a feeder extending to a disconnecting means adjacent to the mobile home. That disconnect is required to be rated as suitable for use as service equipment, *550.32(A)*. The change deals with the feeder conductors run from the remote service and the disconnect at the mobile home site. For new installations, that feeder is required to be 4-wire with an insulated neutral and a separate equipment grounding conductor. The grounded feeder conductor is not permitted to be grounded at the mobile home site disconnecting means. There is an exception for an existing feeder that does not have a separate equipment grounding conductor. The exception permits the grounded circuit conductor to serve as the equipment grounding conductor and be connected to the grounding electrode at the mobile home site. This is illustrated in Figure 6.27. This is the same rule as *250.32(B)* which applies in the case of electrical supply to other buildings or structures on the same property.

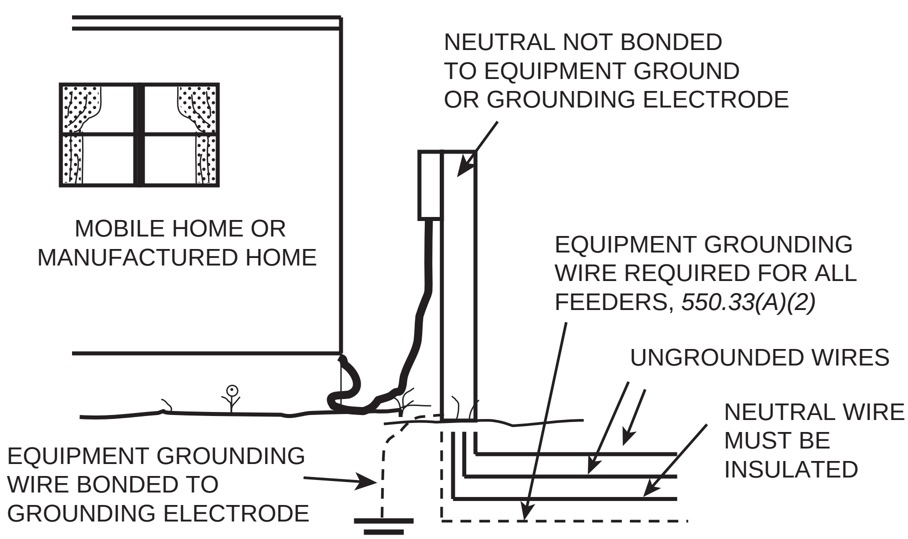


Figure 6.27 For all new feeder installations to a mobile home site, the neutral conductor is required to be insulated, and a separate conductor for equipment grounding is required for both overhead and underground installations.

Article 551 **Recreational Vehicles and Recreational Vehicle Parks**

551.4: A recreational vehicle and recreational vehicle park are now permitted to be supplied using 208/120 volt, 3-phase feeders to supply recreational vehicle sites.

551.31(C): An alternate power supply for a recreational vehicle is now permitted to be derived from a 208/120 volt, 3-phase supply.

551.42(D): A recreational vehicle is permitted to have a power-assembly rated 120/208-240 volt, 50 amperes. The previous edition of the Code only recognized a power-assembly rated 120/240 volt at 50 amperes.

551.46(D): The label near the power supply entrance to a recreational vehicle is now permitted to include 208/120 volt as well as 120/240 volt.

551.47(P)(2): The wiring that is installed in the expandable unit of a recreational vehicle is permitted to be run as flexible cord. There is now a longer list of wiring requirements for the installation of flexible cord as permanent wiring in the expandable unit.

551.47(R)(1): Where a generator on the recreational vehicle provides overcurrent protection for wiring supplied by the generator, additional overcurrent protection is not required to be installed.

551.47(R)(4): The label on the cover of the junction box providing wires for a generator connection is now required to state that the generator is to be listed for RV use.

551.47(S): This is a new section that provides requirements for the pre-wiring of circuit for future appliances. Requirements are provided for the installation of the circuits as well as the safe termination of the circuit conductors.

551.60(4): This is a new provision under factory testing that requires all GFCI devices to be tested by the RV manufacturer to make sure they are working properly.

WORKSHEET NO. 6—BEGINNING OVERCURRENT PROTECTION

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A standard rating of an overcurrent device as recognized by the Code is:
   A. 55 amperes.
   B. 130 amperes.
   C. 700 amperes.
   D. 750 amperes.
   E. 1500 amperes.

   Code reference ___________________

2. A molded-case circuit breaker permitted to be used as a switch for high-pressure sodium luminaires (lighting fixtures) in a gymnasium is required to be labeled:
   A. with circuit rating.
   B. SWD.
   C. suitable as switch for luminaires (lighting fixtures).
   D. HPS loads.
   E. HID.

   Code reference ___________________

3. The screw shell fuse with a hexangular window as shown in Figure 6.28 has a rating of not over:
   A. 10 amperes.
   B. 15 amperes.
   C. 20 amperes.
   D. 25 amperes.
   E. 30 amperes.

   Code reference ___________________

4. A size 14 AWG copper conductor serves less than 12 ampere of fixed lighting load in a commercial building. The conductor insulation and terminations are 75°C rated and the allowable ampacity of the conductors from *Table 310.16* is 20 amperes. The maximum rating overcurrent protection permitted for the circuit is:
   A. 12 amperes.
   B. 15 amperes.
   C. 17.5 amperes.
   D. 20 amperes.
   E. 25 amperes.

   Code reference ___________________

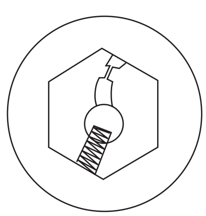


Figure 6.28 What is the maximum rating of a plug fuse with a hexangular window?

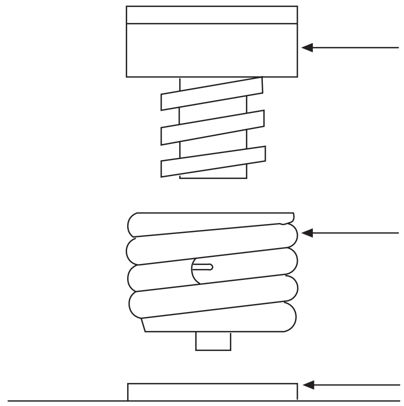


Figure 6.29 What kind of screw shell fuse uses an adapter in the screw shell fuseholder?

5. When an electrician installs a device that accepts screw shell fuses, they are to be of the type shown in Figure 6.29 that have an adapter that will only accept a fuse up to a particular maximum rating. This type of fuse in the Code is called:
   A. a Type S fuse.
   B. an Edison-base fuse.
   C. a current-limiting fuse.
   D. a class K fuse.
   E. an instantaneous fuse.

   Code reference ___________________

6. When terminating neutral conductors and equipment grounding conductors to the neutral terminal bus in a service panelboard:
   A. only a single neutral conductor is permitted to be connected to a terminal.
   B. only one neutral and one equipment grounding conductor of the same circuit are permitted to be connected to a terminal.
   C. any number of neutral and equipment grounding conductors are permitted to be connected to a terminal if they will fit the space available.
   D. not more than two neutral conductors are permitted to be connected to a terminal.
   E. there is no limit to the number of conductors for any terminal provided a minimum torque is applied to the terminal.

   Code reference ___________________

7. A feeder consisting of size 350 kcmil copper conductors is protected with 300-ampere fuses and is run through a commercial building in Rigid Metal Conduit. The feeder is tapped to supply a 100-ampere panelboard with size 3 AWG copper tap conductors run in Rigid Metal Conduit. All conductor insulation and terminations are rated 75°C shown in Figure 6.30. The maximum distance permitted from the tap point on the feeder to the 100-ampere rated overcurrent device in the panelboard is:
   A. 10 ft (3 m).
   B. 25 ft (7.5 m).
   C. 30 ft (9 m).
   D. 50 ft (15 m).
   E. 100 ft (30 m).

   Code reference ___________________

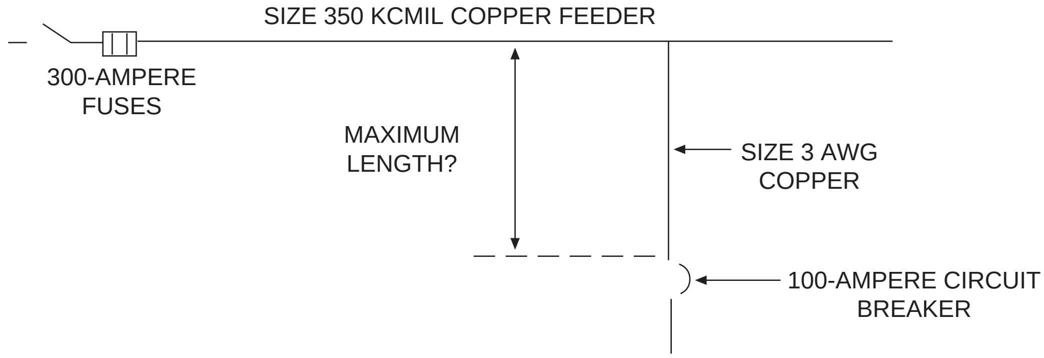


Figure 6.30 Based upon the feeder overcurrent protection and sizes of conductors, what is the maximum distance permitted from the tap point to the 100-ampere circuit breaker?

8. The maximum number of single-pole circuit breakers that are permitted to be installed in a lighting and appliance branch-circuit panelboard is:
   A. 24.
   B. 30.
   C. 36.
   D. 42.
   E. limited to the design and listing of the panel.

   Code reference ___________________

9. A panelboard marked as suitable for use as service equipment is used as the service for a building supplied by a 3-phase, 240/120-volt delta, 4-wire electrical system where the midpoint of one phase is grounded and one of the three phase conductors is 208 volts to ground. The phase with the higher voltage to ground is required to be placed in the center ungrounded lug of the panel and the conductor is required to be identified with tape, paint, or other suitable marking that is the color:
   A. red.
   B. blue.
   C. yellow.
   D. brown.
   E. orange.

   Code reference ___________________

10. A mobile home served with 120/240-volt 3-wire service that has a calculated load greater than 50 amperes is required to be supplied power using a permanent wiring method from the adjacent power supply pole to the mobile home. The power supply feeder is required to consist of:
    A. three insulated conductors and an equipment ground permitted to be bare.
    B. only three insulated conductors if the mobile home panel is grounded to the earth.
    C. four insulated and color-coded conductors—one of which is an equipment grounding conductor.
    D. two insulated and color-coded ungrounded conductors with the neutral permitted to be bare.
    E. three insulated conductors and a bare equipment grounding conductor with the insulated conductors permitted to be identified with colored tape.

    Code reference ___________________

11. A luminaire (lighting fixture) mounted in the ceiling of a mobile home bedroom is required to be:
    A. arc-fault circuit-interrupter protected.
    B. installed on a circuit with other than receptacles in the same room.
    C. ground-fault circuit-interrupter protected.
    D. thermally protected.
    E. only an electric discharge type luminaire (lighting fixture).

    Code reference ___________________

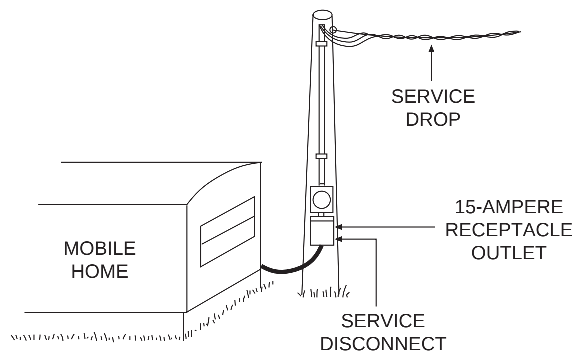


Figure 6.31 What are the requirements on the receptacle outlet in the service equipment for a mobile home?

12. A 15- or 20-ampere, 125-volt rated receptacle located in service equipment for a mobile home, as shown in Figure 6.31, is required to be:
    A. rated as suitable for use as service equipment.
    B. mounted at a height of not less than 2 ft (600 mm) above grade.
    C. arc-fault circuit-interrupter protected.
    D. of the grounding type and grounded with an insulated copper equipment grounding conductor.
    E. ground-fault circuit-interrupter protected for personnel.

    Code reference ___________________

13. A mobile home receives power with a 50-ampere rated power cord. After installation, the minimum length of the power cord permitted from the face of the attachment plug cap to the point where the cord enters the mobile home, as illustrated in Figure 6.32, is:
    A. 6 ft (1.8 m).
    B. 12 ft (3.7 m).
    C. 20 ft (6 m).
    D. 30 ft (9 m).
    E. $36^1/_2$ ft (11 m).

    Code reference ___________________

14. The recreational vehicle site electrical supply pedestal is:
    A. permitted to have a disconnect for all ungrounded conductors at a remote panelboard.
    B. required to have the disconnect for all ungrounded conductors located at a remote panelboard.

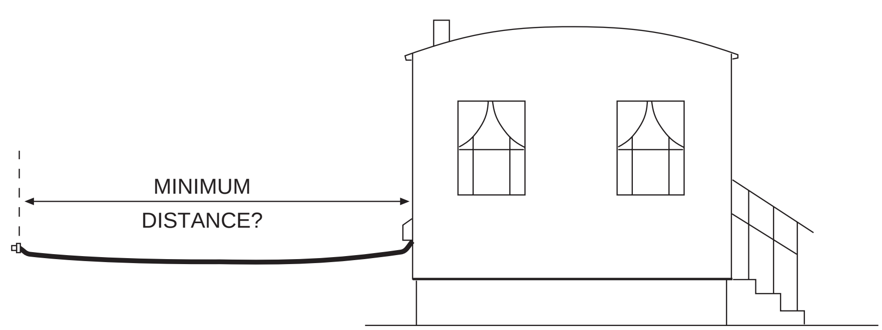


Figure 6.32 What is the minimum length of power cord for a mobile home after installation?

C. required to have a disconnect capable of being locked in the open position.
D. required to be a switch or circuit breaker located at the pedestal.
E. required to have the disconnect and receptacles located not less than 4 ft (1.2 m) above grade.

Code reference ___________________

15. A park trailer has a circuit prewired for a future air conditioner with the wires terminating at a junction box with a blank cover and the ends of the conductors capped and taped. This circuit is:

A. a violation of *Article 552*.
B. permitted to be used for a purpose other than an air conditioner in the future.
C. only permitted to supply a load which is 50% of the circuit rating.
D. required to have a label at the junction box stating the conductors are for future connection of an air conditioner.
E. is only permitted for use with an air conditioner operating at not more than 24 volts.

Code reference ___________________

WORKSHEET NO. 6—ADVANCED OVERCURRENT PROTECTION

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. If a feeder conductor in a manufacturing building area with a ceiling that is at least 35 ft (11 m) high at the walls is tapped, with the tap point at least 30 ft (9 m) above the floor, the total length of the tap is permitted to be greater than 25 ft (7.5 m) in length. The tap conductor is to end at a single overcurrent device with a rating not greater than the ampacity of the tap conductor and the feeder overcurrent device is not permitted to have a rating greater than three times the ampacity of the tap conductor. In this case, the tap conductor is permitted to have a total length not to exceed:
   A. whatever length is needed to reach the load.
   B. 30 ft (9 m).
   C. 50 ft (15 m).
   D. 75 ft (22.9 m).
   E. 100 ft (30 m).

   Code reference ___________________

2. A cartridge fuse that does not have an interrupting rating marked on the exterior of the fuse has an interrupting rating of:
   A. 5000 amperes.
   B. 10,000 amperes.
   C. 50,000 amperes.
   D. 100,000 amperes.
   E. 200,000 amperes.

   Code reference ___________________

3. A 2-pole circuit breaker for a single-phase 240-volt load is installed in a panelboard supplied by a 3-phase, 240/120-volt, 4-wire delta electrical system with the midpoint of one phase grounded and one phase operating with a higher voltage to ground than the other two phases, as shown in Figure 6.33. A circuit breaker installed in a panelboard and connected to the phase with the higher voltage to ground:
   A. shall be marked 240 volts.
   B. shall be marked 120/240 volts.
   C. shall be two single-pole circuit breakers connected with handle ties.
   D. is permitted to be two single-pole circuit breakers connected with handle ties.
   E. is permitted to be marked 120/240 volts.

   Code reference ___________________

4. A molded-case circuit breaker permitted to be used as a switch for fluorescent luminaires (lighting fixtures) in a commercial building can be labeled:
   A. switch duty.
   B. FLU.
   C. HID.
   D. HPS loads.
   E. suitable as switch for luminaires.

   Code reference ___________________

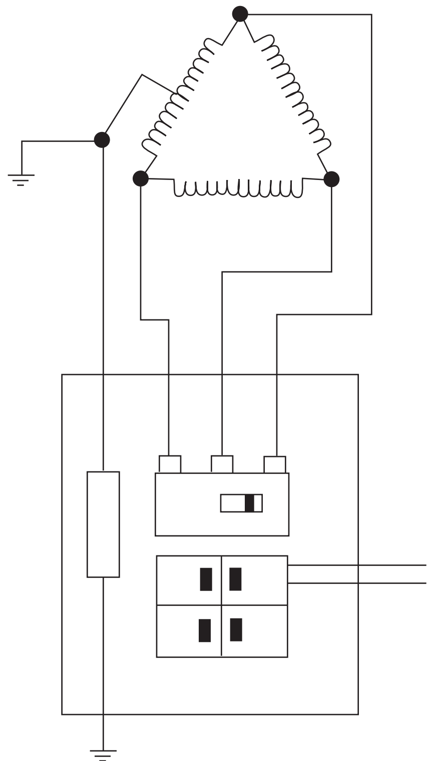


Figure 6.33 What are the requirements on the two-pole circuit breaker in this case connected to the system B phase?

5. Electrical equipment intended to disconnect power at fault levels shall, for the nominal circuit voltage and current that is available, have a sufficient:
   A. continuous current rating.
   B. demand factor.
   C. interrupting rating.
   D. overload capacity.
   E. circuit impedance.

   Code reference ___________________

6. A 300-ampere service entrance consists of a panelboard with a single main overcurrent device rated at 200 amperes and a 100-ampere fused disconnect switch. The panelboard and the disconnect switch are both rated as suitable for use as service equipment and they are tapped from a size 500 kcmil, Type THWN aluminum service-entrance conductors as shown in Figure 6.34. All conductor terminations are rated 75°C. If the service tap conductors to the 100-ampere disconnect are Type THWN aluminum, the minimum size permitted is:
   A. 3 AWG.
   B. 1 AWG.
   C. 1/0 AWG.
   D. 4/0 AWG.
   E. 500 kcmil.

   Code reference ___________________

7. A feeder consisting of size 3/0 AWG copper conductors supplies two 100-ampere rated panelboards for lighting and receptacle loads. This installation is permitted:
   A. provided the panelboards have 100-ampere main overcurrent protection if the feeder is protected at 200 amperes.
   B. provided the feeder overcurrent device is not rated more than 200 amperes and the panelboards are main lug only.
   C. only if both panelboards have 100-ampere main overcurrent protection as well as the feeder having 100-ampere overcurrent protection.

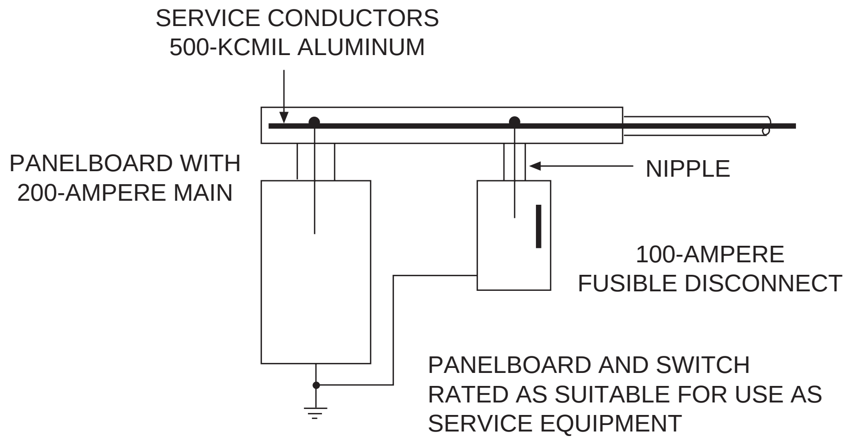


Figure 6.34 Determine the minimum size tap conductor to the 100-ampere service panel.

D. with 100-ampere main overcurrent protection at the panelboards and no overcurrent protection on the feeder if it is not more than 25 ft (7.5 m) in length.
E. if there is 200-ampere overcurrent protection at the source of the feeder and also at the load end ahead of the two panelboards.

Code reference ___________________

8. A 3-phase 208/120-volt electrical system supplies a building and the service equipment consists of an 18-space circuit-breaker panelboard. The building load calculated according to *Article 220* is 130 amperes, but the panelboard is rated 200 amperes and the three ungrounded service-entrance conductors are size 4/0 AWG copper Type THHW. A neutral conductor enters the panel and it is size 1/0 AWG copper Type THHW. There are six 3-pole circuit breakers, one rated 100 amperes, three rated 50 amperes, one rated 30 amperes, and one rated 20 amperes, as shown in Figure 6.35. This service equipment:
A. is permitted without a main overcurrent device.
B. is in violation because it requires a single main overcurrent device.
C. is classified as a lighting and appliance branch-circuit panelboard.
D. would be considered a power panelboard if the neutral was not present in the panel.
E. would not be in violation if it had not more than two main overcurrent devices.

Code reference ___________________

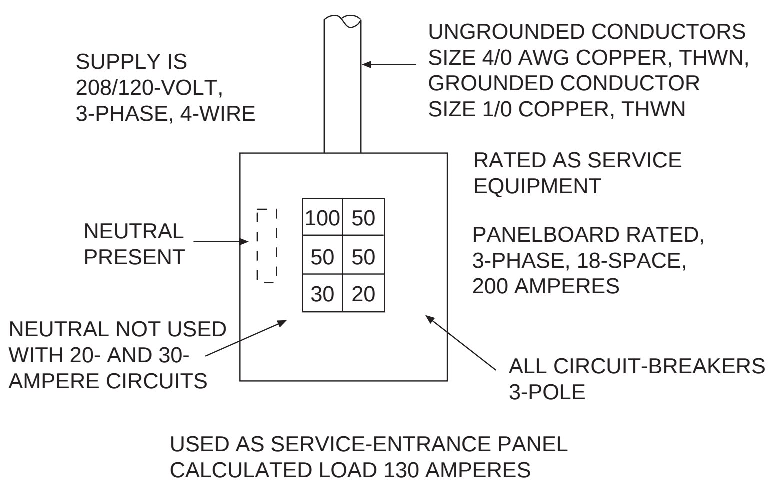


Figure 6.35 The neutral is present in the panelboard used as service equipment, but it is not used with the 20- or 30-ampere circuits.

9. A tap is made to supply a circuit-breaker panelboard from a 400-ampere, 208/120-volt, 3-phase, 4-wire feeder. The feeder ungrounded conductors are 600-kcmil copper with Type THWN insulation. The distance from the tap point on the feeder to the 125-ampere main circuit breaker in the panelboard is 25 ft (7.5 m). The tap conductor is copper, Type THWN, and all conductor terminations are rated at 75°C, as shown in Figure 6.36. The minimum size tap conductor permitted is:
   A. 3 AWG.
   B. 2 AWG.
   C. 1 AWG.
   D. 1/0 AWG.
   E. 2/0 AWG.

   Code reference ___________________

10. A 208-volt, 3-phase feeder in a building, protected by 200-ampere fuses, is run in Electrical Metallic Tubing and has a total length of 275 ft (83.82 m). The expected maximum load on the feeder is 160 amperes and the power factor is close to 1.0. The operating temperature of the feeder is approximately 50°C. The minimum size copper conductors permitted that will also limit the voltage drop on the feeder to not more than 2% with the maximum expected load is:
   A. 2/0 AWG.
   B. 3/0 AWG.
   C. 4/0 AWG.
   D. 250 kcmil.
   E. 300 kcmil.

   Code reference ___________________

11. The service equipment or a disconnecting means listed as suitable for use as service equipment is required to be installed adjacent to a mobile home and within sight of the mobile home and located from the exterior wall of the mobile home not more than:
   A. 6 ft (1.8 m).
   B. 10 ft (3 m).
   C. 15 ft (4.5 m).
   D. 30 ft (9 m).
   E. 50 ft (15 m).

   Code reference ___________________

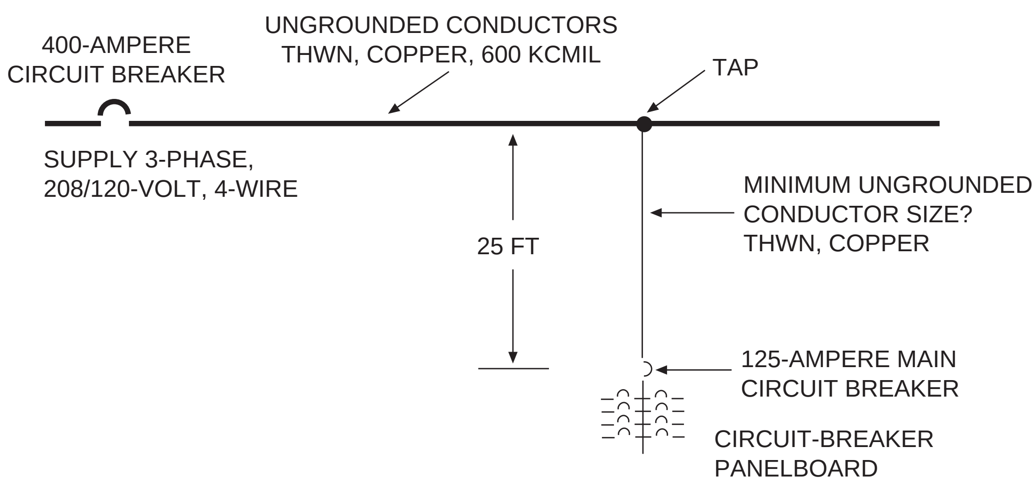


Figure 6.36 Determine the minimum size tap conductor connected to this feeder protected at 400 amperes.

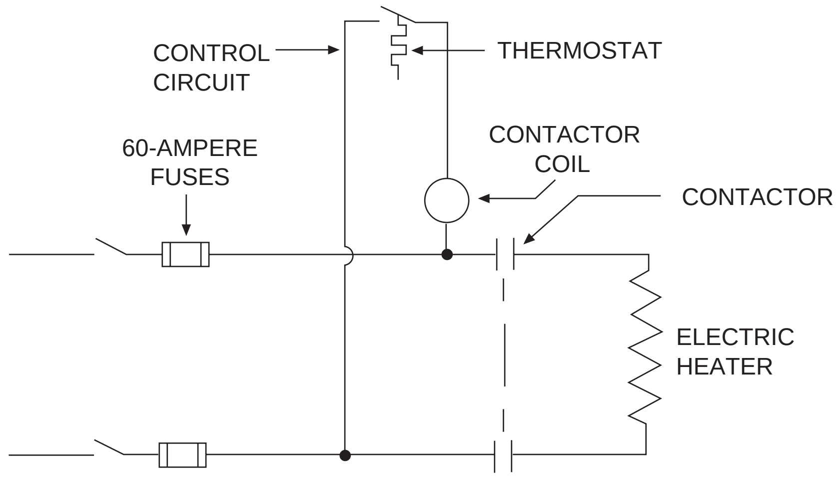


Figure 6.37 Determine the minimum size Class 1 control conductors run to the thermostat when they are copper and only protected by the branch circuit 60-ampere fuses.

12. An electric heater circuit is protected with 60-ampere fuses and the heater is controlled with a contactor. A line voltage thermostat operates the coil of the contactor, as shown in Figure 6.37. All wires are copper, run in conduit, and have 75°C rated insulation and terminations. The Class 1 control circuit wires are protected from overcurrent only by the heater circuit fuses. The minimum size Class 1 control circuit conductors permitted is:
    A. 16 AWG.
    B. 14 AWG.
    C. 12 AWG.
    D. 10 AWG.
    E. 8 AWG.

    Code reference ____________________

13. A recreational vehicle park has 52 recreational vehicle sites with electrical power. The minimum number of sites required to be equipped with 20-ampere, 125-volt receptacles is:
    A. 3 sites.
    B. 15 sites.
    C. 37 sites.
    D. 49 sites.
    E. 52 sites.

    Code reference ____________________

14. A power supply pedestal is to be installed at a back-in recreational vehicle site where a marker is placed at the back left corner of the stand. The power pedestal is permitted to be located in the space from 5 ft (1.5 m) to 7 ft (2.1 m) from the left side of the stand as shown in Figure 6.38 on the next page. The pedestal is not permitted to be located from the back of the stand toward the road a distance of more than:
    A. 9 ft (2.7 m).
    B. 12 ft (3.7 m).
    C. 15 ft (4.5 m).
    D. 30 ft (9 m).
    E. 35 ft (10.6 m).

    Code reference ____________________

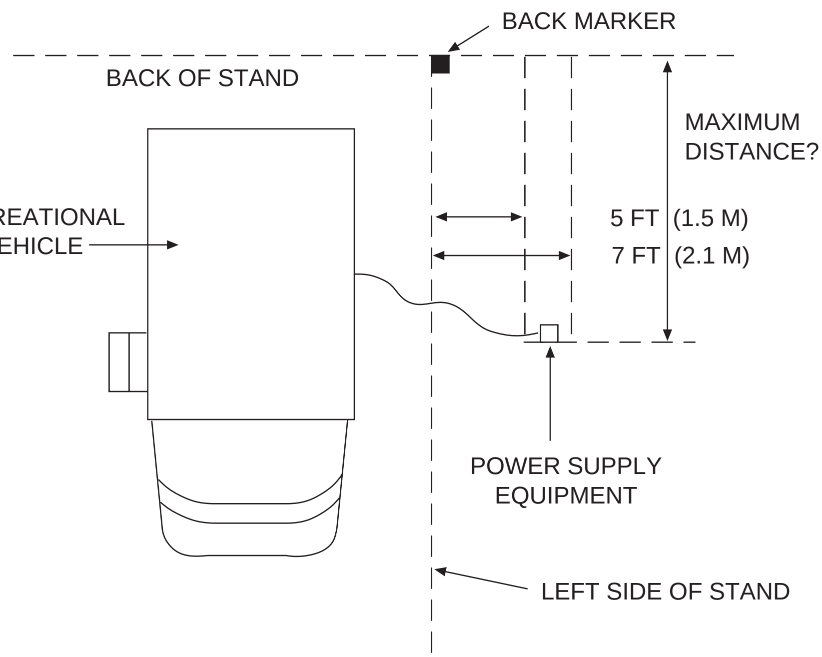


Figure 6.38 What is the maximum distance the power supply equipment is permitted to be installed from the back of the stand for a back-in recreational vehicle site?

15. A park trailer with not more than five 120-volt circuits that is required to be supplied power has a rating of:
    A. 120 volts, 30 amperes, 2 wire.
    B. 120/240 volts, 50 amperes, 3 wire.
    C. 120/240 volts, 30 amperes, 3 wire.
    D. 120 volts 50 amperes, 2 wire.
    E. 120/240 volts, 20 amperes, 2 wire.

Code reference ____________________

UNIT 7

Motor-Circuit Wiring

OBJECTIVES

After completion of this unit, the student should be able to:

- read and explain the use of the information on a motor nameplate.
- determine the minimum size conductor permitted for a motor branch-circuit.
- determine the maximum rating of the overcurrent device for the motor branch-circuit short-circuit and ground-fault protection.
- select the type and rating of disconnect required for a motor circuit.
- select the type and rating of the controller for a motor.
- determine the maximum permitted rating of motor overload protection.
- determine the minimum size conductor permitted for a feeder supplying several motors.
- explain when overcurrent protection for the motor-control circuit is needed in addition to the motor branch-circuit overcurrent device.
- explain the meaning of NEMA enclosure type for motor controllers.
- diagram a control circuit for a magnetic motor starter.
- answer wiring installation questions relating to *Articles 409, 430, 440, 455, 460, 470, 675, 685,* and *Example D8* in *Annex D.*
- state three significant changes that occurred from the 2005 to the 2008 Code for *Articles 409, 430, 440,* or *675.*

CODE DISCUSSION

Sizing and installation of components of an electric motor circuit are covered in this unit. An electric motor is a device to convert electrical energy into mechanical energy or power. An electric motor is a perfect servant. It tries to power any load to which it is connected. For this reason, overcurrent protection must be provided that will prevent self-destruction of the motor and possible fire or an electrical shock hazard. The task of sizing overcurrent protection for a motor is difficult because of the current characteristics of the motor. The motor will typically draw five to six times as much current during starting as it will when running under constant full load. Figure 7.1 shows the typical motor current draw during starting, compared with the full-load running current. The real challenge for overcurrent protection is to protect for overloads during running and yet not experience opening of the overcurrent device during the starting in-rush current.

Article 409 provides specific rules for the installation of an industrial control panel. Although the term is industrial control panel, they are not limited to installation in an industrial building or structure. An industrial control panel contains control equipment such as push buttons, selector switches, timers switches, control relays, terminal blocks, and pilot lights. It also may contain circuit breakers, fuses, disconnect switches, overload relays, and controllers. The main difference between an industrial control panel and a motor control center is that the industrial control panel may provide power and control for a complete process including non-motor loads. An industrial control panel is permitted to serve as service equipment *(409.108),* although it is only permitted to contain one main circuit breaker or set of fuses *(409.21).* It must be rated as suitable for use as service equipment if used for that purpose. All industrial control panels must be marked with a short-circuit current rating, unless it contains only control circuit components. The conductors supplying an industrial control panel are sized by a similar rule as a feeder to a specific motor load as described in *430.24.* The maximum rating of overcurrent protection for the industrial control panel is determined by a similar rule as the overcurrent protection for a feeder for a specific motor load in *430.62.*

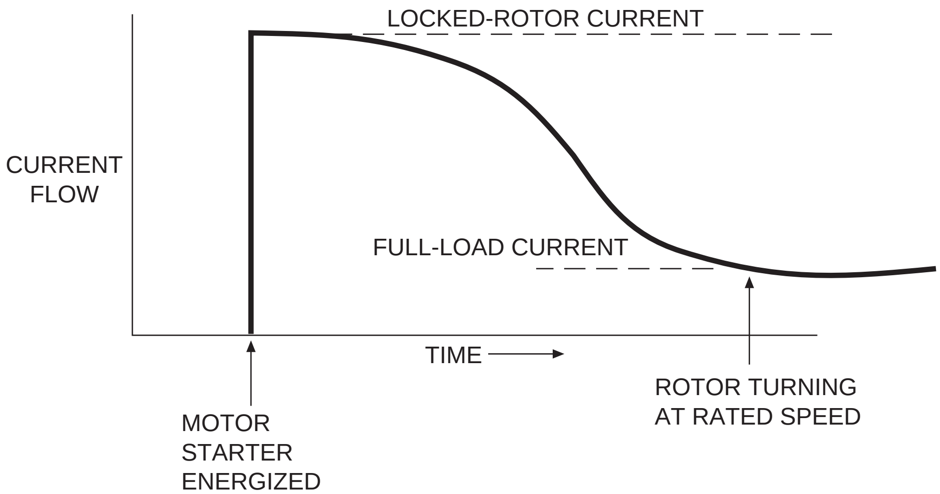


Figure 7.1 When a motor is started, there is an in-rush of current until the motor obtains running speed.

Article 430 deals with motors, motor branch-circuits and feeders, conductors and their protection, motor overload protection, motor-control circuits, motor controllers, and motor-control centers. *Figure 430.1* in the Code shows a motor circuit and can be used as an index to find the section of the article dealing with the various circuit components. *Part I* of this article provides general information about various motors and general wiring requirements for the motor circuit. There are several tables at the end of the article, which will be used frequently when sizing components for a motor circuit. *Tables 430.247* through *430.250* give the motor full-load current for various types of motors. *NEC® 430.6(A)(1)* requires that these values are used except when sizing the motor running overcurrent protection, and unless the nameplate full-load current for the motor is a higher value than given in the table. For a motor-operated appliance with both the horsepower and full-load current listed on the nameplate, the full-load current is to be used for sizing conductors and other circuit components, *430.6(A)(1) Exception 3.*

The rules for determining the minimum permitted size of single motor branch-circuit conductors are found in *430.22*. The minimum wire size for a feeder serving a specific group of motors is determined according to *430.24.* The wire size for a motor circuit is determined directly from *Table 310.16* once the ampacity has been determined in *Part II*. *NEC® 240.4(D)*, which states that the overcurrent protection for a 14 AWG copper wire is not to exceed 15 amperes, 20 amperes for a 12 AWG, and 30 amperes for a 10 AWG, does not apply in the case of a motor circuit. Other references in the Code that clarify that overcurrent protection for motor branch-circuits is to be sized according to the provisions of *Article 430* are *430.1* and *240.4(G).*

Part III discusses the type of overload protection permitted for an electric motor and the sizing of the overload protection. *Part IV* explains the short-circuit and ground-fault protection for the motor branch-circuit. Frequently, a single overcurrent device does not protect for overloads, ground-faults, and short-circuits. *Part V* deals with the overcurrent protection of motor feeders. This would be a conductor supplying power to more than one motor branch-circuit. *Table 430.52* is used when determining the maximum permitted rating of motor branch-circuit short-circuit and ground-fault protection.

The electrical current to many motors is controlled by a motor-control circuit. The wiring to a start-stop station for a magnetic motor starter is a Class 1 control circuit. *Part VI* covers the wiring and overcurrent of motor-control circuits. *Part VII* covers controllers for motors. This part provides requirements to what is permitted to be a motor controller and the ratings of controllers. *Part VIII* deals with motor-control centers. A motor-control center is an assembly of one to several sections in which there is a bus on which motor-control units are attached. The requirements for the motor-control center are in this part of *Article 430,* including installation requirements. *Part IX* covers the type and ratings of disconnecting means for motors and controllers.

An important safety issue with motors and the machinery they power is the disconnection of electrical power to the controller and to the motor. Rules for disconnects are found in *430.102*. Each controller is required to have an individual disconnecting means. The disconnecting means is required to be located in sight from the controller. *NEC® 430.102(A) Exception 2* does permit a single disconnect for a group of coordinated controllers. *NEC® 430.102(B)* requires a disconnecting means to be located in sight from the motor and the driven machinery. A single disconnecting means is permitted for the controller, the motor, and the

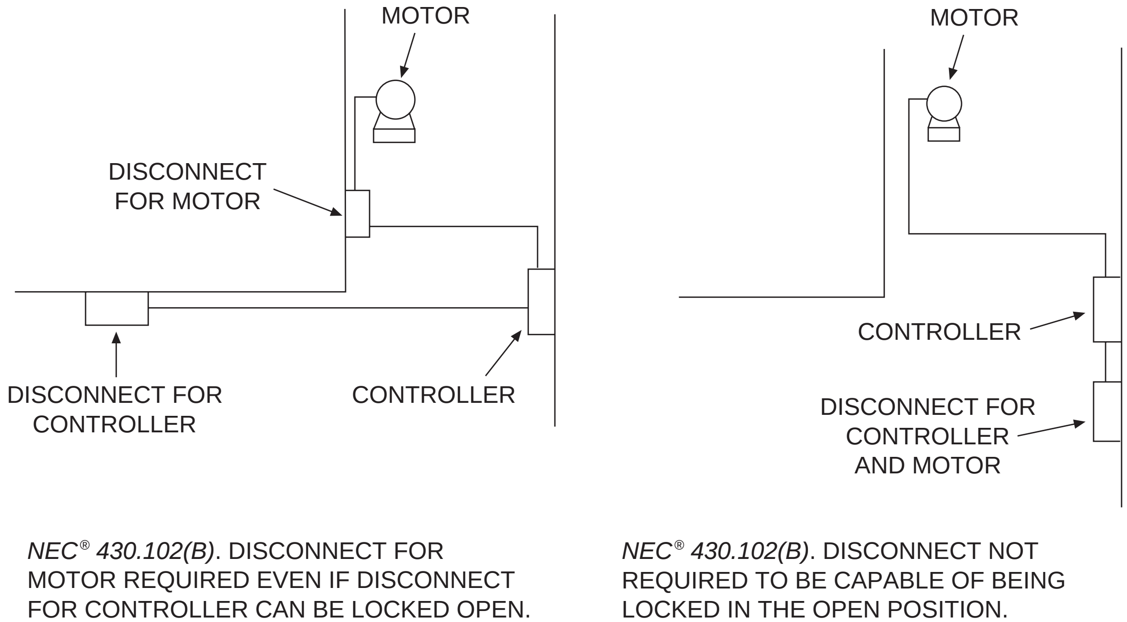


Figure 7.2 A disconnect is required to be located in sight of the controller and the motor. One disconnect is permitted if located in sight of both the controller and the motor.

driven machinery provided it is located within sight of all three and it is not required to be of a type that can be locked in the open position. The rules requiring a disconnect are illustrated in Figure 7.2.

NEC® 430.102(B) Exception only permits a single disconnect to serve both the controller and motor and be out of sight of the motor if it is impractical to locate the disconnect within sight of the motor. In the case of industrial buildings where there is a qualified maintenance staff on duty at all times, it is permitted to have one disconnect, capable of being locked in the open position, serve both the controller and the motor and still not be located in sight from the motor.

Article 440 deals with the branch-circuits and motors associated with air-conditioning and refrigeration equipment. These are special cases because of frequent use of hermetically sealed motor compressors, and the use of multimotor branch-circuits. Branch-circuit selection current is covered in *440.4(C).* The minimum permitted size of the branch-circuit conductors is found in *Article 440, Part IV.* The minimum permitted rating of the disconnecting means for the refrigerant motor compressor is determined from *Article 440, Part II. NEC® 440.22(C)* states that if the maximum permitted rating of branch-circuit short-circuit and ground-fault protective device is marked on the nameplate, that value shall not be exceeded. Overload protection for the motor compressor and for the branch-circuit conductors shall not exceed the value required in *Article 440, Part VI.* The installation of room air conditioners is covered in *Part VII.* When a cord-and-plug connected room air conditioner is installed on a dedicated branch-circuit, the marked ampere rating of the air-conditioner is not permitted to exceed 80% of the rating of the branch-circuit. Sometimes a cord-and plug-connected room air conditioner may be supplied by an existing general-purpose branch-circuit that supplies lights and receptacles. This is permitted provided the addition of the air-conditioner load does not overload the circuit, and provided the marked ampere rating of the air-conditioner does not exceed 50% of the rating of the branch circuit, *440.62(C).*

Article 455 deals with the installation of phase converters. A phase converter is an electrical device that permits a 3-phase electric motor or other 3-phase equipment to be operated from a single-phase electrical supply. The sizing of components of the circuit or feeder for a phase converter installation is difficult because of the 1.73-to-1 current ratio between the single-phase and 3-phase portions of the circuit. It theoretically takes 17.3 amperes flowing on the single-phase input conductors to a phase converter to supply 10 amperes at 3-phase to a load connected to the phase converter. A phase-converter circuit is illustrated in Figure 7.3. An electric motor is permitted to be operated at the nameplate rated horsepower, but the motor-starting torque will be greatly reduced when operated from a phase converter. Motors powering hard starting loads should not be operated from a phase converter unless recommended by the manufacturer.

Phase converters may be a static type with no moving parts. A static phase converter usually serves only one 3-phase load, and it is sized specifically for that load. Most static phase converters consist primarily of capacitors. A transformer can be used to provide an output voltage different from the input voltage.

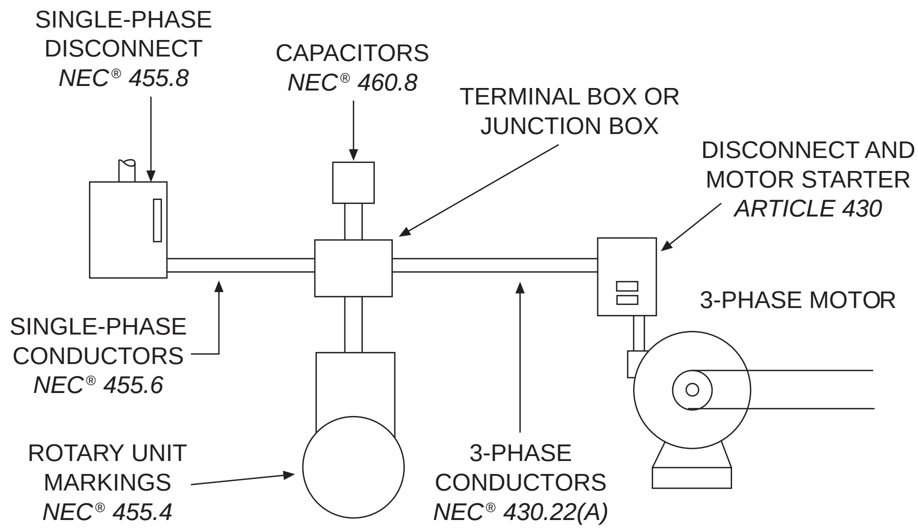


Figure 7.3 A phase converter permits a 3-phase motor or load to be operated from a single-phase electrical supply.

Rotary phase converters are capable of supplying one or more loads. If an installation consists of several 3-phase motors, then it may be possible to supply the 3-phase power from a single-phase supply with one rotary phase converter. The basic components of a rotary phase converter are a rotating unit that is actually a 3-phase motor, a capacitor bank, and if the output voltage is different than the input voltage, a transformer is included. With this type of unit, it is necessary to start the phase converter and bring the rotating unit to full speed before any 3-phase load is applied.

When sizing the conductors and overcurrent protection for a phase converter installation, it is necessary to know the "rated single-phase input full-load amperes" from the nameplate or the actual load to be served. *NEC® 455.6(A)(1)* requires that the minimum single-phase input conductor ampacity not be less than 1.25 times the rated single-phase input full-load current as marked on the nameplate. It is not uncommon for a phase converter to be oversized for the load to be served. In this case, *455.6(A)(2)* permits the single-phase input conductors to have an ampacity not less than 2.5 times the full-load current of the 3-phase load supplied by the phase converter.

Overcurrent protection is required for the single-phase input conductors and the phase converter. That overcurrent protection is located at the supply end of the single-phase input conductors. *NEC® 455.7(A)* requires that the overcurrent protection not be more than 1.25 times the rated single-phase input full-load current as marked on the phase converter nameplate. *NEC® 455.7* permits the calculated value to be rounded up to the next standard rating of overcurrent device as given in *240.6* when the calculated value does not correspond with a standard rating. *NEC® 455.7(B)* permits the maximum rating of overcurrent protection to be sized not more than 2.5 times the sum of the 3-phase loads supplied by the phase converter.

A disconnecting means is required to be located within sight of the phase converter. *NEC® 455.8* permits that disconnecting means to be a switch rated in horsepower, a circuit breaker, or a molded-case switch. If only nonmotor loads are served and a switch is used as the disconnecting means, the switch is not required to have a horsepower rating. The disconnecting means is required to have an ampere rating not less than 1.15 times the rated single-phase input full-load current as marked on the phase converter nameplate. *NEC® 455.8(C)(1)* permits a circuit breaker or a molded-case switch to be sized not less than 2.5 times the sum of the 3-phase full-load currents of the loads supplied. *NEC® 455.8(C)(2)* explains how to determine the horsepower rating of the load served by the phase converter. The disconnecting means must be capable of opening the circuit under full-load or locked-rotor conditions. The horsepower rating is selected from either *Table 430.251A* or *Table 430.251B* by using a calculated equivalent locked-rotor current. That equivalent locked-rotor current is 2.0 times the locked-rotor current of the largest motor served, plus the full-load current of all other motors served, plus the full-load current of all nonmotor loads served.

Example 7.1 A 20-kVA rotary phase converter with a rated single-phase input full-load current of 105 amperes is connected to a 240-volt single-phase electrical system to supply several 230-volt, 3-phase design B motors. The electric motors supplied are 10, 3, and 2 horsepower. The layout of the

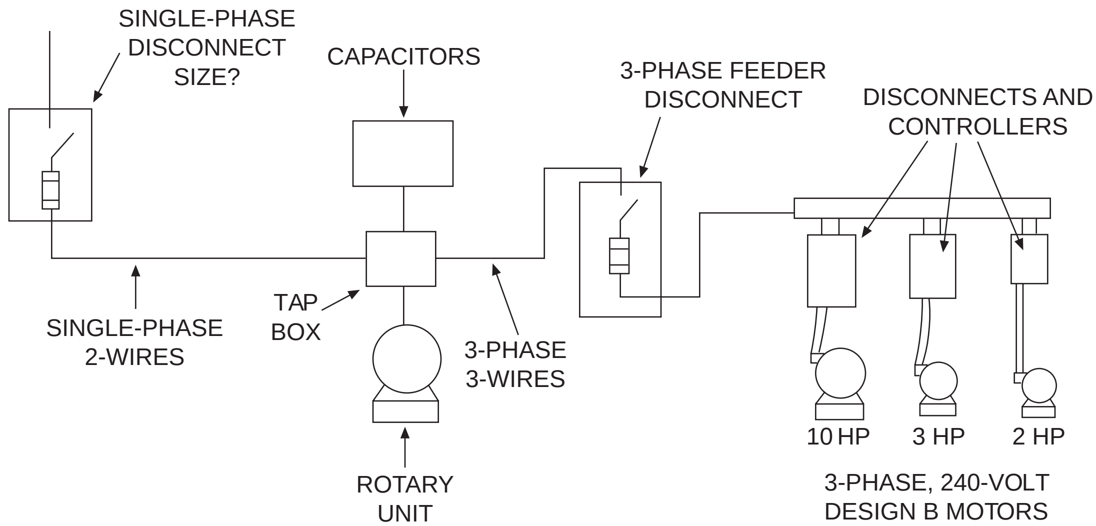


Figure 7.4 A fusible switch is frequently used as the single-phase disconnect for a rotary phase converter supplying several 3-phase motors.

circuit is shown in Figure 7.4. A fusible switch is the disconnect for the single-phase power to the rotary phase converter. This is the switch being sized in this question. Another fusible switch on the load side of the phase converter serves as the disconnect for the feeder to the individual motor circuits. Determine the minimum horsepower rating of fusible switch on the single-phase side of the phase converter permitted to supply this specific motor load.

Answer: *NEC® 455.8(C)(2)* requires adding the locked-rotor current of the 10-horsepower, 230-volt, 3-phase design B motor (*Table 430.250B*) to the full-load currents of the 3- and 2-horsepower motors and then multiply the sum of these numbers by 2.0.

$$\text{Equivalent locked-rotor current} = 2.0 \times (162\ \text{A} + 9.6\ \text{A} + 6.8\ \text{A}) = 357\ \text{A}$$

Now find a single-phase horsepower rating from *Table 430.251A* that has a locked-rotor current equal to or greater than 357 amperes. Note that there is no single-phase switch shown in *Table 430.251A* with a horsepower rating high enough to handle the equivalent locked-rotor current of 357 amperes. Manufacturers usually have single-phase switches with horsepower ratings higher than listed in *Table 430.252A*. If a single-phase switch is not available, a 3-phase switch can be used as the phase-converter disconnecting means. In this case, one of the switch poles is not used. It is important that the 3-phase switch has a locked-rotor current rating equal to or higher than the calculated equivalent locked-rotor current for the load. In this example, the equivalent locked-rotor current was 357 amperes. Look down the 230-volt 3-phase column of *Table 430.252B* until a locked-rotor current value is found that is equal to or greater than 357 amperes. A switch rated 20-horsepower 3-phase is not adequate because it only has a locked-rotor current rating of 290 amperes. The 25-horsepower 3-phase switch has a locked-rotor current rating of 365 amperes, which is larger than 357 amperes. Therefore, a 25-horsepower 3-phase switch can be used as the disconnecting means for the phase converter.

Article 460 deals with the installation of capacitors wired as part of electrical circuits, and not as a component part of electrical equipment. Typical examples would be capacitors added for power factor correction or auxiliary capacitors added to motor circuits. An important aspect of this article is the discharging of the capacitor when it is de-energized. A capacitor will store a charge when power is shut off. If the charge is not removed from the capacitor, it can in some cases become a serious electrical hazard even though power has been disconnected. Capacitors are a part of the power supply in an adjustable-speed drive, and they take time to discharge when power is disconnected from the drive. Capacitors operating at 600 volts or less are required to be discharged to 50 volts in not more than one minute after power is disconnected.

NEC® 460.12 gives the requirements for marking capacitors. The rating of capacitors connected to 60-hertz alternating current systems is required to be given in amperes or kilovars (kVAR), which is reactive volt-amperes. Conductors supplying capacitors and ratings of switches for capacitors are required to have an ampacity not less than 135% of the rated capacitor current, *460.8*. If rated current is marked on the capacitors, determining the conductor size is easy. If the capacitors are rated in kVARs, then a calculation is required to get the rated current. Capacitor rated current for single-phase capacitors is determined from kVARs and the circuit voltage using Equation 7.1. For a 3-phase capacitor bank use Equation 7.2. Individual capacitors are rated in microfarads (μf) and calculating the current for a specific application is beyond the scope of this text.

Single-phase capacitor rated current:

$$\textbf{Rated capacitor current} = \frac{\textbf{kVAR} \times \textbf{1000}}{\textbf{Voltage}} \qquad \textbf{Eq. 7.1}$$

Three-phase capacitor bank rated current:

$$\textbf{Rated capacitor current} = \frac{\textbf{kVAR} \times \textbf{1000}}{\textbf{1.73} \times \textbf{Voltage}} \qquad \textbf{Eq. 7.2}$$

Article 470 covers the installation of resistors and reactors, which are sometimes used as a part of a motor or other equipment circuit. The main points of this article are the prevention of physical damage to the components and the prevention of overheating of wiring. Resistors and reactors are sometimes used in motor controllers for soft starting to reduce initial motor in-rush current.

Article 675 covers the installation of electrically driven or controlled irrigation machines. These are devices consisting of aluminum water pipe with periodic sprinkler nozzles to irrigate crop land. These devices are frequently propelled through the field with electric motor-driven wheels at regular intervals along the machine. Some irrigation machines rotate about a central pivot point, while others laterally move across the field. A typical center pivot irrigation machine is shown in Figure 7.5. The equivalent current rating of *675.7* is used to determine the size of conductors, overcurrent protection, disconnecting means, and controller for the irrigation machine. The drive motors for some irrigation machines, such as the center pivot type, operate intermittently. Therefore, a duty cycle is permitted to be applied when determining the equivalent current rating of the machine. *NEC® 675.22* provides the value to use for the duty cycle for the center pivot machine. *NEC® 675.8(B)* requires a disconnecting means at the point where electrical power connects to the machine or within 50 ft (15 m) of that point. *NEC® 675.15* requires a grounding electrode system for lightning protection.

Article 685 applies to integrated electrical systems in industrial applications where equipment must be shut down in an orderly manner for a particular reason. In the event of a malfunction in a component machine of a continuous process, automatic shutdown of that particular machine may cause great economic loss or even endanger human life. A malfunction signal to the required on-duty maintenance personnel is permitted in place of automatic shutdown.

Annex D, Example D8 is an excellent example of an installation of three motors served by a common feeder. Each motor is on a separate branch-circuit. This example gives a clear understanding of the meaning

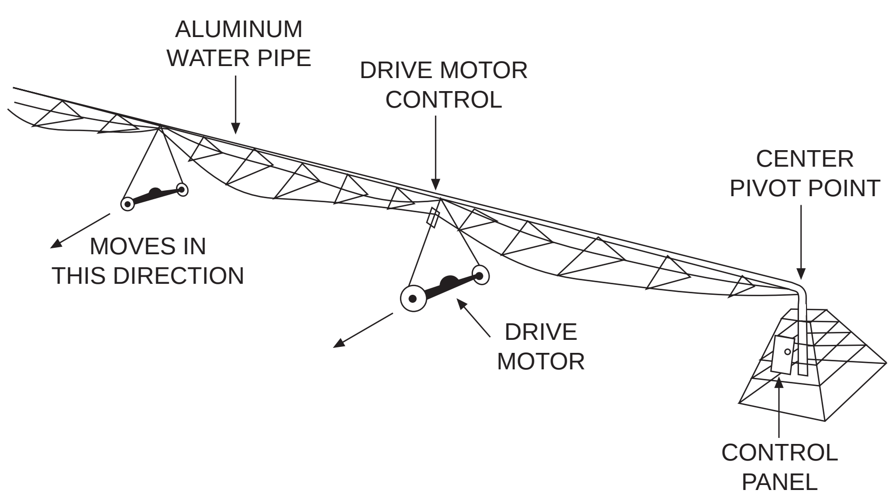


Figure 7.5 The control panel and main disconnect are located at the center pivot point of an irrigation machine with an electrical drive motor and controller located at each support tower radially out along the machine.

of the various rules in *Article 430*. It is highly recommended that the person learning about motor-circuit and feeder installations work through this example. This example shows the method of determining the maximum permitted rating of the branch-circuit short-circuit and ground-fault protective device. *NEC® 430.52(C)(1) Exception 1* permits rounding up to the next standard rating of overcurrent device listed in *240.6.* The full-load current of the motor as determined from *Table 430.248* or *Table 430.250* is multiplied by the factor found in *Table 430.52.* It is permitted to round up to the next higher standard overcurrent device rating.

Two of the motors in the example are wound-rotor motors. However, for the purpose of this example, they are treated in a similar manner as other induction motors. A wound-rotor motor is an induction motor that has windings on the rotor that leave the motor through slip rings. Resistors are connected in series with the rotor windings to control the in-rush current and starting speed of the motor. *NEC® 430.23* gives the rules for sizing the branch-circuit wires and the secondary conductors from the rotor. The secondary full-load current will be marked on the motor nameplate. *NEC® 430.32(E)* permits the motor overload protection to also protect the secondary conductors.

MOTOR CIRCUITS AND CALCULATIONS

Information is provided in the Code that is necessary to size and install the components of a motor circuit. It is also necessary to determine information from the specific motor to be installed. The type of environment must be known to choose the proper enclosures for the motor and other equipment of the circuit.

Motor Nameplate and Other Information

A motor circuit is wired to fit the specifications of a specific motor. Information for determining the size or rating of the various parts is found on the motor nameplate, and the full-load current for single-phase and 3-phase motors from *Table 430.248* and *Table 430.250.* A motor nameplate is shown in Figure 7.6. The most important information needed for wiring the circuit is (1) horsepower, (2) phase, (3) voltage, (4) full-load current, (5) temperature rise above ambient or service factor, and (6) design letter. Also, it is important to know about the physical environment, the location of the installation, the type of controller desired, and the type of load that will be powered (easy starting or hard starting load). The motor nameplate of Figure 7.6 shows ambient temperature, and not temperature rise above ambient. Ambient temperature is the maximum environmental temperature in which the motor is to be operated. If the surrounding temperature is higher than the ambient temperature marked on the nameplate, the motor will be in danger of overheating if operated at the nameplate horsepower rating.

The in-rush current of a motor is affected by the design of the motor. The National Electrical Manufacturers Association (NEMA) has established specifications and designations for motor design. Design letters are used to group motors into categories of similar operating characteristics. These characteristics include rotor slip at 100% load, locked-rotor current, and torques at various speeds. The most common type

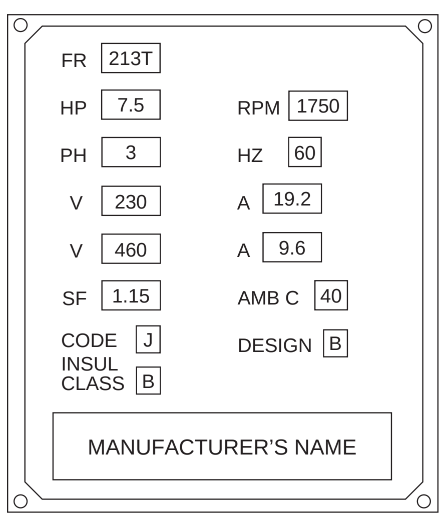


Figure 7.6 The motor nameplate contains essential information for sizing components of a motor circuit. The nameplate current may be different than the current listed for the same motor in *Article 430.*

of motor in use is the design B motor. Motors are available that are designed especially as high-efficiency motors. These are designated as "energy efficient" motors. A motor intended to be a high-efficiency motor is the prime efficiency motor. Motors operating at low speeds or high torque may have full-load currents in excess of the values listed in *Table 430.248* or *Table 430.250.* In these cases, the nameplate current shall be used if it is higher than the values given in the tables.

Motor Circuit

A typical motor circuit is diagrammed in Figure 7.7. There is a chart in *430.1* that gives the location in the article where necessary information is found for sizing and wiring the circuit. The following components shall be sized or specified for a motor branch-circuit:

1. Branch-circuit disconnecting means minimum rating, *Part IX*
2. Branch-circuit short-circuit and ground-fault protection rating, *Part IV*
3. Branch-circuit conductors minimum size, *Part II*
4. Motor controller minimum size, *Part VII*
5. Motor and branch-circuit overload protection maximum rating, *Part III*
6. Motor-control circuit conductor minimum size, *Part VI*
7. Motor-control circuit overcurrent protection maximum rating, *Part VI*
8. Motor feeder conductor minimum size, *Part II*
9. Motor feeder short-circuit and ground-fault protection maximum rating, *Part V*
10. Motor-control center, *Part VIII*
11. Grounding, *Part XIII*

Methods of Controlling Motors

The motor controller directly controls the flow of electrical current to the motor. The definition is found in *Article 100.* Several methods are permitted to control a motor, as the following list indicates:

- For portable motors rated 1/3 horsepower and less, the cord-and-plug, as stated in *430.81(B)*
- For stationary motors not over 1/8 horsepower, normally operating continuously, the branch-circuit protective device, as stated in *430.81(A)*
- For stationary motors rated not more than 2 horsepower, a snap switch, as stated in *430.83(C)(1)*
- For a stationary motor, an inverse-time circuit breaker rated in amperes, as stated in *430.83(A)(2)*
- For a stationary motor, a fusible switch rated in horsepower, as stated in *430.90*
- A manual motor starter rated in horsepower, as stated in *430.83(A)(1)*
- A magnetic motor starter rated in horsepower, as stated in *430.83(A)(1)*

The National Electrical Manufacturers Association (NEMA) has established a size numbering system for horsepower ratings of electric motor starters. The NEMA sizes are shown in Table 7.1. A 3-pole motor starter may be used to control a single-phase motor. If only 3-phase horsepower is listed on a 3-pole motor starter to be used for a single-phase motor, divide the 3-phase horsepower rating for the desired voltage by 2 to obtain the maximum single-phase horsepower rating permitted for that motor starter. A single-phase motor with the same horsepower and voltage rating as a 3-phase motor will draw 1.73 times as much current as the 3-phase motor.

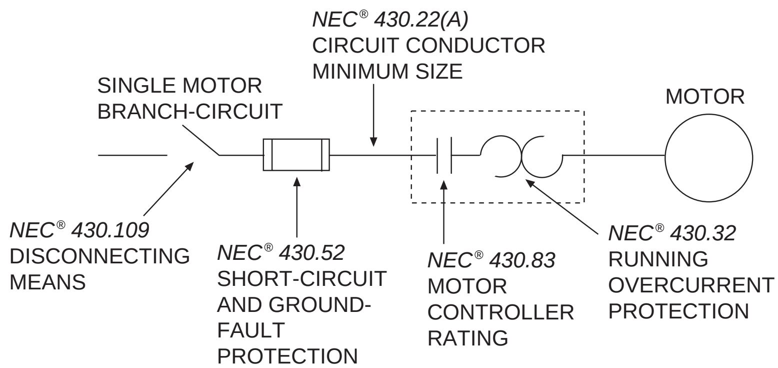


Figure 7.7 Required components of a motor branch-circuit are the disconnect, short-circuit and ground-fault protection, the controller, running overload protection, and proper conductor size.

Table 7.1 Motor horsepower and voltage ratings for NEMA size motor starters.

NEMA size	Single-phase 120 Volts	Single-phase 240 Volts	Three-phase 208 Volts	Three-phase 240 Volts	Three-phase 480 Volts
00	⅓	1	1½	1½	2
0	1	2	3	3	5
1	2	3	7½	7½	10
1P	3	5	—	—	—
2	3	7½	10	15	25
3	7½	15	25	30	50
4	—	25	40	50	100
5	—	50	75	100	200
6	—	—	150	200	400
7	—	—	—	300	600
8	—	—	—	450	900

Enclosure Types

Enclosure type ratings for different environmental conditions have been established by NEMA. Enclosure types for motor starters for applications other than hazardous locations are listed in *Table 110.20.* The following is a general description of some common NEMA enclosure types and their typical applications:

NEMA 1: General-purpose enclosure used in any location that is dry and free from dust and flying flammable materials.

NEMA 3: Weather-resistant enclosure suitable for use outdoors. Not suitable for use in dusty locations. This type is no longer available for motor starters from some manufacturers.

NEMA 3X: Weather-resistant and corrosion-resistant enclosure suitable for use outdoors. Not suitable for use in dusty locations.

NEMA 4: Watertight and dusttight enclosure suitable for outdoor locations and inside wet locations. Water can be sprayed directly on the enclosure without leaking inside. Suitable for most agricultural locations, provided corrosion is not a problem.

NEMA 4X: Watertight, dusttight, and corrosion-resistant enclosure suitable for outside and inside wet, dusty, and corrosive areas. Suitable for agricultural buildings.

NEMA 7: Explosion-proof enclosure suitable for installation in Class I areas containing hazardous vapors. Required to be rated for type of hazardous vapor such as gasoline, Group D or Group IIA.

NEMA 9: Dust-ignition-proof enclosure suitable for installation in Class II hazardous areas such as grain elevators. Required to be rated for the type of dust such as grain dust, Group G. There is a tendency for manufacturers to build one enclosure rated as NEMA 7 and 9.

Overcurrent Device Ratings

Manufacturers' ratings of time-delay fuses not larger than 30 amperes are frequently used to provide overload protection for electric motors. Table 7.2 is a listing of some generally available fuses of sizes not listed in the Code as standard ratings. Refer to *240.6* for the list of standard ratings of fuses and circuit breakers. The standard ratings of fuses less than 15 amperes recognized by the Code are 1, 3, 6, and 10 amperes.

Motor Overload Protection

Electric motors are required to be protected against overload, according to the rules in *430.32.* Overload protection is usually provided as a device responsive to motor current or as a thermal protector integral with

Table 7.2 Typical time-delay fuse ratings available up to 30 amperes.

1⁄10	15⁄100	2⁄10	4⁄10	½	6⁄10	8⁄10	
1	1⅛	1¼	1 4⁄10	1 6⁄10	1 8⁄10		
2	2¼	2½	2 8⁄10	3 2⁄10	3½		
4	4½	5	5 6⁄10	6¼	7	8	
9	10	12	15	17½	20	25	30

the motor. A device responsive to motor current could be a fuse, a circuit breaker, an overload current sensor, or a thermal reset switch in the motor housing. An automatically resetting thermal switch placed in the windings will sense winding temperature directly.

The service factor or temperature rise must be known from the motor nameplate when selecting the proper size motor overload protection. These are indicators of the amount of overload a motor can withstand. If a motor has a service factor of 1.15 or greater, the manufacturer has designed extra overload capacity into the motor. In this case, the overload protection shall be permitted to be sized not greater than 125% of the **nameplate** full-load current. *NEC® 430.32(C)* permits the maximum setting of running overcurrent protection to be increased if the size determined in *430.32(A)(1)* is not sufficient to permit the motor to start.

Internal heat is damaging to motor winding insulation. A motor with a temperature rise of 40°C (104°F) or less has been designed to run relatively cool; therefore, it has greater overload capacity. The overload protection is permitted to be sized not greater than 125% of the nameplate full-load current. A service factor of less than 1.15 or a temperature rise of more than 40°C (104°F) indicates little overload capacity. The overload protection under these circumstances is permitted to be sized not greater than 115% of the nameplate full-load current.

A time-delay fuse is permitted to serve as motor overload protection. Screw-shell fuses or cartridge fuses are used for small motors. The fuse size is determined by selecting the proper multiplying factor, 1.15 or 1.25, based on the service factor or temperature rise marked on the motor nameplate. Time-delay fuse ratings 30 amperes and smaller are listed in Table 7.2.

Circuit breakers are permitted to be used as running overload protection, but they are not generally available in sizes smaller than 15 amperes. If they are used for large motors, they will usually trip on starting if they are sized small enough to provide overload protection.

Magnetic and manual motor starters have an overload relay or trip mechanism activated by a heater sensitive to the motor current. The manufacturer of the motor starter usually provides a chart inside the motor starter listing the part number for thermal overload unit. The heaters are sized according to the actual full-load current listed on the motor nameplate. Find the thermal overload unit number from the manufacturer's list corresponding to the motor nameplate full-load current. A typical manufacturer's thermal overload unit selection chart is shown in Figure 7.8. An example will help show how the thermal overload sensing unit chart is used.

> **Example 7.2** A 3-phase, 240-volt motor has a nameplate full-load current marked as 1.5 amperes, and the service factor is 1.15. Assume the manufacturer part numbers for the overload relay sensing element are listed in Figure 7.8. Select the maximum overload relay sensing element part number permitted for this motor assuming normal starting.
>
> **Answer:** The manufacturer's part number charts for overload relay sensing elements are based upon a service factor of 1.15 or larger or a temperature rise of 40°C or lower. This means the sensing element has already included the 1.25 multiplier permitted by *430.32(A)(1)*. Therefore, simply look up the nameplate full-load current in the chart (Figure 7.8) and find the part number of JR 2.40.

If the service factor of the motor is less than 1.15 or the temperature rise is above 40°C, then the overload relay sensing element is not permitted to have a rating greater than 1.15 times the motor nameplate full-load current. The manufacturer chart for selecting the overload sensing element is approximately 10% too high. Before selecting the overload relay sensing element from a manufacturer chart if the service factor is less than 1.15 adjust the nameplate full-load current to a lower value by using Equation 7.3. If the service factor for the motor in example 7.2 had been 1.0, then the adjusted nameplate full-load current would have been 1.38 amperes ($1.5\text{ A} \times 1.15 / 1.25 = 1.38\text{ A}$) and the manufacturer part number for the overload sensing element would be JR 2.10.

Motor Full-Load Current (Amperes)	Thermal Unit No.	Maximum Fuse Rating (Amperes)	Motor Full-Load Current (Amperes)	Thermal Unit No.	Maximum Fuse Rating (Amperes)
0.28–0.30	JR 0.44	0.6	2.33–2.51	JR 3.70	5
0.31–0.34	JR 0.51	0.6	2.52–2.99	JR 4.15	5.6
0.35–0.37	JR 0.57	0.6	3.00–3.42	JR 4.85	6.25
0.38–0.44	JR 0.63	0.8	3.43–3.75	JR 5.50	7
0.45–0.53	JR 0.71	1.0	3.76–3.98	JR 6.25	8
0.54–0.59	JR 0.81	1.125	3.99–4.48	JR 6.90	8
0.60–0.64	JR 0.92	1.25	4.49–4.93	JR 7.70	10
0.65–0.72	JR 1.03	1.4	4.94–5.21	JR 8.20	10
0.73–0.80	JR 1.16	1.6	5.22–5.84	JR 9.10	10
0.81–0.90	JR 1.30	1.8	5.85–6.67	JR 10.2	12
0.91–1.03	JR 1.45	2.0	6.68–7.54	JR 11.5	15
1.04–1.14	JR 1.67	2.25	7.55–8.14	JR 12.8	15
1.15–1.27	JR 1.88	2.5	8.15–8.72	JR 14.0	17.5
1.28–1.43	JR 2.10	2.8	8.73–9.66	JR 15.5	17.5
1.44–1.62	JR 2.40	3.2	9.67–10.5	JR 17.5	20
1.63–1.77	JR 2.65	3.5	10.6–11.3	JR 19.5	20
1.78–1.97	JR 3.00	4.0	11.4–12.7	JR 22	25
1.98–2.32	JR 3.30	4.0	12.8–14.1	JR 25	25

Figure 7.8 Chart for selecting thermal overload sensing units.

$$\textbf{Adjusted Nameplate Current}_{\textbf{SF} < \textbf{1.15}} = \textbf{Nameplate Current} \times \frac{\textbf{1.15}}{\textbf{1.25}} \qquad \textbf{Eq. 7.3}$$

Sometimes a motor is required to start a load where the start-up time is long enough to overheat and trip the overload relay. One way to deal with this problem is to install a sensing element with a longer time rating. *NEC® 430.32(C)* does permit increasing the sensing element rating but not to exceed 140% when the service factor is 1.15 or greater, and to 130% when the service factor is less than 1.15. Once again, the nameplate current must be adjusted before selecting a manufacturer part number from a chart already based upon 125% of the motor nameplate full-load current. Equation 7.4 can be used for making the adjustment in nameplate current when the overload sensing element is being sized not to exceed 140%. In the case of the motor in Example 7.2, the adjusted nameplate current would be 1.68 amperes and the manufacturer part number would be JR 2.65.

$$\textbf{Adjusted Nameplate Current}_{\textbf{Applying } \textbf{\textit{430.32(C)}}} = \textbf{Nameplate Current} \times \frac{\textbf{1.40}}{\textbf{1.25}} \qquad \textbf{Eq. 7.4}$$

Remote Control Circuit Wires

A magnetic motor starter is operated with an electric solenoid coil. A control circuit is installed to operate the solenoid. One or more operating devices may be on a control circuit. The control circuit wires are permitted to be smaller than the motor-circuit wires, and they are considered to be protected by the motor branch-circuit short-circuit and ground-fault protection. There is a limit as to how high a rating is permitted for this branch-circuit protection before the control circuit is no longer considered to be adequately protected. The rules for determining the minimum control circuit wire size permitted based on the branch-circuit protection rating are given in *430.72*. When the rating of the branch-circuit protective device is too high, overcurrent protection shall be installed to protect the control circuit.

Motor-Circuit Examples

Some examples of motor-circuit component sizing will help illustrate the application of *Article 430.* Nameplate information is given for the motor in each example. The motor nameplate current, as stated in *430.6(A)(1),* is used to determine the rating of the running overcurrent protection. The current as found in *Tables 430.247*, *430.248*, *430.249*, and *430.250* is generally used to determine the size of branch-circuit conductors and branch-circuit short-circuit and ground-fault protection. Example 7.3 illustrates how components of a circuit are sized for a small horsepower motor.

Example 7.3 A $^1/_4$-horsepower, 115-volt, single-phase electric motor is operated from an automatic controller, as shown in Figure 7.9. The nameplate full-load current is 5.4 amperes and the service factor is 1.15. A fusible switch acts as the disconnect and contains fuses that act as both short-circuit and ground-fault protection, as well as running overload protection. The motor is not thermally protected, and it is not powering a hard starting load. Determine (1) the minimum size copper, Type THWN branch-circuit conductor permitted assuming 75°C terminations, and (2) the maximum permitted rating of time-delay fuse to protect the motor from overloads and the branch-circuit from short circuits and ground faults.

Answer: First, look up the motor full-load current from *Table 430.248.* The value of full-load current will be 5.8 amperes. The minimum permitted branch-circuit wire size is determined according to *430.22(A).* The ampacity of the conductor is determined by multiplying the full-load current for the motor by 1.25, then the minimum wire size is found in *Table 310.16.* The smallest wire size permitted for a branch-circuit is 14 AWG, even though the calculated value for the motor was 7.25 amperes.

$$1.25 \times 5.8 \text{ A} = 7.25 \text{ A}$$

A single set of fuses will serve as both branch-circuit short-circuit and ground-fault protection, as well as overload protection for the motor. Fuses can often provide both functions. The overload protection for the motor is a more restrictive requirement than short-circuit and ground-fault protection; therefore, size the fuses for the overload condition. Use the nameplate full-load current of 5.4 amperes to determine overload protection. The maximum overload rating selection is covered in *430.32(B)(1).* It is not permitted to round up to the next standard rating fuse unless the size selected using *430.32(B)(1)* is not adequate to start the motor. When an increase in rating is required, it is not permitted to exceed 140% of the nameplate full-load current, as stated in *430.32(C).* It is not permitted to select the 10-ampere standard rating of overcurrent device, as listed in *240.6,* because it is larger than 140%. Select a set of fuses with a rating of 6.0 or 6.25 amperes from Table 7.2. If the 6.25-ampere fuse is not adequate to start the motor, then it is permitted to choose a 7-ampere fuse.

$$1.25 \times 5.4 \text{ A} = 6.75 \text{ A}$$

$$1.40 \times 5.4 \text{ A} = 7.56 \text{ A}$$

Example 7.4 A 10-horsepower, design B, 3-phase, 460-volt electric motor is controlled by a magnetic motor starter on a branch-circuit with a fusible switch as the disconnecting means. The circuit is shown in Figure 7.10. The nameplate full-load current is 14 amperes and the service factor is 1.15. The

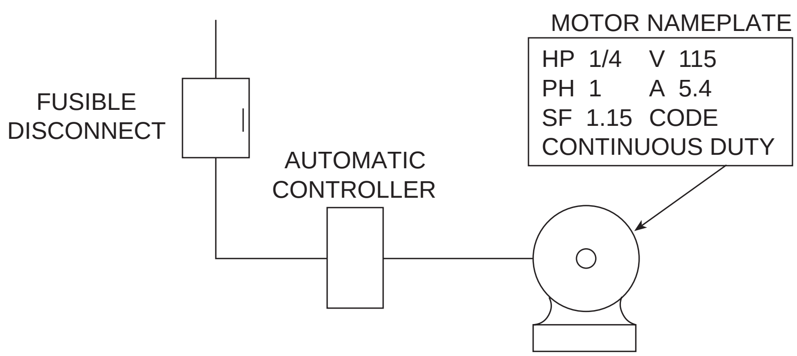


Figure 7.9 An automatically controlled, $^1/_4$-horsepower, single-phase, 115-volt electric motor branch-circuit.

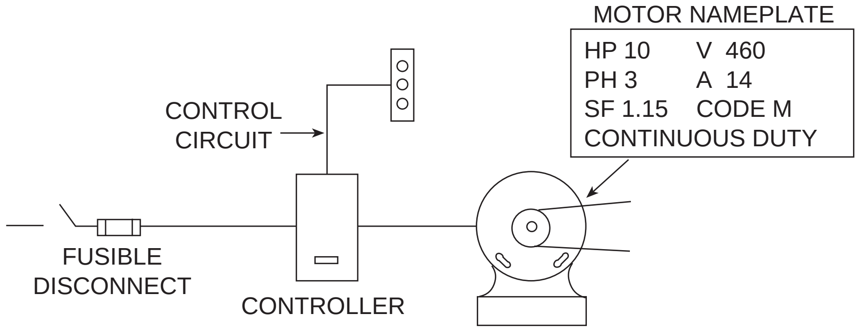


Figure 7.10 A 10-horsepower, design B, 3-phase, 460-volt squirrel-cage motor controlled with a magnetic motor starter.

conductors are in conduit, and the motor is not powering a difficult starting load. Determine the following for the motor circuit:

1. The minimum permitted size copper, Type THWN branch-circuit conductor with 75°C terminations
2. The minimum permitted rating of the circuit disconnect
3. The minimum NEMA size motor starter permitted
4. The maximum permitted rating of time-delay fuses to be used for branch-circuit short-circuit and ground-fault protection
5. The maximum permitted rating of motor overload device as found in the sample manufacturer chart of Figure 7.8
6. The minimum permitted size of Type THWN control circuit wire when protected from overcurrent by the branch-circuit fuses and assuming 75°C terminations

Answer: (1) Look up the motor full-load current rating of 14 amperes from *Table 430.250* in the Code. Next, determine the minimum permitted rating in amperes of the branch-circuit wire. The wire size is determined from *Table 310.16. NEC® 240.4(D)*, which limits the overcurrent protection for sizes 14, 12, and 10 AWG, does not apply in the case of motor circuits. The minimum wire size permitted is 14 AWG copper.

$$1.25 \times 14 \text{ A} = 17.5 \text{ A}$$

(2) The disconnect is required to be rated in horsepower for the operating voltage of the motor. Electrical equipment typically has voltage ratings of 150, 250, and 600 volts. In the case of this motor, choose a 600-volt rated disconnect switch with a minimum 3-phase rating of 10 horsepower.

(3) The motor starter (controller) is required to have a minimum rating of 10-horsepower, 3-phase at 480 volts. Find the minimum permitted NEMA size 1 from Table 7.1.

(4) The maximum rating of the branch-circuit short-circuit and ground-fault protection is determined using the information from the following Code sections:

- *NEC® 430.52(C)(1)* and *Table 430.52*
- *NEC® 430.52(C)(1), Exception 1,* which permits rounding up to the next standard rating of overcurrent device, as listed in *240.6,* when the size is determined according to *Table 430.52*
- *NEC® 430.52(C)(1), Exception 2(b).* It is permitted to increase size if high motor starting current causes the overcurrent device to open, but the overcurrent device is not permitted to have a rating in excess of 225% of motor full-load current when time-delay fuses are used.

$$1.75 \times 14 \text{ A} = 24.5 \text{ A} \quad \text{maximum fuse ampacity}$$

$$2.25 \times 14 \text{ A} = 31.5 \text{ A} \quad \text{absolute maximum ampacity}$$

It is permitted to round the 24.5 amperes up to the next standard rating of fuse, which would be 25 amperes. If this fuse rating is too small to prevent fuse opening during difficult motor starting, then it is permitted to choose higher rating fuses, but it is not permitted to exceed 31.5 amperes. In this case, it would be permitted to use a 30-ampere fuse only if the 25-ampere fuse was not of a sufficiently high rating to carry the starting current.

(5) The motor overload protection for this motor is determined by using the nameplate full-load current of 14 amperes. In this case, the nameplate current and the current from *Table 430.250* are identical. Next, check the service factor (SF) or the temperature rise on the motor nameplate. This motor has a service factor of 1.15. This means that the overload protection is permitted to be sized at a maximum of 125% of the nameplate full-load current. The manufacturer has already taken the 125% into account; therefore, use the nameplate full-load current and look up the manufacturer's number for the overload thermal unit to be installed into the motor starter. Using the nameplate full-load current of 14 amperes, the manufacturer's thermal unit number using the chart of figure 7.8 is JR 25.

(6) The branch-circuit fuses for this motor circuit are rated at 25 amperes. The control circuit is covered by *430.72(B)(2)*. The maximum permitted branch-circuit overcurrent device rating for various wire sizes is given in column C of *Table 430.72(B)*. If a size 14 AWG wire is used, the branch-circuit fuses are permitted to be rated at 45 amperes. For this circuit, the fuses are 25 amperes, and the minimum permitted wire size is 14 AWG.

Example 7.5 A 3-phase, 3/4-horsepower, design B, 230-volt motor is operated by a motor starter from a circuit protected with an inverse-time circuit breaker, as shown in Figure 7.11. The nameplate full-load current is 2.8 amperes and the service factor is 1.15. Is the 15-ampere circuit breaker permitted to act as short-circuit and ground-fault protection for the motor and controller?

Answer: The minimum branch-circuit wire size permitted is 14 AWG, as determined by multiplying the 2.8-ampere full-load current for the motor by 1.25. The maximum permitted size of branch-circuit short-circuit and ground-fault protective device rating is determined from *430.52* and *Table 430.52*. The maximum permitted rating of circuit breaker for the circuit is stated in *430.52(C)(1), Exception 2(c)* as 400% of the motor full-load current. This is still smaller than the smallest circuit breaker rating available and would tend to indicate that the circuit breaker rating is still too high for the motor circuit. But this situation is covered in *Exception 1* to *430.52(C)(1)*. Standard ratings for circuit breakers smaller than 15 amperes are not available; therefore, this is the smallest standard circuit breaker. The answer to the question is yes. The 15-ampere circuit breaker is permitted to be used for this motor circuit.

$$2.5 \times 2.8\text{ A} = 7.0\text{ A}$$

$$4.0 \times 2.8\text{ A} = 11.2\text{ A}$$

Example 7.6 A specific fixed motor load consisting of 10-, 7.5-, and 5-horsepower, 3-phase, 230-volt design B motors is supplied by a specific purpose feeder. Fuses are used as short-circuit and ground-fault protection for each motor branch-circuit, and the ratings of these time-delay fuses for the branch-circuits are as follows: 10-horsepower motor, 45-ampere; 7.5-horsepower motor, 30-ampere; and 5-horsepower motor, 25-ampere. The circuit is shown in Figure 7.12. Determine the following:

1. The minimum copper, Type THWN feeder wire size permitted assuming 75°C terminations
2. The maximum feeder time-delay fuse size
3. The minimum tap wire sizes for each motor branch-circuit assuming 75°C terminations

Answer: (1) Look up the motor full-load current from *Table 430.250*. Then determine the minimum size wire permitted using the rule in *430.24*. Look up the minimum wire size permitted from *Table 310.16*. The minimum feeder wire size is 4 AWG.

$$15.2\text{ A} + 22\text{ A} + 28\text{ A} + 0.25 \times 28\text{ A} = 72.2\text{ A}$$

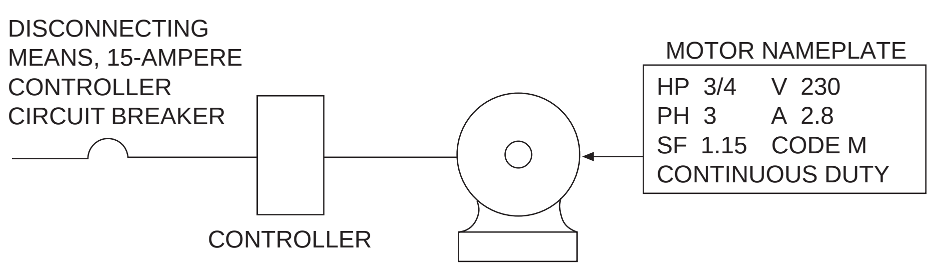


Figure 7.11 A circuit breaker provides the branch-circuit short-circuit and ground-fault protection for a 3/4 horsepower, 3-phase, 230-volt design B, squirrel cage-motor.

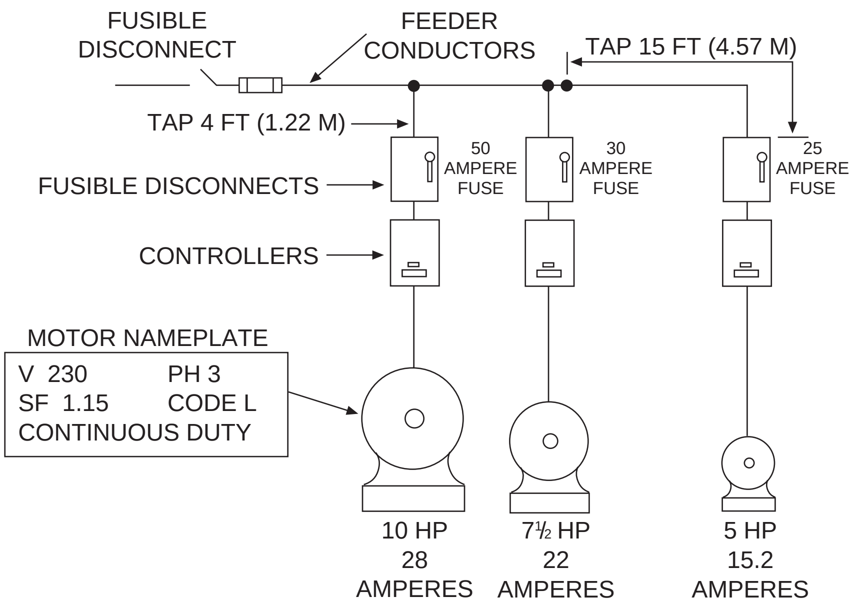


Figure 7.12 Three design B squirrel-cage motor branch-circuits are tapped from a feeder where these motors are the only loads on the feeder.

(2) The maximum permitted feeder time-delay fuse size is determined from *430.62*. Start with the maximum branch-circuit fuse rating permitted (50A) and add to it the full-load currents of the other motors supplied by the feeder and get 87.2 amperes. It is not permitted to exceed this value calculated; therefore, an 80-ampere time-delay fuse would seem to be the maximum permitted for the feeder. In this case, *430.62(A)* would require overcurrent protection on the feeder that was less than the ampacity of the feeder conductor. *NEC® 430.62(B)* permits the feeder conductor to be sized larger than required for the specific motor load, and the overcurrent protection to be based upon the ampacity of the conductors. This means the rules of *240.4* will apply with respect to selecting the overcurrent device rating and conductor size. In this case the size 4 AWG copper feeder conductor is permitted to be protected with a 90-ampere overcurrent device. Another example of this procedure is given in *Example D8, Annex D* of the Code.

$$50\text{ A} + 22\text{ A} + 15.2\text{ A} = 87.2\text{ A}$$

(3) The minimum branch-circuit tap sizes permitted are determined using the tap rule of *430.28*. With the 10-ft (3 m) rule, the minimum tap conductor ampacity is one-tenth of the rating of the feeder overcurrent device. In this case, the feeder overcurrent device is a set of 80-ampere time-delay fuses. One-tenth of that rating is 8 amperes. In this case, the tap conductors will be simply sized adequate to serve the individual motor branch-circuits.

$$\text{10-horsepower motor: } 28\text{ A} \times 1.25 = 35\text{ A, size 10 AWG}$$

$$\text{7.5-horsepower motor: } 22\text{ A} \times 1.25 = 27.5\text{ A, size 10 AWG}$$

For the 5-horsepower motor, the branch-circuit tap is more than 10 ft (3 m); therefore, the 25-ft (7.5- m) tap rule shall be used. The tap conductor shall have an ampacity of not less than one-third that of the feeder conductors, which is 85 amperes for a size 4 AWG copper Type THWN conductor with 75°C terminations. Also, be sure to check the minimum size wire required to supply the motor. A size 14 AWG wire is the minimum permitted to supply the motor, but it is required to use a size 10 AWG wire to satisfy the minimum tap permitted.

$$\text{5-horsepower motor: } 15.2\text{ A} \times 1.25 = 19\text{ A, size 14 AWG}$$

$$\frac{85\text{ A}}{3} = 28.3\text{ A, size 10 AWG}$$

Grounding Motors and Controllers

Grounding of equipment in a motor circuit is discussed in *Part XIII* of *Article 430* and in *250.122(D). Part XIII* specifies what equipment is required to be grounded and how the grounding is to be accomplished. Frequently, metal raceway acts as the equipment grounding conductor for components of the circuit such as the disconnecting means enclosure, controller, and control devices. A typical motor installation has a flexible section of raceway between the controller and the motor. This flexible section is necessary for motor alignment to the driven machine and to minimize vibration from being transmitted to other equipment. A bonding jumper can be installed across this flexible section of raceway or an equipment grounding wire can be run inside the raceway with the circuit conductors. When supplied by flexible cord, an equipment grounding conductor is also required to be installed. Determining the minimum size of equipment grounding conductor for a motor circuit is based upon the size of overcurrent device protecting the branch-circuit, *250.122(D)(1)*. The minimum size bonding jumper or equipment grounding conductor is determined according to the rule in *250.122(A)*. *Table 250.122* is used to determine the minimum wire size using the branch-circuit overcurrent device rating. Since the branch-circuit overcurrent device is only intended to protect for ground faults and short circuits, it often has a rating much higher than the ampacity of the motor-circuit conductors. The following example will illustrate how the minimum size of an equipment grounding conductor is determined for a motor circuit:

> **Example 7.7:** Determine the minimum size copper equipment grounding conductor required for a motor branch-circuit where the design B motor is rated 20 horsepower, 460 volts, 3 phase with a full-load current of 27 amperes. Assume the circuit is protected with time-delay fuses rated at 50 amperes, and the circuit conductors are size 10 AWG copper. Determine the minimum size copper equipment grounding conductor permitted for this circuit.
>
> **Answer:** Look up the minimum size grounding electrode conductor for this motor circuit in *Table 250.122* using the 50 ampere circuit overcurrent device rating. The minimum size grounding conductor for this motor circuit is 10 AWG copper which is the same size as the ungrounded circuit conductors.

MOTOR-CONTROL CIRCUIT WIRING

Motor-control circuit wiring can be confusing, but after the general concept is understood, it can be easily performed. Common types of control circuit wiring for a magnetic motor starter are the 3-wire control and the 2-wire control. A typical example of the 3-wire control circuit is a start-stop station that operates the solenoid of a magnetic motor starter, shown in Figure 7.14. A 2-wire control is any device that opens and closes a switch to operate the motor starter. A pressure switch, limit switch, and thermostat are typical examples of a 2-wire control device, shown in Figure 7.15. Ladder diagrams are frequently used to provide a means of visualizing the control circuit and how it works. Figure 7.13 shows a ladder diagram for a start-stop station operating a motor starter.

A schematic diagram of a magnetic motor starter operated with a start-stop station is shown in Figure 7.14. Compare the diagram of Figure 7.14 with Figure 7.13 to see how a ladder diagram represents the actual control circuit. With the ladder diagram, it is easy to see how the circuit works, but with Figure 7.14 it is easy to see how the wiring is installed.

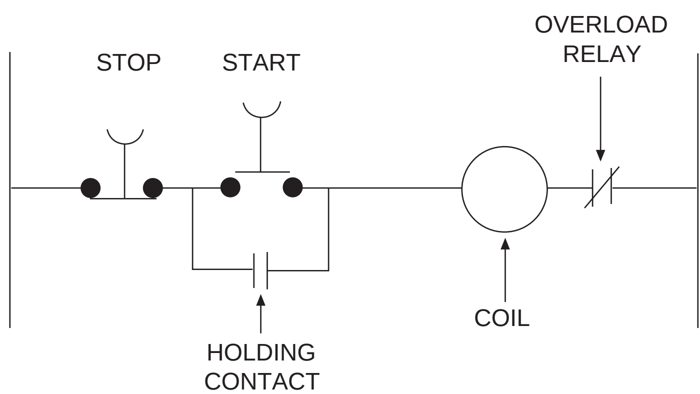


Figure 7.13 Ladder diagram for a start-stop station controlling a magnetic motor starter.

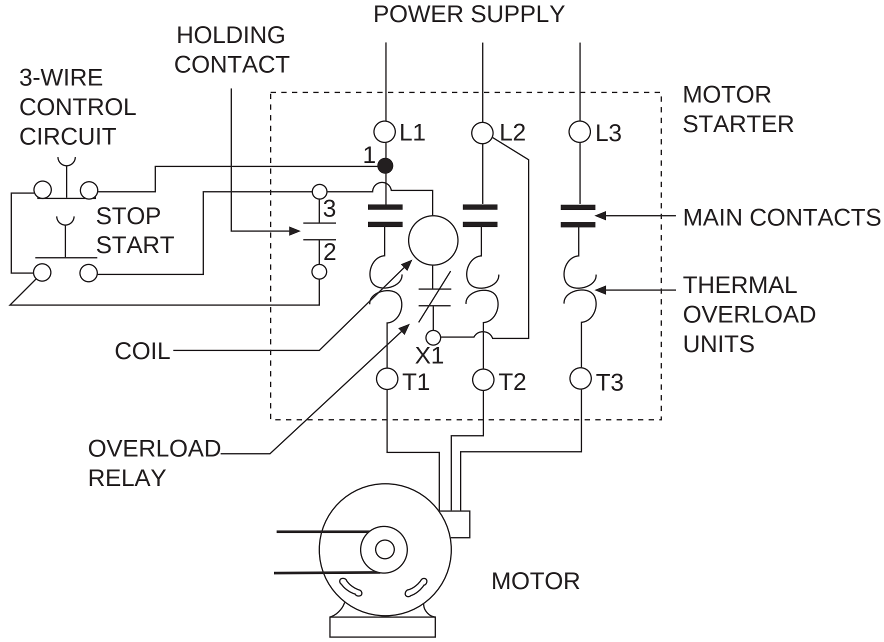


Figure 7.14 The wiring of a start-stop station to control a magnetic motor starter for a 3-phase design B squirrel-cage motor.

A 2-wire control device is frequently used to open and close the motor-control circuit. Figure 7.15 shows a motor starter operated with a thermostat using power from two of the supply lines of the 3-phase source. Note that the thermostat in Figure 7.15 simply completes the circuit from line L1 to the coil. In the case of a 2-wire control circuit, the holding contact in the magnetic motor starter is not needed. Some physical action opens and closes the contacts of the 2-wire control device. In the case of Figure 7.15, that physical action is change in temperature. Other types of physical action are pressure, fluid level, flow rate, mechanical pressure, proximity, and many other physical quantities that can be detected by some type of sensor. It is important to remember that when power is restored after a power interruption, the motor will start immediately if the 2-wire control device is still in the closed position. This is the importance of *455.22* in the case of a power interruption of a rotary phase converter circuit. It is necessary to make sure that the phase converter is restarted before the loads are started. Safety may be a factor in the case of a power interruption, and automatic restarting of loads may not be desirable. Note that in the case of the 3-wire control circuit of Figure 7.14, the motor will not restart after a power interruption because the holding contact is now open.

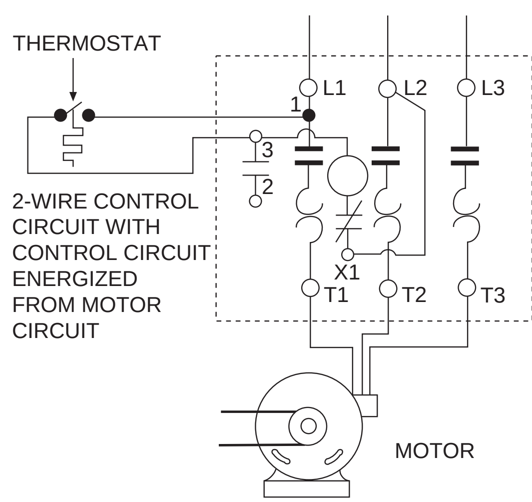


Figure 7.15 The wiring of a simple switch device such as a thermostat to control a magnetic motor starter.

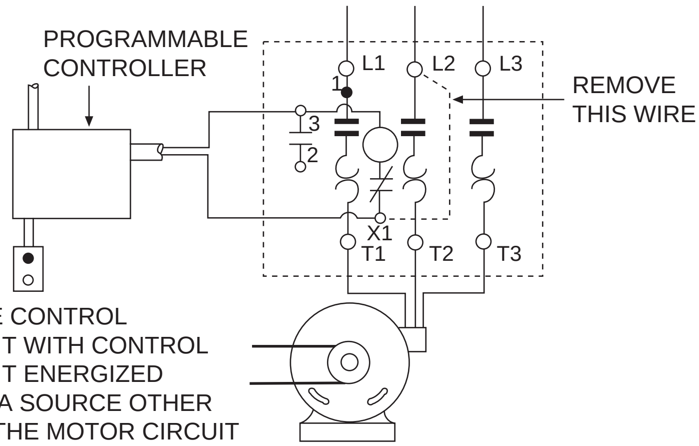


Figure 7.16 An external power source such as a programmable controller is used to control the motor at 120 volts.

A 2-wire control circuit is used when an external device, such as a programmable controller, is used to operate the motor starter as illustrated in Figure 7.16. In this case, the power source to operate the motor starter solenoid may be from a source other than the motor branch-circuit. It will be necessary to make sure there is no connection between the two power sources.

In the case of a control circuit power source separate from the motor branch-circuit, *430.74(A)* requires that all power sources be capable of being disconnected from the motor and the controller. It is permitted to have a separate disconnecting means for the motor branch-circuit and the control circuit. The dotted line in Figure 7.16 shows the wire that must be removed to make sure the control circuit power source is separated from the motor branch-circuit power source. The solenoid in the motor starter must match the control circuit voltage, and the control circuit must be separated from the motor power supply by removing a factory-installed wire inside the motor starter.

When a motor is operated at 480 volts, a control circuit is permitted to reduce the 480-volt supply to a lower voltage such as 120 volts by installing a control transformer inside or adjacent to the motor starter. Figure 7.17 shows a typical installation of a control transformer for a motor-control circuit. Note in Figure 7.17 that a factory-installed wire inside the motor starter must be removed when a control transformer is supplying the control circuit power.

CONDENSATION IN MOTORS

Electric motors installed in some locations where there is high humidity, especially with changes in temperature, can result in condensation inside the motor. Even a totally enclosed motor frame does not always

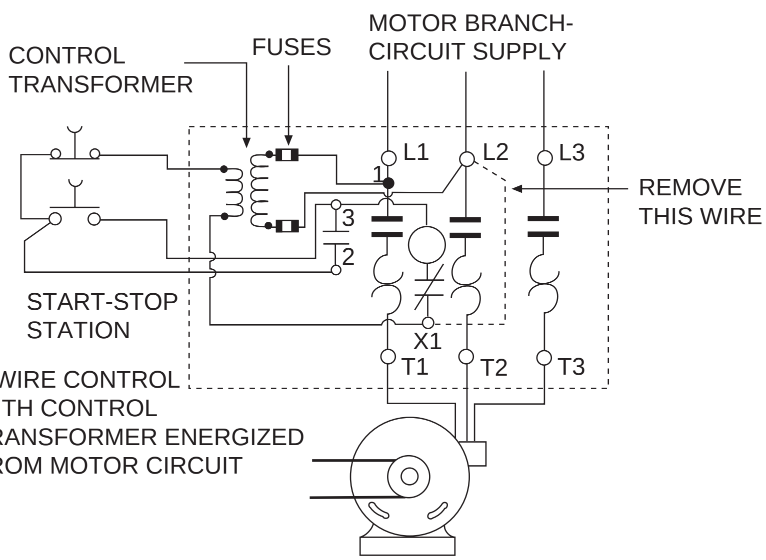


Figure 7.17 A control transformer steps 480 volts down to 120 volts for the control circuit.

keep out moisture. This condensation can lead to corrosion, deterioration of winding insulation, and other problems that result in premature motor failure. Resistance heaters are sometimes installed inside motors to keep the inside warm enough to prevent condensation when not in operation. If a motor is equipped with an internal condensation-prevention heater, the heater voltage, phase, and rated power are required to be marked on the motor according to *430.7(A)(15)*. These condensation-prevention electric resistance heaters are usually installed at one or both ends of the stator windings, as shown in Figure 7.18. Since these heaters are energized when the motor is not running, a separate set of wires with overcurrent protection is required to be run from the controller to the motor. The Code does not specifically address the wiring of these heaters; therefore, it is assumed that the typical rules for wiring a branch circuit are to be followed.

ADJUSTABLE-SPEED-DRIVES

The majority of the electric motors in use are induction motors that operate at a nearly constant speed. By applying 3-phase power to the windings in the stator of the motor, a magnetic field rotates in space about the axis of the motor. This rotating magnetic field induces a current into the aluminum squirrel cage of the rotor. That induced current in the rotor creates a magnetic field that tries to follow the stator magnetic field. The rotor of an induction motor will always turn at a speed slightly slower than the stator magnetic field. In a 4-pole induction motor energized with 3-phase, 60-Hz power, the stator magnetic field will rotate at a constant 1800 rpm. The rotor will turn at somewhere between 1725 rpm to 1750 rpm, depending upon the load being powered. If the frequency of the supply to the motor can be increased, the rotor will turn at a faster speed. If the frequency of the supply to the motor is decreased, the rotor will turn at a slower speed. This is how an adjustable speed drive works. The power conversion unit of the drive rectifies the 60-Hz input power into direct current, then creates an output that is not a sine wave, but it does have a repetitive pattern. If the output frequency of the conversion unit is less than 60 Hz, the rotor of the motor will turn at a slower speed. An adjustable-speed drive makes it possible to vary the rotor speed of what would normally be a fixed-speed motor. A common method of creating a variable frequency output to power a 3-phase induction motor is by a method called pulse width modulation (PWM). The induction motor is supplied with a repetitive pattern of positive and negative pulses with varying width to the pulses. Figure 7.19 is a simplified representation of a pulse width modulated output of one of the phases supplied to an induction motor from an adjustable-speed drive.

The power developed by an electric motor is proportional to the torque developed by the shaft times the revolutions per minute (rpm). Horsepower developed at the shaft of a motor can be determined using Equation 7.5 where torque is in lb-ft and rotor speed is in rpm. Motors are frequently used on loads that do not require a constant horsepower. A centrifugal pump may be required to maintain a constant pressure, but

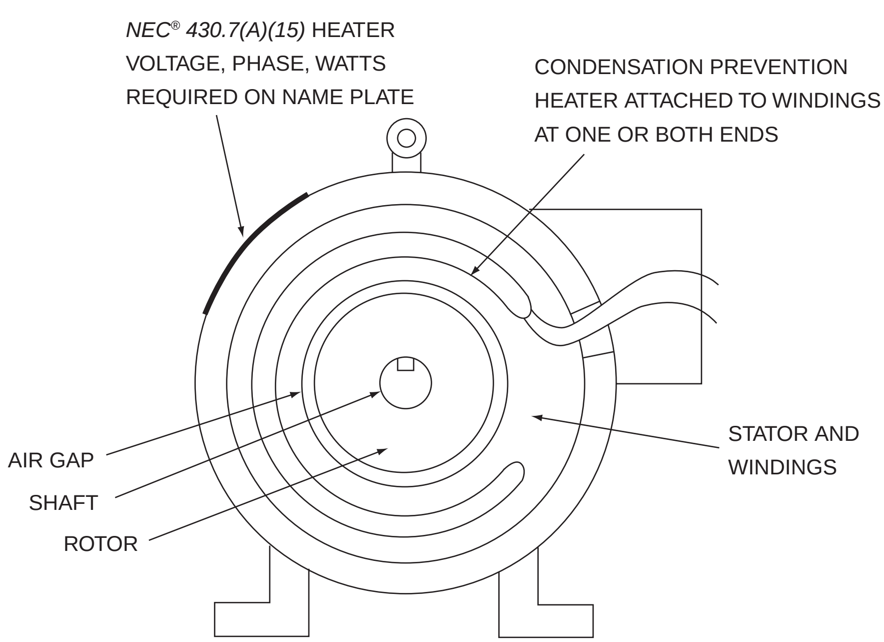


Figure 7.18 Resistance heaters are sometimes installed inside motors to prevent condensation when the motor is not in operation.

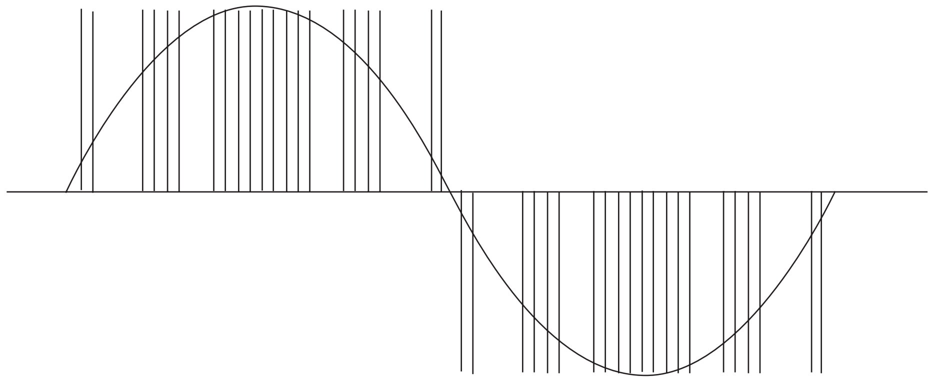


Figure 7.19 The output power from an adjustable-speed drive conversion unit is typically a series of positive and negative pulses with varying spacing that to a motor acts similar to a sine wave.

the flow is variable. If the motor operates at a constant speed when the flow is variable, some means must be devised to prevent the motor from over pressurizing the system. This type of regulation is a waste of energy. Using an adjustable-speed drive, the motor rpm can be reduced when the flow decreases, and still maintain the desired pressure. Note in Equation 7.5 that a reduction in rpm results in a reduction in horsepower and yet the torque is maintained at a constant level. This is how adjustable-speed drives are used to save energy.

$$\text{Horsepower} = \frac{2 \times \pi \times \text{torque} \times \text{rpm}}{33{,}000} \qquad \text{Eq. 7.5}$$

Another example of the installation of an adjustable-frequency drive for the purpose of energy savings is the vacuum system of a dairy farm. It is not uncommon for some dairy farms to be milking cows for up to 22 hours per day, with a short down time for cleaning and maintenance of the equipment and facilities. The electric motor powering this vacuum system typically ranges in size from 10 to 20 horsepower. The vacuum system is sized for the maximum capacity requirement, which is the cleaning cycle. This capacity is typically four times the capacity needed for milking the cows. What this means is that the vacuum system, when operated with a direct supply motor, is working 50% to 75% harder than necessary most of the day. By supplying this motor with an adjustable-speed drive, the motor speed will be varied to keep the vacuum level exactly as required. The vacuum load during a milking operation is constantly changing; therefore, the speed of the motor is constantly changing. Experience on thousands of installations has shown energy savings ranges greater than 50% over a direct drive constant speed motor. There are many similar commercial and industrial applications that can save a significant amount of energy and cost of operation.

The motor supplied by the adjustable-speed drive must be a 3-phase motor. If the facility is supplied with single-phase power, the adjustable-speed drive can be operated from the single-phase supply, but the load must be a 3-phase motor. The adjustable-speed drive can be somewhat hard on motor winding insulation, and motors must be rated for use with these drives. It must be pointed out that when the motor operates at a speed below full-load speed, the cooling of the motor is reduced. These motors should be installed in locations where they get good ventilation to help keep the motor cool. The adjustable-speed drive is mostly a solid-state electronic device delivering large amounts of power, and it is sensitive to inadequate power quality. If such a drive is powering a critical load, such as a dairy milking operation, it is suggested there be either a back-up system, or a by-pass switch for the drive so it can be operated directly from the 3-phase power supply. In the case where the premises are supplied only with single-phase power, a by-pass switch is not an option. A one-line diagram of an adjustable-speed drive powering a 3-phase motor with a by-pass switch is shown in Figure 7.20. The adjustable-speed drive generally provides the overload protection for the motor; therefore, the by-pass circuit is required to contain motor overload protection.

WYE-DELTA MOTOR STARTING

A 3-phase delta connected motor that has all six leads available can be reduced-voltage started by connecting the windings in a wye configuration during starting then switching the windings to a delta configuration when the motor reaches nearly full speed. This is called wye-delta starting. Since there are size leads

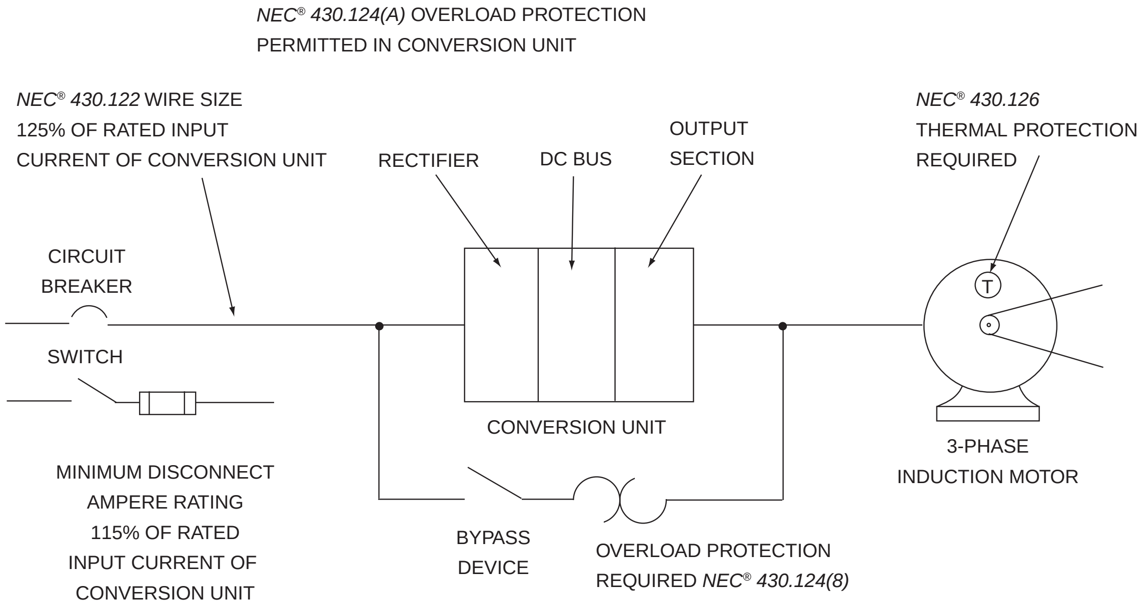


Figure 7.20 An adjustable-speed drive converts normal 60-Hz power into a form of power at varying frequencies for the purpose of adjusting the rotor speed of a 3-phase induction motor. Sometimes, a by-pass switch is installed in the event the drive fails.

between the controller and the motor, each lead does not carry the full-load current of the motor. Once the motor is running at full speed and the windings are in delta configuration, each lead carries 58% of the full-load current of the motor. In *430.22(C)* and *440.32*, the motor-circuit conductors are required to be sized at 125% of the current, and when factored into the 58%, the result is that the wires between the controller and the motor are to be sized not smaller than 72% of the full-load current of the motor. This point is not made clear in the Code. A diagram of a delta-wound motor started in a wye configuration and operated in a delta configuration is shown in Figure 7.21.

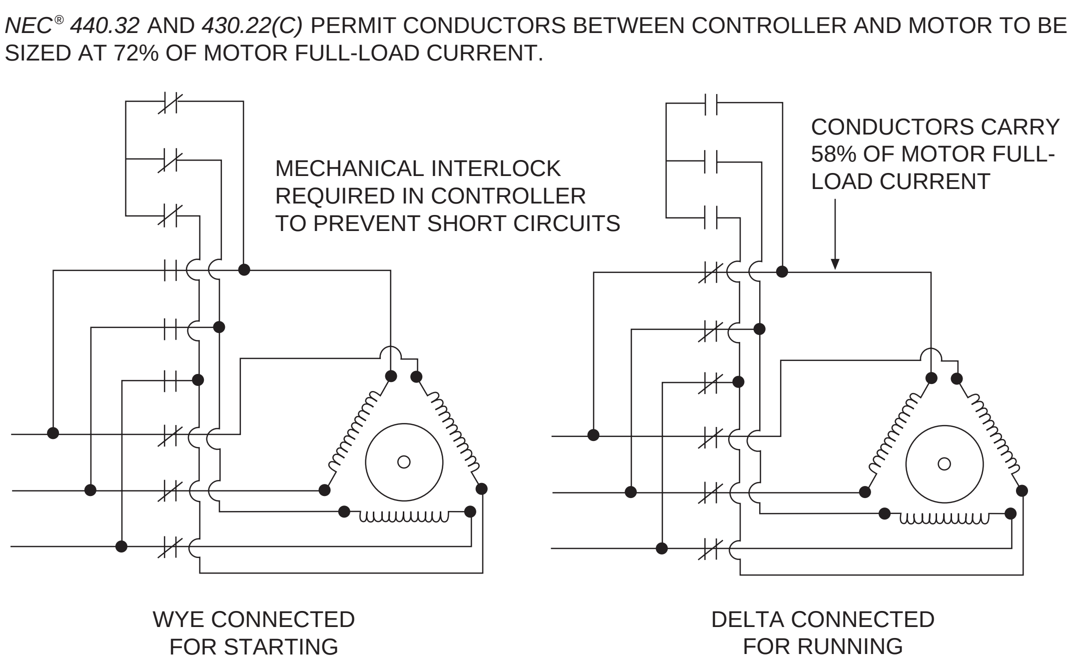


Figure 7.21 When a motor compressor is operated with windings in a wye configuration for starting and a delta configuration for running, there will be six wires between the controller and motor, and each wire will not carry more than 58% of the motor full-load current. The conductors are required to have an ampere rating not less than 72% of the motor full-load current.

A similar application where reduced voltage starting is used is a technique called part-winding starting. Part-winding motor starting involves two parallel sets of phase conductors between the controller and motor, as indicated in *430.22(D)*. The wires between the controller and the motor each carry half of the motor full-load current. It is necessary to multiply the 50% full-load current by 1.25 for part-winding motors so that each controller to motor supply wire is required to have an ampere rating of not less than 63% of motor full-load current.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the *2008 NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 409 Industrial Control Panels

409.2: There is a new definition of a control circuit. It does not carry the motor load current, but only the current required to direct the performance of the controller.

409.2: The definition of industrial control panel was revised. It now points out that an industrial control panel may consist of power circuits only such as motor controllers, overload relays, and similar devices, but no control circuit components. An industrial control panel may also consist of control circuit components and no power circuit components. The new definition is illustrated in Figure 7.22. An industrial control panel may contain both power-circuit components as well as control-circuit components.

409.106: A new section was added that set minimum spacing distances for live bare metal parts and terminals associated with feeders in an industrial control panel. There is an exception that permits closer spacing for listed components such as the terminals of a circuit breaker.

409.110 Exception: An industrial control panel is required to be marked with a short-circuit current rating unless the panel only contains control-circuit components. This exception for industrial control-circuit panels was not part of the previous edition of the Code.

Article 430 Motors, Motor Circuits, and Controllers

430.2: A new definition was added for a valve actuator motor assembly or VAM. These motors and the associated controls open and close valves in industrial process systems. The motors typically develop high torque for short periods of time.

430.87 Exception 2: This section requires a separate controller for each motor. The exception simply covers a practice that was permitted in the past, but not specifically covered in the Code. Such motors rated

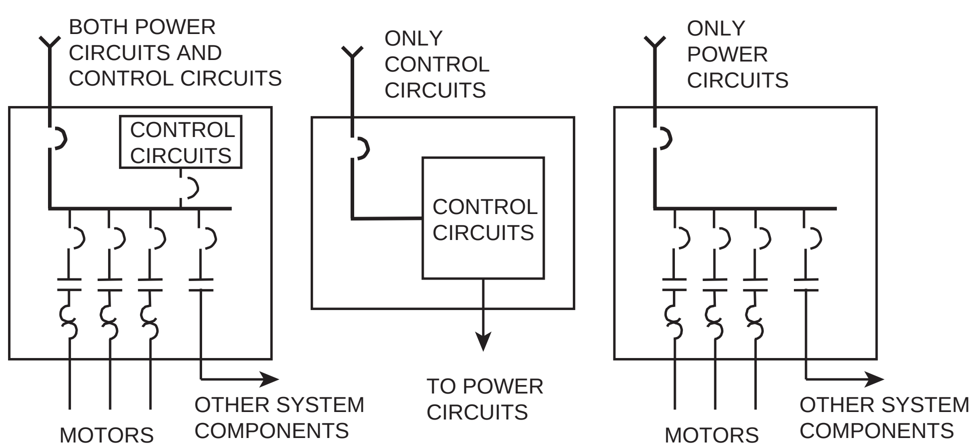


Figure 7.22 An industrial control panel may only contain control circuit components; it may only contain power circuit components, or it may contain both; and it not only controls motors, but may control other components of an industrial system.

not over 1/8 horsepower are permitted to be controlled by the branch-circuit overcurrent device, but there was never a provision for more than one to be on the same circuit.

430.102 Exception 3: This section requires a disconnecting means to be located in sight of a motor controller. The new exception deals with the case where a valve actuator motor assembly (VAM) containing a controller is located such that it would create a hazard to provide a disconnecting means within sight of the VAM assembly. The disconnecting means provided at an alternate location is permitted where a label is provided at the VAM assembly giving the location of the disconnecting means, and permanent provisions are made to lock the disconnect in the open position. This is illustrated in Figure 7.23.

430.103: The disconnecting means for a motor or controller is required to be designed such that it is incapable of being closed automatically.

430.126(A): Over temperature protection of motors operated from adjustable speed drive systems is a problem. This section in the previous edition of the Code required over temperature protection of the motor in all cases in addition to the typical motor circuit overload protection sized in accordance with *430.32*. The change is that now this additional motor over temperature protection is only required where the motor is not rated to operate at full load current over the speed range of the particular application. Motors have internal and sometimes external fans for cooling. When motor shaft speed is reduced, the ability of these fans to cool the motor is reduced, thus resulting in potential over temperature conditions within the motor.

430.126(A)(2) Exception: Some adjustable speed drive systems have the ability to keep track of potential motor over temperature by monitoring load current and speed. Paragraph (2) requires that when this system of over temperature protection is utilized, the drive unit must be capable of maintaining a memory of this thermal information, even when the drive is deenergized so that if power is restored, the unit will be able to keep track of the previous motor temperature condition. If there is a short time interruption of power and the drive does not retain this thermal history, the motor can be damaged by over heating because the drive no longer remembers the previous conditions. The exception is new and does not require such thermal memory retention when the system is rated for continuous duty operation. Applications where thermal memory is most likely necessary are for short-time, intermittent, periodic, or varying duty loads.

430.126(A) FPN: The fine print note from the previous edition of the Code was revised to more clearly explain the conditions of an adjustable-speed drive that can lead to an over temperature condition in motors. A recommendation related to external cooling systems for motors was added since a requirement relating to external cooling systems was removed since the previous edition of the Code.

430.227: This section requires the locking means for the disconnecting means for a motor controller for a circuit operating at more than 600 volts to be one that remains in place when the lock is removed. This means that portable add-on locking means to a disconnect is not permitted. All that an electrician needs to bring to the site is a lock.

430.243 Exception 1: This is a new exception where grounding is not required where motors operating at over 150 volts to ground are double-insulated, marked as such, and part of listed tools, listed appliances, or other listed equipment. The previous edition of the Code required that all equipment with motors operating at over 150 volts to ground be grounded.

430.243 Exception 2: Motors operating at over 150 volts to ground and part of cord and attachment plug connected listed tools, listed appliances, and listed equipment are permitted to not be grounded.

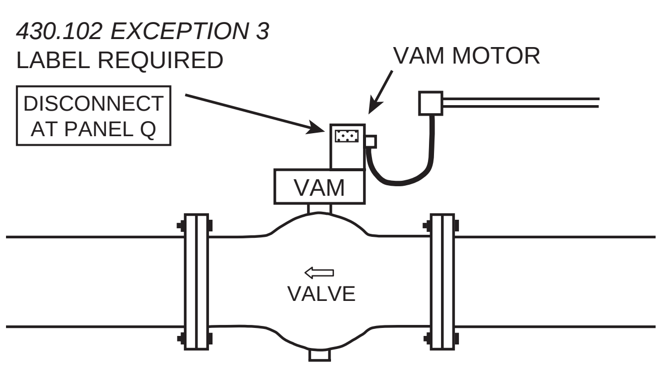


Figure 7.23 Short-time duty motors, generally delivering high torque used in industrial systems to control flow valves, are known as valve actuator motors (VAMs) and have special installation requirements now covered in *Article 430.*

Article 440 Air-Conditioning and Refrigerating Equipment

440.14: When a disconnect is installed attached to an air-conditioning or refrigeration unit, it is not permitted to be installed in such a way that it obstructs view of the nameplate on the unit.

440.14 Exception 1: For certain industrial applications, the disconnecting means for an air-conditioning or refrigeration unit is permitted to be located out of sight of the unit. In these cases, the disconnecting means is required to be capable of being locked in the open position. The change means that the locking means is required to be a fixed part of the disconnecting means and not some portable means that is added by the electrician.

Article 675 Electrically Driven or Controlled Irrigation Machines

675.8(B): This change deals with the method of locking the main disconnecting means for an electrically powered irrigation machine in the open position. The previous edition of the Code only required that the disconnect be capable of being locked in the open position. A maintenance person may arrive at the site only to find that a portable locking device, which may not be available, is required to lock out power. The change requires that the switch or circuit breaker be of a type that can be locked or that has a locking means added.

WORKSHEET NO. 7—BEGINNING MOTOR-CIRCUIT WIRING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A 3-phase, 460-volt, 30-horsepower, design B, squirrel-cage induction motor is supplied with size 8 AWG copper conductors with 75°C insulation and terminations. The branch-circuit is protected from short circuits and ground faults with 70-ampere rated time-delay fuses. A short section of Liquidtight Flexible Nonmetallic Conduit is installed in the raceway between the controller and the motor to prevent transmission of vibration as shown in Figure 7.24 and a copper equipment grounding conductor is run from a grounding lug on the controller enclosure to a grounding lug in the motor terminal housing. The minimum size equipment grounding conductor permitted is:
   A. 14 AWG.
   B. 12 AWG.
   C. 10 AWG.
   D. 8 AWG.
   E. 6 AWG.

   Code reference ___________________

2. According to *430.102(B)* in the Code, a disconnecting means is required to be located “in sight from” a motor and driven machinery location. In addition to being directly in the line of sight, the term “in sight from” means the disconnect must not be located from the motor and driven machine a distance greater than:
   A. 10 ft (3 m).
   B. 15 ft (4.5 m).
   C. 20 ft (6 m).
   D. 25 ft (7.5 m).
   E. 50 ft (15 m).

   Code reference ___________________

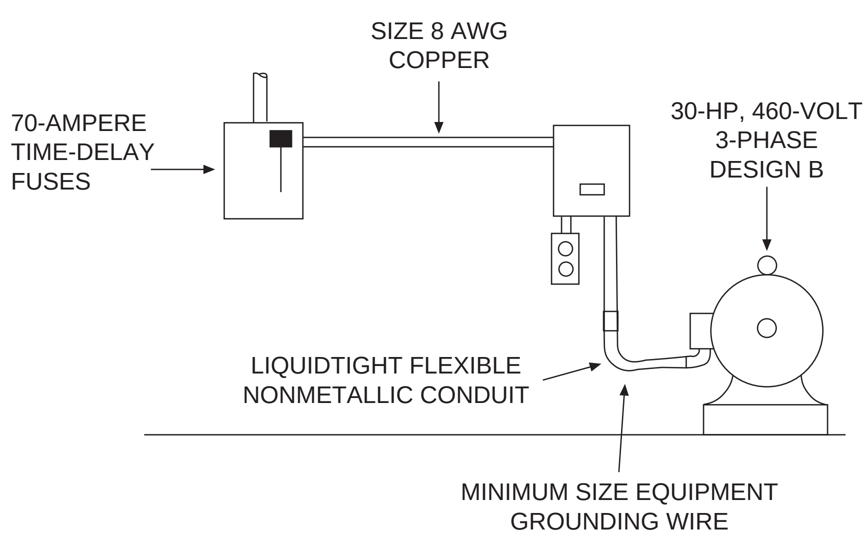


Figure 7.24 Determine the minimum size copper equipment grounding conductor required from the controller to the motor with the circuit protected with 70-ampere time-delay fuses.

3. A flexible cord attachment plug and receptacle are permitted to serve as the controller for a 230-volt, single-phase, portable induction motor that has a rating not greater than:
   A. 1/8 horsepower.
   B. 1/4 horsepower.
   C. 1/3 horsepower.
   D. 1/2 horsepower.
   E. 3/4 horsepower.

   Code reference ___________________

4. A 3-phase, 5-horsepower, 230-volt, design B, squirrel-cage induction motor has a nameplate full-load current of 14 amperes and a service factor of 1.15. The branch-circuit short-circuit and ground-fault protection is provided with a 40-ampere inverse-time circuit breaker. The circuit is shown in Figure 7.25. The minimum branch-circuit copper conductor size with 75°C insulation and terminations permitted for this motor is:
   A. 16 AWG.
   B. 14 AWG.
   C. 12 AWG.
   D. 10 AWG.
   E. 8 AWG.

   Code reference ___________________

5. Each controller shall be capable of starting and stopping the motor and shall be capable of:
   A. interrupting the locked-rotor current of the motor.
   B. interrupting the full-load current of the motor.
   C. interrupting 125% of the full-load current of the motor.
   D. sensing overload currents.
   E. sensing short circuits and ground faults.

   Code reference ___________________

6. A 10-horsepower, 230-volt, 3-phase, design B, squirrel-cage induction motor has a nameplate full-load current of 26 amperes and a service factor of 1.15. The branch-circuit conductors are size 10 AWG copper with 75°C insulation and terminations. The motor has no difficulty starting the load. The circuit is similar to Figure 7.25. If an inverse-time circuit breaker is used as the branch-circuit short-circuit and ground-fault protection, the maximum standard rating permitted for this circuit is:
   A. 30 amperes.
   B. 40 amperes.
   C. 50 amperes.
   D. 60 amperes.
   E. 70 amperes.

   Code reference ___________________

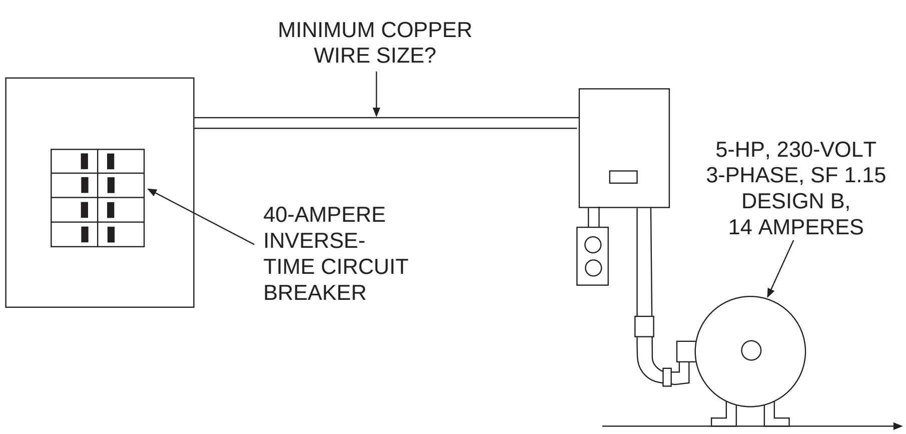


Figure 7.25 Determine the minimum size copper conductor for a motor branch-circuit that is short-circuit and ground-fault protected by a 40-ampere inverse-time circuit breaker and supplies a 5-horsepower, 230-volt, 3-phase motor.

7. A 230-volt, 3-phase, 10-horsepower, design B, squirrel-cage induction electric motor has a nameplate full-load current of 26 amperes and a service factor of 1.15. The branch-circuit conductors are size 10 AWG with 75°C insulation and terminations. If a set of time-delay fuses is installed to provide both running overload protection and branch-circuit short-circuit and ground-fault protection, the maximum standard rating permitted is:

   A. 30 amperes. C. 40 amperes. E. 50 amperes.
   B. 35 amperes. D. 45 amperes.

   Code reference ___________________

8. A motor and driven machine are located within sight of the controller and a fusible switch capable of being locked in the open position is located within sight of the controller, but not within sight of the motor or driven machine as shown in Figure 7.26. This commercial installation is permitted:

   A. in any type of occupancy.
   B. only in commercial occupancies where there are qualified personnel on duty to service the installation.
   C. if there is an additional disconnect located between the controller and the motor within sight of the motor and driven machine.
   D. even if the disconnect cannot be locked in the open position as long as a warning label can be attached to the disconnect during servicing.
   E. because the fuses can be removed from the disconnect during servicing.

   Code reference ___________________

9. A 3-phase, 230-volt, 7 1/2-horsepower squirrel-cage induction motor is required to be free to move during operation and is supplied power with a Type SO flexible cord. The cord is copper with three insulated ungrounded conductors and a green insulated equipment grounding conductor. The minimum size cord permitted for this motor is:

   A. 14 AWG. C. 10 AWG. E. 6 AWG.
   B. 12 AWG. D. 8 AWG.

   Code reference ___________________

10. A 3-phase, 230-volt, design B squirrel-cage induction motor has branch-circuit short-circuit and ground-fault protection provided by a 60-ampere circuit breaker. The magnetic motor starter is operated by a start-stop station located 10 ft (3 m) from the controller as shown in Figure 7.27. Separate overcurrent protection for the

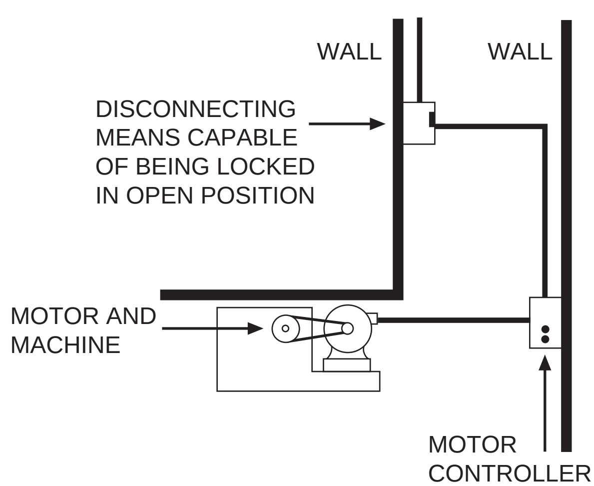


Figure 7.26 The single disconnect is capable of being locked in the open position and is in sight from the controller, but not in sight from the motor.

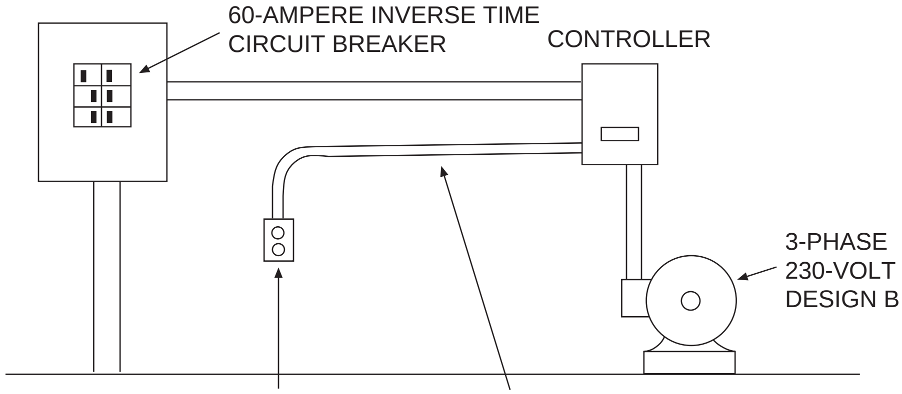


Figure 7.27 Determine the minimum size class 1 copper control-circuit conductors to the start-stop station where the motor circuit is protected with a 60-ampere inverse-time circuit breaker.

control circuit is not provided and the 60-ampere circuit breaker is the only protection for the control circuit. This is permitted provided the copper control-circuit wires with 75°C insulation and terminations are not smaller than size:

A. 18 AWG. C. 14 AWG. E. 10 AWG.
B. 16 AWG. D. 12 AWG.

Code reference ___________________

11. An air-conditioning unit is located on the roof of a commercial building. The disconnecting means for the equipment is:
    A. permitted to be a switch capable of being locked in the open position and located not in sight of the equipment.
    B. required to be located within sight of the equipment and readily accessible from the equipment.
    C. is required to be capable of being locked in the open position even when located within sight of the equipment.
    D. not permitted to be attached to the outside of the air-conditioning equipment.
    E. not permitted to be installed within the air-conditioner enclosure.

Code reference ___________________

12. A wound-rotor motor circuit is installed with a resistor bank separate from the controller as shown in Figure 7.28. For this application, the resistors may be in the circuit during normal operation and not just motor starting. The insulation temperature rating for the conductors between the controller and the resistor bank is required to be not less than:
    A. 75°C. C. 105°C. E. 200°C.
    B. 90°C. D. 150°C.

Code reference ___________________

13. A 125-volt room air conditioner is permitted to be supplied by a 15- or 20-ampere, 125-volt general lighting branch-circuit in a dwelling if the air-conditioner load is not:
    A. more than 50% of the rating of the branch-circuit.
    B. more than 80% of the rating of the branch-circuit.
    C. large enough to overload the branch-circuit.
    D. more than 12 amperes.
    E. sharing the circuit with general-use receptacles.

Code reference ___________________

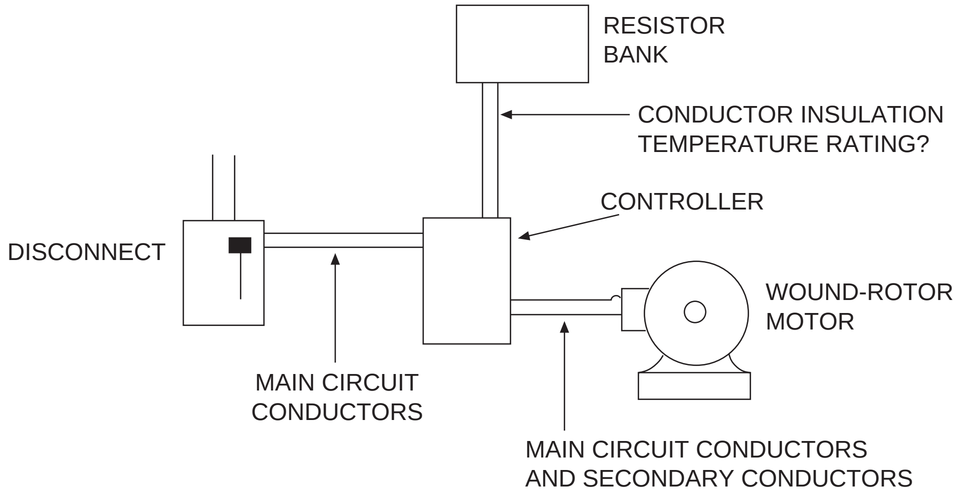


Figure 7.28 The wound-rotor motor circuit has a resistor bank separate from the controller. Determine the minimum temperature rating of the conductors from the controller to the resistor bank.

14. A 3-phase bank of capacitors is installed on an electrical system for power factor correction. The nameplate full-load current of the capacitor bank is 50 amperes. The minimum size copper conductors with 75°C terminations permitted to connect to the capacitor bank is:
    A. 8 AWG.
    B. 6 AWG.
    C. 4 AWG.
    D. 3 AWG.
    E. 2 AWG.

Code reference ___________________

15. The main disconnecting means that is separate from the control panel for a center pivot irrigation machine, as illustrated in Figure 7.29, is required to be located:
    A. not more than 10 ft (3 m) from the center pivot point of the machine.
    B. at any distance from the center pivot point provided the disconnect is capable of being locked in the open position.
    C. where it will not be exposed to falling water.
    D. at any distance from the center pivot point of the machine provided it is in direct line of sight of the center pivot point.
    E. within 50 ft (15 m) of the machine and capable of being locked in the open position.

Code reference ___________________

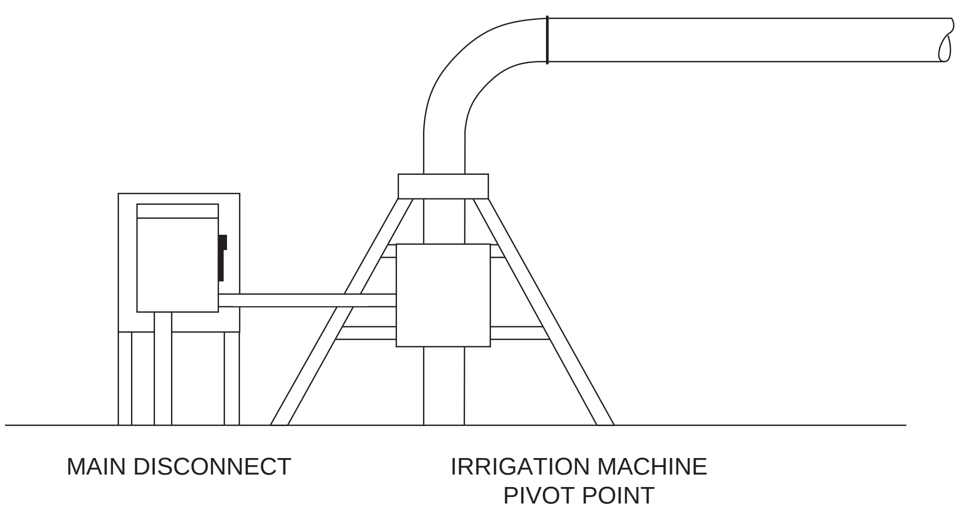


Figure 7.29 What is the requirement for the location of the main disconnect for a center pivot irrigation machine operating at 460 volts.

WORKSHEET NO. 7—ADVANCED MOTOR-CIRCUIT WIRING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A 75-horsepower, 3-phase, 460-volt design B squirrel-cage induction motor has a service factor of 1.15 and a nameplate full-load current of 92 amperes. The *motor* current to be used to determine the minimum size branch-circuit conductor is:
   A. 92 amperes. B. 96 amperes. C. 104 amperes. D. 110 amperes. E. 130 amperes.

   Code reference ___________________

2. A 15-horsepower, 3-phase, 230-volt design B squirrel-cage induction motor has a service factor of 1.15 and a nameplate full-load current of 39 amperes. If the branch-circuit conductors are copper with 75°C insulation and terminations, the minimum size conductor permitted is:
   A. 10 AWG. B. 8 AWG. C. 6 AWG. D. 4 AWG. E. 3 AWG.

   Code reference ___________________

3. A 25-horsepower, 3-phase, 460-volt design B squirrel-cage induction motor has a service factor of 1.15 and a nameplate full-load current of 30 amperes. The branch-circuit conductors are size 8 AWG copper with 75°C insulation and terminations. The overload sensing elements in the controller are set at not more than 38 amperes. The motor circuit illustrated in Figure 7.30 is powering an easy starting load. If the motor branch-circuit is protected from short circuits and ground faults by time-delay fuses, the maximum standard rating permitted is:
   A. 35 amperes. B. 40 amperes. C. 45 amperes. D. 50 amperes. E. 60 amperes.

   Code reference ___________________

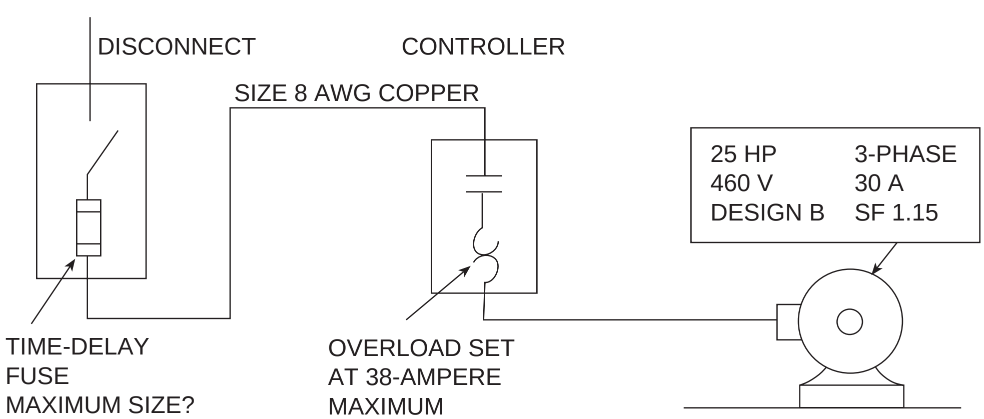


Figure 7.30 Determine the maximum rating of the time-delay fuse permitted for branch-circuit short-circuit and ground-fault protection of the 25-horsepower, 3-phase, 460-volt motor.

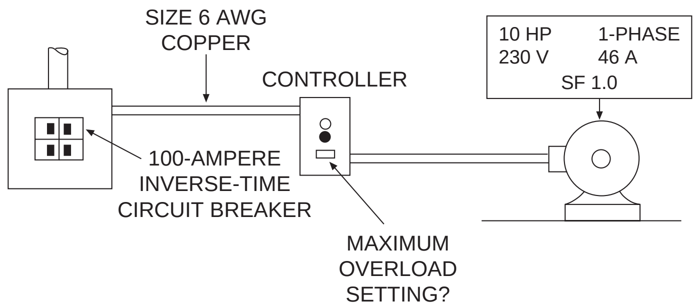


Figure 7.31 Determine the maximum setting in amperes for the running overload protection for a 10-horsepower, single-phase, 230-volt motor with a service factor of 1.0.

4. A flexible cord attachment plug not horsepower-rated and receptacle are permitted to be used as the disconnect for a portable electric motor that is:
   A. single-phase, 115 volts, rated not over 1/2 horsepower.
   B. 3-phase, 460 volts, rated not over 1 horsepower.
   C. 3-phase, 208 volts, rated not over 1/2 horsepower.
   D. 3-phase, 230 volts, rated not over 3/4 horsepower.
   E. 3-phase, 230 volts, rated not over 1/3 horsepower.

Code reference ___________________

5. A 10-horsepower, single-phase, 230-volt, squirrel-cage induction motor has a service factor of 1.0 and a nameplate full-load current of 46 amperes. The branch-circuit conductors are size 6 AWG copper with 75°C insulation and terminations. The short-circuit and ground-fault protection for the branch-circuit is provided by a 100-ampere rated inverse-time circuit breaker as illustrated in Figure 7.31. The maximum current setting permitted for the running overload protection of this motor is:
   A. 40 amperes. C. 53 amperes. E. 63 amperes.
   B. 46 amperes. D. 58 amperes.

Code reference ___________________

6. A thermal protector is integral with a 7 1/2-horsepower, 230-volt, single-phase, squirrel-cage motor to act as the running overload protection. The nameplate full-load current is 40 amperes, and the service factor is 1.15. The circuit is shown in Figure 7.32. If an inverse-time circuit breaker is used as the controller for the motor, the maximum standard rating permitted is:
   A. 50 amperes. C. 80 amperes. E. 100 amperes.
   B. 70 amperes. D. 90 amperes.

Code reference ___________________

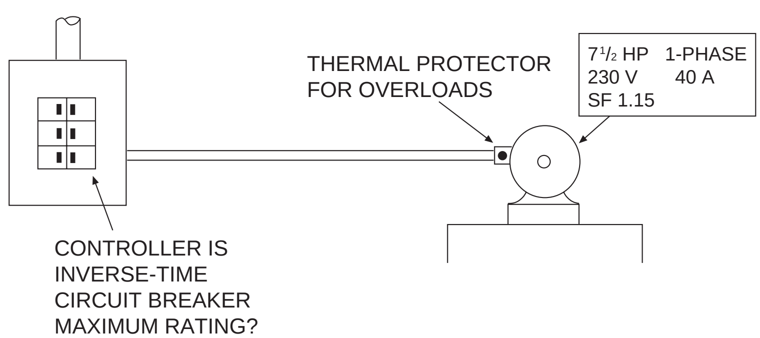


Figure 7.32 Determine the maximum rating permitted for a circuit breaker to act as a controller and disconnect for a thermally protected 7 1/2-horsepower, single-phase, 230-volt motor.

7. A 3-phase, 230-volt, 10-horsepower, design B, squirrel-cage induction motor is supplied with size 8 AWG copper conductors with 75°C insulation and terminations. The nameplate full-load current is 28 amperes and the service factor is 1.15. The branch-circuit is tapped from a feeder to a combination disconnect/motor controller containing a 200-ampere rated instantaneous-trip circuit breaker as the short-circuit and ground-fault protection. A short section of Liquidtight Flexible Nonmetallic Conduit is installed in the raceway between the controller and the motor to prevent transmission of vibration as shown in Figure 7.33 and a copper equipment grounding conductor is run from a grounding lug on the controller enclosure to a grounding lug in the motor terminal housing. The minimum size equipment grounding conductor permitted is:

   A. 14 AWG. C. 10 AWG. E. 6 AWG.
   B. 12 AWG. D. 8 AWG.

   Code reference ____________________

8. A 3-phase, 460-volt, 40-horsepower continuous-duty wound-rotor induction motor has a nameplate primary full-load current of 45.5 amperes and a nameplate secondary full-load current of 82 amperes. There is a resistor bank remote from the controller, as shown in Figure 7.34, and is classified as heavy-starting duty. The motor has a temperature rise of 40°C marked on the nameplate. All circuit conductors are copper with 75°C insulation and terminations. The minimum size secondary conductors permitted between the motor and the controller is:

   A. 6 AWG. C. 3 AWG. E. 1 AWG.
   B. 4 AWG. D. 2 AWG.

   Code reference ____________________

9. A controller for an electric motor is within sight of a circuit breaker panel where a circuit breaker acts as the disconnect for the controller. The electric motor and machine are not located in sight from the controller or the disconnect for the controller. Due to

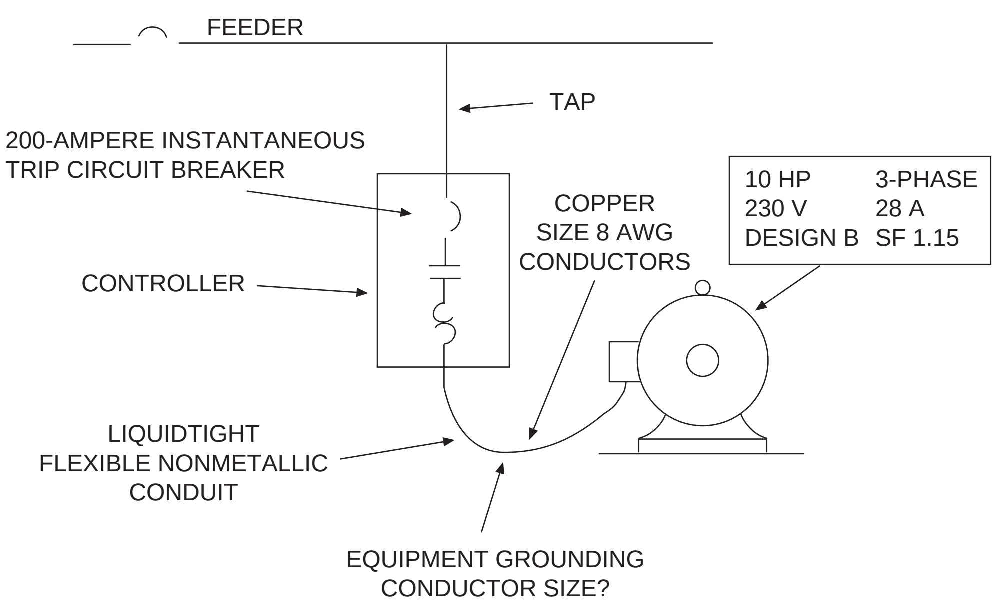


Figure 7.33 Determine the minimum size permitted for a copper equipment grounding conductor installed between a controller and a motor when the instantaneous-trip circuit breaker has a 200-ampere rating.

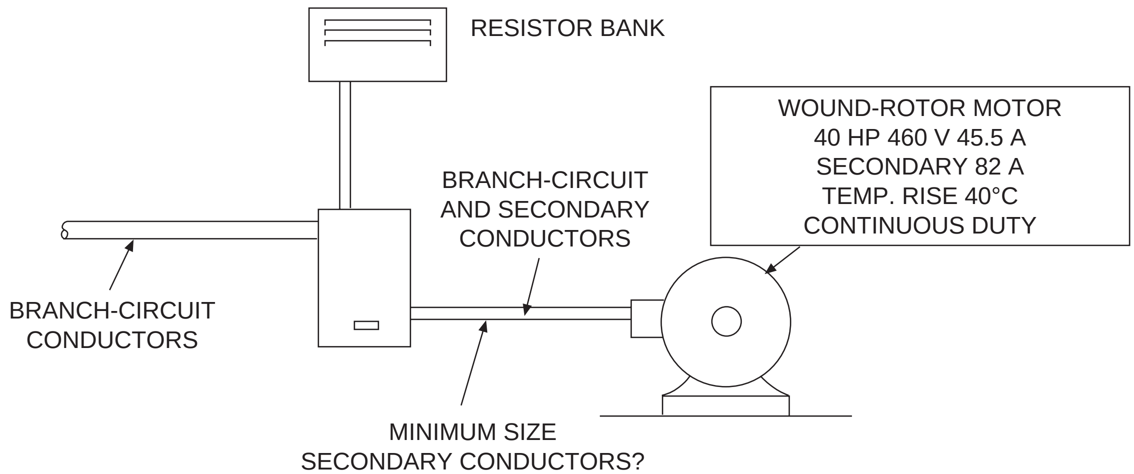


Figure 7.34 Determine the minimum size permitted for the secondary conductors between a wound-rotor motor and the controller where the secondary current is listed on the motor nameplate as 82 amperes.

the nature of the machine, power is supplied to the motor with a Type SO flexible cord. An acceptable disconnect for the motor and machine is:

A. a disconnect switch located on the machine next to the motor.
B. a lock on the door of the circuit breaker panel where the controller disconnect is located.
C. a removable locking mechanism for the circuit breaker acting as the controller disconnect.
D. a permanently installed locking mechanism for the circuit breaker acting as the controller disconnect where another disconnect within sight would be practical.
E. an attachment plug and connector installed in the cord within 3 ft (900 mm) of the motor.

Code reference ___________________

10. A 3-phase bank of capacitors is installed at a main service to a building to provide power factor correction. The rating of the capacitor bank is 55 kVAR, at 480 volts, 60 hertz. A fusible switch is provided as the disconnect and overcurrent protection for the conductors and the capacitors. If all conductors are copper with 75°C rated insulation and terminations, the minimum size permitted for this capacitor bank is:

A. 6 AWG.
B. 4 AWG.
C. 3 AWG.
D. 2 AWG.
E. 1 AWG.

Code reference ___________________

11. A ladder diagram is shown for a start-stop station operating a magnetic motor starter in Figure 7.35 on the next page. The control circuit is supplied from a transformer in the motor controller enclosure with a 120-volt secondary that has one conductor grounded. The Code violation for the control circuit is that:

A. a pilot light is required to be installed in parallel with the solenoid coil.
B. an accidental ground fault can energize the coil and operate the motor.
C. control circuits are required to be operated at motor line voltage.
D. a manual disconnect switch is required to be installed in series with the start-stop station.
E. one conductor is not permitted to be grounded.

Code reference ___________________

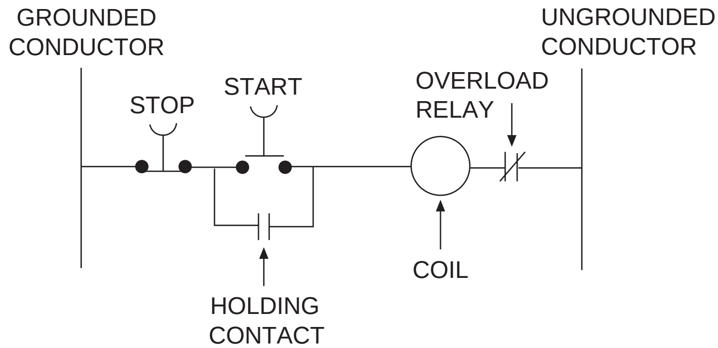


Figure 7.35 Find the Code violation in the way this control circuit of an electric motor is connected.

12. A refrigeration motor compressor is rated 208-volt, 3-phase, and has a branch-circuit selection current of 32 amperes. If the branch-circuit conductors are copper with 75°C insulation and terminations, the minimum size permitted is:
    A. 10 AWG.
    B. 8 AWG.
    C. 6 AWG.
    D. 4 AWG.
    E. 3 AWG.

    Code reference ___________________

13. A center pivot irrigation machine is operated with twelve design B, 3/4-horsepower, 460-volt, 3-phase, squirrel-cage motors located on towers along the machine. The motors operate drive wheels that propel the machine in a circle around the center pivot point. These drive motors are tapped to a branch-circuit conductor that runs the entire length of the machine. The equivalent continuous-current rating for the selection of branch-circuit conductors for this machine is:
    A. 12.6 amperes.
    B. 15.8 amperes.
    C. 19.2 amperes.
    D. 19.6 amperes.
    E. 24.0 amperes.

    Code reference ___________________

14. In an industrial installation with a trained and documented qualified maintenance staff on duty at all times, if an automatic shutdown of a motor in a system due to an overload would create a safety hazard greater than continued operation of a motor, it is:
    A. permitted to connect the overload sensing devices to a supervised alarm.
    B. permitted to eliminate motor overload relays from the control system.
    C. required to supply all motors of the system with an ungrounded electrical supply.
    D. permitted to eliminate motor overload relays if all motors are double insulated.
    E. required to ground all metal equipment in reach of personnel with an insulated copper equipment grounding conductor.

    Code reference ___________________

15. A single-phase, 240-volt feeder consisting of size 2 AWG copper conductors with 75°C insulation and terminations supplies four induction motors rated one at 7 1/2 horsepower, one at 5 horsepower, one at 3 horsepower, and one at 2 horsepower as shown in Figure 7.36. Each motor has a service factor of 1.15. The branch-circuit short-circuit and ground-fault protection for each motor is provided with time-delay fuses and the fuse ratings for each motor circuit is 70 amperes for the 7 1/2-horsepower motor, 50 amperes for the 5-horsepower motor, 30 for the 3-horsepower motor, and 25 amperes for the 2-horsepower motor. If a circuit breaker is used as the short-circuit and ground-fault protection for the feeder, the maximum standard rating permitted is:
    A. 90 amperes.
    B. 100 amperes.
    C. 110 amperes.
    D. 125 amperes.
    E. 150 amperes.

    Code reference __________________

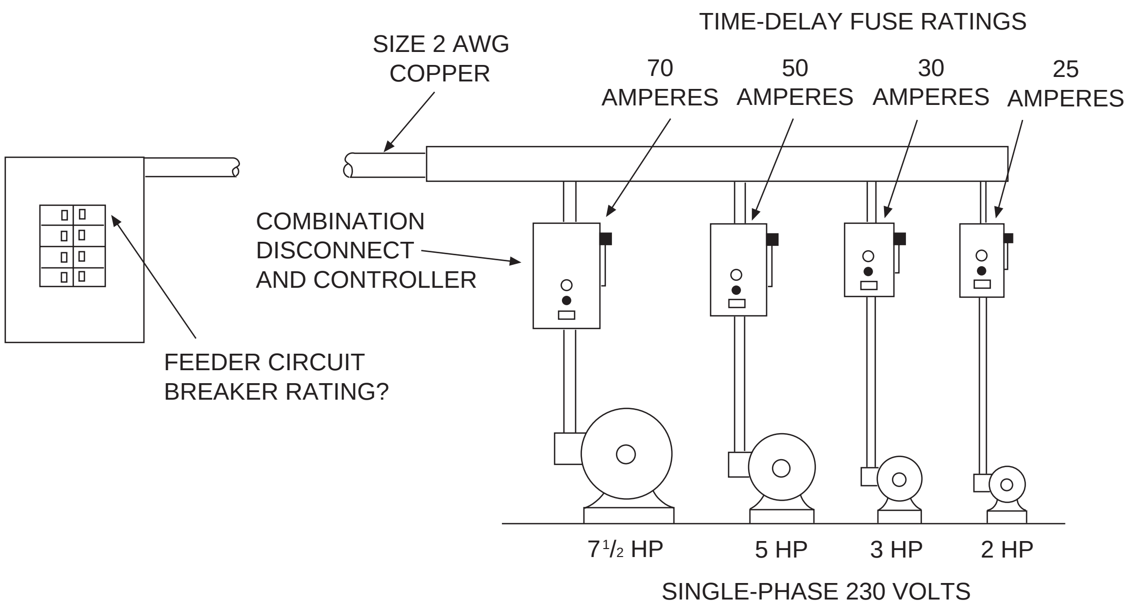


Figure 7.36 Determine the maximum rating permitted for the feeder overcurrent protection supplying a single-phase, 230-volt, 7 1/2-, 5-, 3-, and 2-horsepower motors.

UNIT 8

Transformers

OBJECTIVES

After completion of this unit, the student should be able to:

- define insulating transformer and autotransformer.
- determine the voltage of a transformer winding if turns ratio and the other winding voltage are given.
- determine the full-load current of a transformer winding if the voltage and kilovolt-amperes of the transformer are given for single-phase or 3-phase transformers.
- determine the minimum permitted kilovolt-amperes required for a specific application.
- draw the proper connections of the windings of a dual-voltage single-phase transformer for the desired voltage.
- explain the purpose of the taps on the primary winding of some transformers.
- state a specific example of the use of a boost and buck transformer.
- determine the maximum permitted overcurrent protection for a specific transformer.
- determine the minimum permitted primary and secondary conductors for a specific transformer application.
- determine the maximum distance permitted from a feeder tap to the transformer overcurrent protection.
- determine the maximum permitted input overcurrent protection for a boost or buck transformer application.
- explain how to ground the transformer and the secondary electrical system of the transformer.
- answer wiring installation questions relating to *Article 450.*
- state a significant change that occurred in Code *Article 450* from the 2005 to the 2008 edition.

CODE DISCUSSION

Article 450 deals with transformers and transformer vaults. *NEC® 450.1* gives the exceptions for transformers that are covered in other sections of the Code. *NEC® 450.3* deals with overcurrent protection of transformers. Some specific rules for autotransformer overcurrent protection are covered in *450.4.* The remainder of *Part I* of this article covers general installation requirements. *Part II* covers requirements for specific types of transformers. *Part III* deals with transformer vaults that are enclosures of specific construction for the purpose of housing transformers and other equipment such as switchboards and panelboards.

Article 450 of the Code applies only to the transformer itself, and not to the conductors leading to or away from the transformer. The branch-circuit, feeder, and tap conductors must be protected according to the rules of *Article 240.* Grounding must be accomplished according to the rules of *Article 250.* Here are Code sections helpful in working transformer circuit problems: *240.4(F), 240.21(B)(3), 240.21(C), 250.30, 250.104(D), 408.36(B), 430.72(C), 600.21, 600.23, 600.31, 600.32, 680.23(A), 725.41(A)(1), 725.121(A)(1),* and *725.124.* These are in addition to information found in *Article 450.*

TRANSFORMER FUNDAMENTALS

The purpose of a transformer is to change electrical voltage to a different value. For example, a large 480-volt, 3-phase motor is powering a well pump. The motor is in a building, and one 120-volt circuit for a few lights and a receptacle outlet is needed. A transformer is used to lower the voltage from 480 to 120 for the lighting circuit. The controls for furnaces and air-conditioning units are often operated at 24 volts. A small transformer inside the equipment lowers the line voltage to 24 volts for the control circuit. Transformers are frequently used inside electronic equipment.

Types of Transformers

Transformers are of the dry type or oil-filled. Two to five percent of the electrical energy is lost in a transformer, mostly due to the resistance of the windings. Large transformers circulate oil through the windings to remove the heat. Dry transformers use air for cooling. Heat is moved from the windings to the case by conduction in smaller sizes of the dry type. Large dry-type transformers actually allow air to circulate through the windings. Oil-cooled transformers are used by the electric utility and for industrial or large commercial applications.

Common two-winding transformers are often called insulating transformers. The primary winding and the secondary winding are separate from each other, and they are not electrically connected. An autotransformer has the windings interconnected so that the primary and the secondary share the same winding. These transformers, therefore, have an electrically connected primary and secondary. A major advantage of the autotransformer over the insulating type is its lighter weight and compact size. An insulating transformer and an autotransformer are compared in Figure 8.1. A common application of an autotransformer is for electric discharge lighting ballasts.

A special type of autotransformer called a grounding autotransformer, or zig-zag transformer, is occasionally used to create a neutral wire or a ground for an ungrounded 480-volt 3-phase electrical system. These transformers are found occasionally in industrial wiring. The name zig-zag is derived from the shape of the schematic diagram. Standard insulating transformers can be used to make a zig-zag transformer. The wiring of these transformers is covered in *450.5*.

Voltage and Turns Ratio

The input winding to a transformer is called the primary winding. The output winding is called the secondary winding. If there are more turns of wire on the primary winding than on the secondary winding, the output voltage will be lower than the input voltage.

It is important to know the ratio of the number of turns of wire on the primary winding as compared with the secondary winding. This is called the turns ratio of the transformer. The actual number of turns is not important, just the turns ratio. The turns ratio of a transformer can be determined with Equation 8.1 if the actual number of turns on the transformer windings is known.

$$\textbf{Turns Ratio} = \frac{\textbf{Number of Turns on the Primary}}{\textbf{Number of Turns on the Secondary}} \qquad \textbf{Eq. 8.1}$$

The step-down transformer of Figure 8.2 has 14 turns on the primary winding and 7 turns on the secondary winding; therefore, the turns ratio is 2 to 1, or just 2. The step-up transformer has 7 turns on the

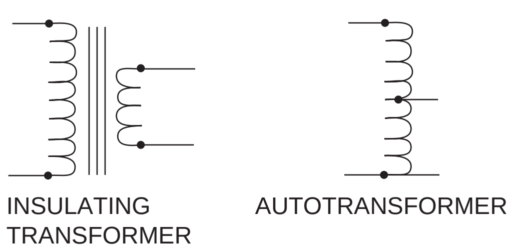


Figure 8.1 Two basic types of transformers are the insulating transformer and the autotransformer.

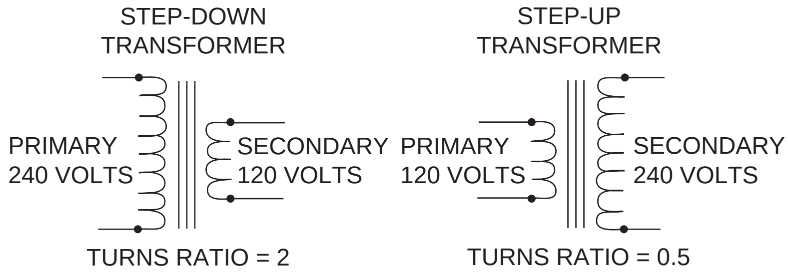


Figure 8.2 Schematic diagrams of step-down and step-up transformers.

primary and 14 on the secondary; therefore, the turns ratio is 1 to 2, or 0.5. If the voltage of one winding and the turns ratio are known, the voltage of the other winding can be determined using either Equation 8.2 or Equation 8.3.

$$\textbf{Primary voltage} = \textbf{Secondary Voltage} \times \textbf{Turns Ratio} \qquad \textbf{Eq. 8.2}$$

$$\textbf{Secondary Voltage} = \frac{\textbf{Primary Voltage}}{\textbf{Turns Ratio}} \qquad \textbf{Eq. 8.3}$$

Transformer Ratings

Transformers are rated in volt-amperes (VA) or kilovolt-amperes (kVA). This means that the primary winding and the secondary winding are designed to withstand the VA or kVA ratings stamped on the transformer nameplate. The primary and secondary full-load current usually are not given. The installer must be able to calculate the primary and secondary full-load current from the nameplate information. If the volt-ampere rating is given along with the primary voltage, then the primary full-load current can be determined using Equation 8.4 or Equation 8.5 for the case of a single-phase transformer. Equation 8.6 is used for determining the full-load current of either the primary or the secondary winding of a 3-phase transformer.

Single-phase:

$$\textbf{Full-Load Current} = \frac{\textbf{VA}}{\textbf{Voltage}} \qquad \textbf{Eq. 8.4}$$

$$\textbf{Full-Load Current} = \frac{\textbf{kVA} \times \textbf{1000}}{\textbf{Voltage}} \qquad \textbf{Eq. 8.5}$$

Three-phase:

$$\textbf{Full-Load Current} = \frac{\textbf{kVA} \times \textbf{1000}}{\textbf{1.73} \times \textbf{Volts}} \qquad \textbf{Eq. 8.6}$$

An example will help to show how the previous equations are used to determine the full-load current of a transformer winding. It may be a good idea to write Equations 8.5 and 8.6 into a copy of the Code for easy reference when making transformer installations.

Example 8.1 A single-phase transformer is connected for a 480-volt primary and a 120-volt secondary. The transformer has a rating of 2 kVA. Determine the primary winding and the secondary winding full-load current of the transformer.

Answer: This is a single-phase transformer rated in kilovolt-amperes; therefore, Equation 8.5 is used to determine the full-load current for both windings. The full-load current of the primary winding of the transformer is 4.17 amperes, and for the secondary winding, the full-load current is 16.67 amperes.

$$\text{Primary Full-Load Current} = \frac{2\ \text{kVA} \times 1000}{480\ \text{V}} = 4.17\ \text{A}$$

$$\text{Secondary Full-Load Current} = \frac{2\ \text{kVA} \times 1000}{120\ \text{V}} = 16.67\ \text{A}$$

Connecting Transformer Windings

Transformer wiring diagrams are printed on the transformer nameplate, which may be affixed to the outside of the transformer or printed inside the cover to the wiring compartments. The lead wires or terminals are marked with Xs and Hs. The Hs are the primary leads, and the Xs are the secondary leads.

Some transformers have two primary and two secondary windings so they can be used for several applications. These are called dual-voltage transformers. Connections must be made correctly with dual-voltage transformers. If connected improperly, it is possible to create a short-circuit that will usually damage or destroy the transformer when it is energized.

Consider a dual-voltage transformer rated 240/480 volts on the primary and 120/240 volts on the secondary. Each of the two primary windings is, therefore, rated 240 volts. Each secondary winding is rated 120 volts. The transformer must be connected so each primary winding receives the proper voltage. Figure 8.3 shows the transformer with the primary windings connected in series with H1 and H4 connected to a 480-volt supply. The voltage across H1 and H2 is 240, and the voltage across H3 and H4 is 240. Each winding is receiving the proper voltage. With each primary winding receiving the proper 240 volts, each secondary winding will have an output of 120 volts. Connecting the secondary windings in series produces 240 volts across X1 and X4.

Next, consider a case where the primary voltage available is 480, but the desired output is 120 volts, single-phase. In this case, the primary windings are connected in series, while the secondary windings are connected in parallel, as shown in Figure 8.4.

Three-Phase Transformers

Changing the voltage of a 3-phase system can be done with a 3-phase transformer, or it can be done with single-phase transformers. Three-phase transformers are generally designed and constructed for specific voltages. For example, a transformer may have a 480-volt delta primary and a 208/120-volt wye secondary.

The 3-phase transformer has one core with three sets of windings. A primary and secondary winding are placed one on top of the other on each of the three legs of the core. Single-phase transformers can be used to form a 3-phase transformer bank. It is important that single-phase transformers are identical when connecting them to form a 3-phase system. They should be identical in voltage, kilovolt-amperes, impedance, manufacturer, and model number. Transformer impedance is the combined effect of resistance and inductance and is given in percent.

Connecting single-phase transformers to form a 3-phase bank must be done with extreme caution. The windings can only be connected in a certain way. Reversing a winding can damage the transformer. Figure 8.5 shows three individual single-phase transformers connected to step down from 480 volts delta

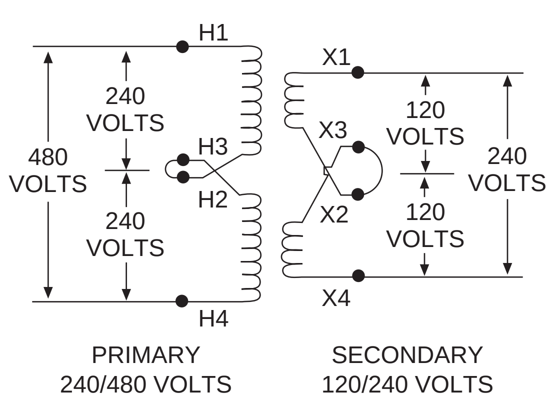


Figure 8.3 The windings are connected in series to obtain the higher of the rated transformer voltages.

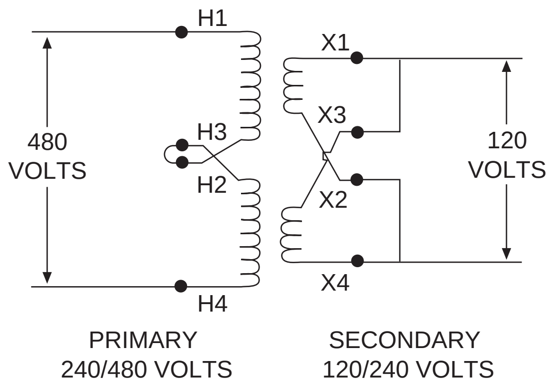


Figure 8.4 The secondary windings are connected in parallel for an output of 120 volts.

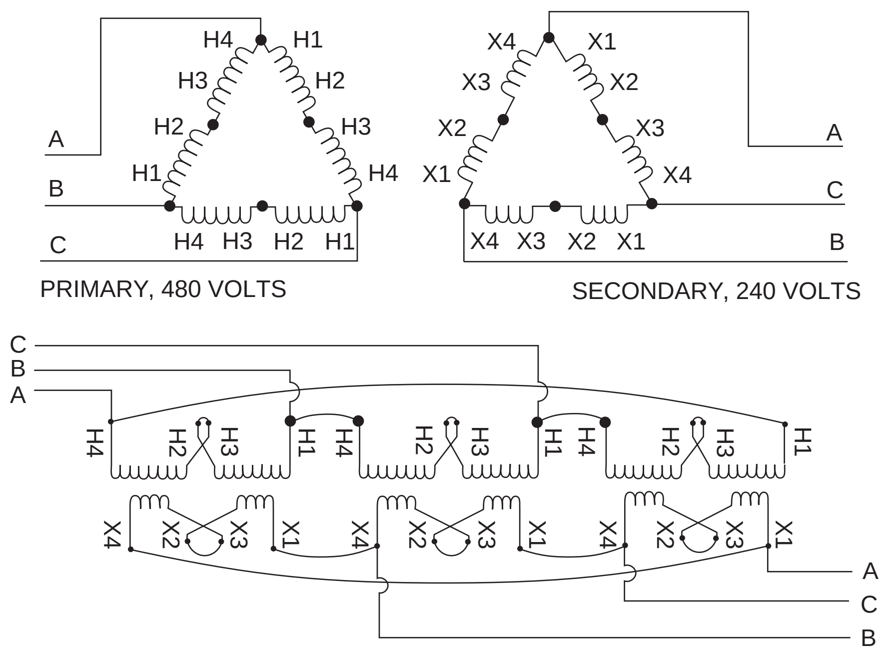


Figure 8.5 Dual-voltage single-phase transformers with 240/480-volt primary windings and 120/240-volt secondary windings are shown connected to form a 480-volt delta to a 240-volt delta 3-phase step-down transformer bank.

to 240 volts delta. It may be advisable to obtain a 3-phase transformer rather than connecting single-phase transformers. To illustrate the complexity, standard dual-voltage single-phase transformers are used to change 480-volt 3-phase delta to 208/120-volt wye, as shown in Figure 8.6.

Winding Taps

Transformers, except for small sizes, are often supplied with winding taps to compensate for abnormally low or high primary voltage. Assume, for example, that a transformer is rated 480 volts primary and 240 volts secondary. This means that 240 volts will be the output if the input is 480 volts. But what if the input is only 444 volts? The turns ratio for this transformer is 2-to-1; therefore, the output will be 222 volts. Equation 8.3 is used to determine the output, which would be 222 volts.

$$\text{Secondary Voltage} = \frac{444\text{ Volts}}{2} = 222\text{ Volts}$$

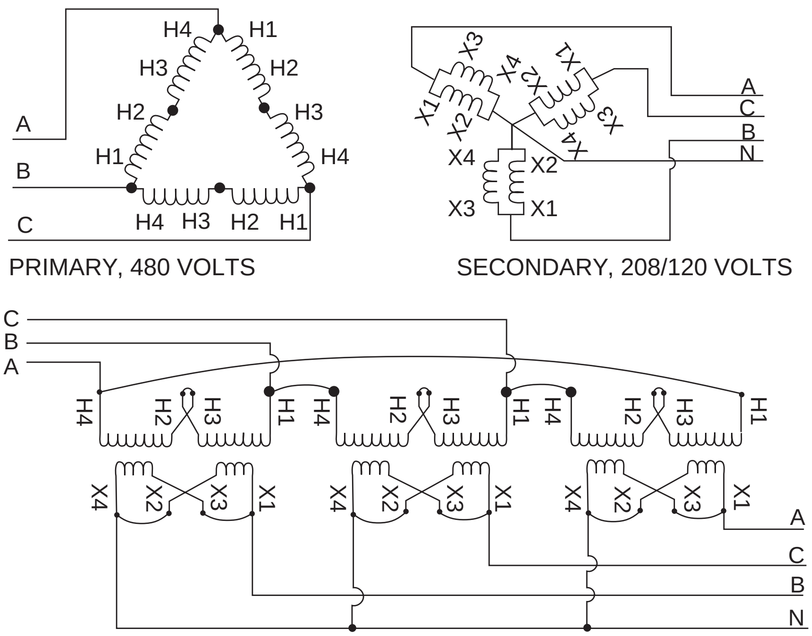


Figure 8.6 Dual-voltage single-phase transformers with 240/480-volt primary windings and 120/240-volt secondary windings are shown connected to form a 480-volt delta to a 208/120-volt wye 3-phase step-down transformer bank.

To get an output of 240 volts with an input of only 444 volts, the turns ratio will have to be changed to 1.85-to-1. The 1.85 was determined by dividing the 444 volts by 240 volts. The purpose of the tap connections, usually on the primary, is to easily change the transformer turns ratio. A typical single-phase transformer nameplate with primary taps is shown in Figure 8.7.

Consider an example in which the desired output voltage from a single-phase step-down transformer is 120/240 volts, but the available input is only 450 volts rather than 480 volts. A standard step-down transformer with a 2-to-1 turns ratio will give an output of 112.5/225 volts with a 450-volt input. By changing the primary taps, as shown in Figure 8.8, the turns ratio of the transformer is changed, and the output is now close to the desired 120/240 volts.

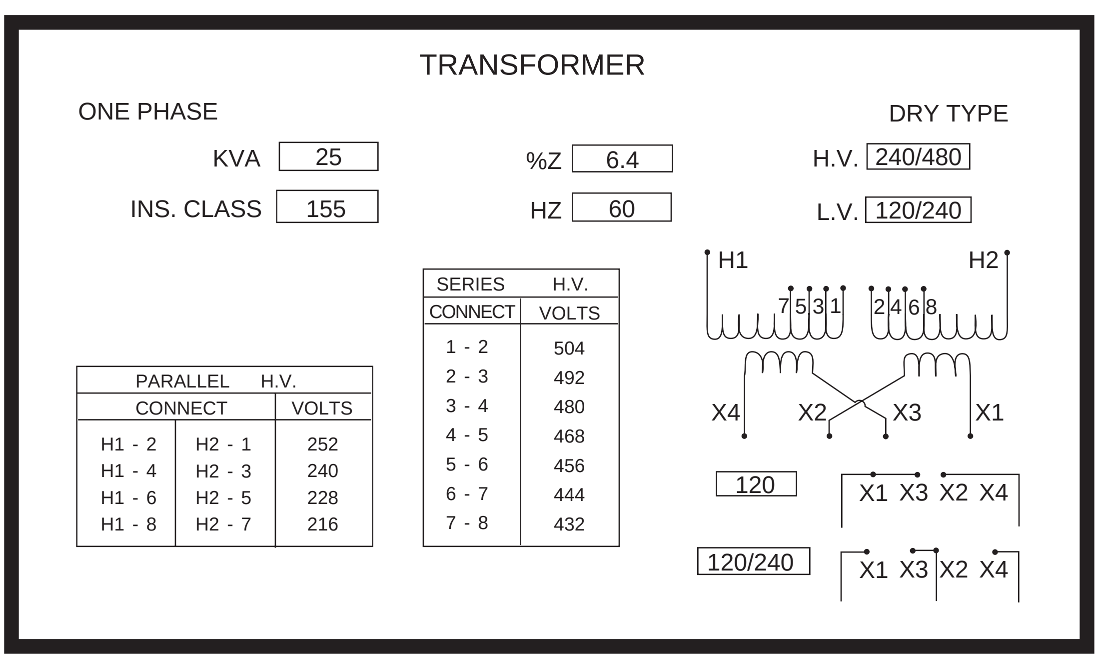


Figure 8.7 Transformer nameplate showing primary taps.

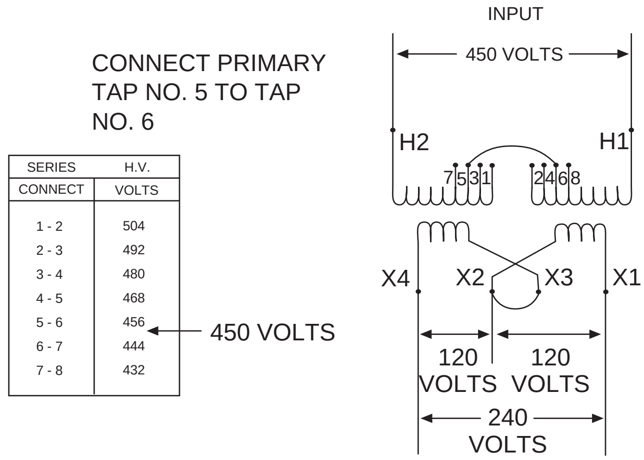


Figure 8.8 Single-phase transformer showing tap connection for an input of 450 volts and a 3-wire, 120/240-volt output.

Winding taps each make a 2.5% change in the voltage. A transformer will often have two taps above normal voltage and four taps below normal voltage. A transformer usually comes preconnected for normal voltage. If an abnormal voltage is present, it is up to the installer to change the tap connections.

Input and Output Current

The primary kilovolt-amperes (kVA) of a transformer will be equal to the secondary kVA less any small losses. If the primary voltage is reduced from 240 to 120 volts, this is a voltage ratio reduction of 2-to-1. If the primary and secondary kVA are to remain equal, the current must be higher on the secondary than on the primary by a factor of two. For example, assume the 240-volt primary current of the previous transformer is 5 amperes. The primary volt-amperes will be 1200 VA. For the 120-volt secondary, 10 amperes must flow to keep the volt-amperes at 1200 VA. If the primary and secondary voltages are known and if either the primary or secondary current is known, the other current may be determined using Equation 8.7 or Equation 8.8. These are useful equations especially when working with autotransformers.

Find primary input current when secondary output current is known:

$$\textbf{Input Current} = \textbf{Output Current} \times \frac{\textbf{Output Voltage}}{\textbf{Input Voltage}} \qquad \textbf{Eq. 8.7}$$

Find secondary output current when primary input current is known:

$$\textbf{Output Current} = \textbf{Input Current} \times \frac{\textbf{Input Voltage}}{\textbf{Output Voltage}} \qquad \textbf{Eq. 8.8}$$

Boost and Buck Transformers

A boost and buck transformer is an insulating transformer that can be connected as an autotransformer. The boost and buck transformer is used to make small adjustments in voltage, either up or down. For example, a machine has an electric motor that requires 208 volts, but the electrical supply is 240 volts. If ordering the machine with a 240-volt motor is expensive, a less costly solution to the problem may be to buck the voltage from 240 down to 208 with a boost and buck transformer.

Low voltage resulting from voltage drop can be corrected with a boost and buck transformer. This practice may not be energy-efficient, but it may be the best solution in unusual circumstances. Voltage drop on wires is wasted energy and should be avoided.

Boost and buck transformers for single-phase applications have a dual-voltage primary rated 120/240 volts. There is a choice of two sets of secondary voltages depending on the amount of boosting

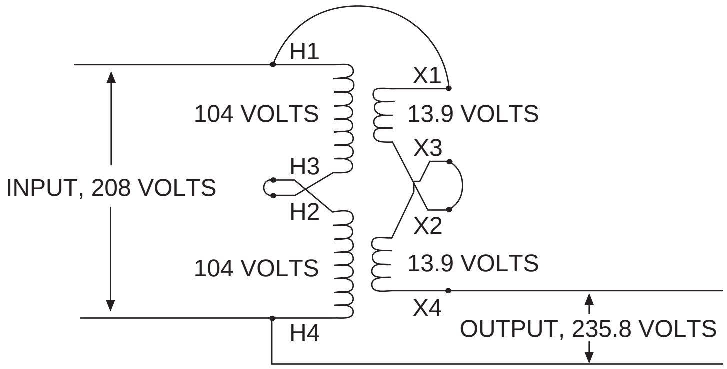


Figure 8.9 A boost and buck transformer is connected to boost a 208-volt supply to approximately 236 volts.

or bucking required: 12/24 volts and 16/32 volts. Three-phase applications from 380 to 500 volts require the use of a boost and buck transformer with a 240/480-volt primary and a 24/48-volt secondary. Figure 8.9 shows a single-phase boost and buck transformer connected to boost 208 volts to approximately 240 volts. Refer to manufacturer literature for other combinations of boosting and bucking.

Boost and buck transformers may be connected for 3-phase applications, but all 3-phase combinations are not possible. The commonly used 3-phase boost and buck transformer connections are:

- Wye (4-wire) to wye (3- or 4-wire)
- Wye (3- or 4-wire) to open delta (3-wire)
- Delta (3-wire) to open delta (3-wire)

A confusing aspect of boost and buck transformers is the kVA rating of the transformer required to supply a load. For some applications, the kVA rating of the load may be several times larger than the kVA rating of the boost and buck transformer. A boost and buck transformer, when used as an autotransformer for boosting or bucking, can supply a load several times the kVA rating of the transformer. The maximum kVA rating of the load supplied depends on the full-load current rating of the transformer secondary winding and the operating voltage of the load. Each manufacturer supplies load current and kVA data for boost and buck transformers for all combinations of input and output voltages.

K-Rated Transformers

The K-rating marked on some transformers is an indication of the ability of the transformers to supply loads, which produce harmonic currents. A transformer designated K-1 is one that has not been modified to supply loads that produce nonlinear or harmonic currents. Standard transformer ratings are K-4, K-9, K-13, K-20, K-30, K-40, and K-50. The higher the K-rating number, the greater is the ability of the transformer to supply loads that have a higher percentage of harmonic current-producing equipment without overheating. It is most important to select a transformer with a K-rating for the specific harmonic frequencies present and their magnitude in relation to the total 60-hertz current. A number that is probably of little use when selecting transformer K-rating is the percent of total harmonic distortion (THD). Another value that can give an indication that harmonics are present but is of little use in determining proper transformer K-rating is the value of root-mean-square (rms) current. When viewed on an oscilloscope, the current sine wave will distort when large numbers and significant levels of harmonic currents are present. This will usually result in an increase in the rms line current. Transformer overheating due to harmonics is primarily the effect of specific frequencies of harmonics and their magnitudes.

Electronic equipment that draws current for only a portion of the cycle is the type that produces harmonic currents in the electrical system. Electronic dimmer switches and some other electronic controllers switch on for only a portion of the cycle. As a result, current flows to the loads in pulses. Other electronic equipment that produces nonlinear currents includes personal computers, video display terminals, copiers, fax machines, uninterruptible power supplies (UPS), variable speed drives, electronic high-efficiency ballasts, some medical electronic monitors, welders, mainframe computers, data processing equipment, and induction heating systems. Most electronic office equipment has switching-mode power supplies (SMPS) that draw current in pulses for only part of the cycle. These pulsing input currents produce harmonic currents in the electrical system. These harmonic currents can result in overheating of a transformer and other distribution equipment and wiring.

One way of dealing with loads that consist of a high percentage of harmonic-producing electronic equipment is to oversize the transformer for the load. But a transformer designed to supply 60-hertz loads does not perform the same when currents are at a higher frequency than 60 hertz. Core saturation can occur when a standard transformer is subjected to loads with a high percentage of harmonic currents. This can occur even when the transformer is supplying less than rated full-load current. Transformer heating is different for a given level of rms current at a different frequency.

There are industry recommendations for transformer K-ratings for particular loads. Dealing with loads that produce harmonic currents is sometimes complex, and even these K-rating recommendations may not be correct for all applications. A harmonic analysis may be necessary in some cases with the transformer specifically matched to the load. Here are some general recommendations for matching transformers to loads:

- Use nonrated K-l transformers when the loads producing harmonic currents are less than 15% of the total load.
- Use K-4 rated transformers when the loads producing harmonic currents are 15 to 35% of the total load.
- Use K-13 rated transformers when the loads producing harmonic currents are 35 to 75% of the total load.
- Use K-20 rated transformers when the loads producing harmonic currents are 75 to 100% of the total load.
- Use K-30 and higher rated transformers for specific equipment where the load and transformer are matched for harmonic characteristics.

In the case where a transformer is supplying specific loads known to be producers of harmonic currents, some general guidelines can be used to help avoid transformer overheating. The transformer can be sized to the load kVA to be supplied when the proper K-rating is selected. Not only do different brands of the same equipment produce different harmonic currents, the identical equipment can produce different harmonic currents when supplied by different electrical systems. The harmonic current problem, when it exists, may be complex, sometimes requiring experienced personnel for analysis and design. The following is a general industry recommendation of approximate current K-ratings for different types of loads. Actual specifications for a specific installation made by an experienced engineer or technician may be different.

- K-4 welders and induction heaters
- K-4 electric discharge lighting
- K-4 solid-state controls
- K-13 telecommunications equipment
- K-13 branch-circuits in classrooms and in health care facilities
- K-20 mainframe computers and data processing equipment
- K-20 variable-speed drives

On a balanced 3-phase wye electrical system, odd-numbered harmonics in multiples of the third harmonic (3rd, 9th, 15th, 21st, and so on) if present will not cancel and will increase the neutral current. Examples are the 208/120-volt and the 480/277-volt 4-wire 3-phase electrical systems serving line-to-neutral loads. When a 3-phase wye transformer is supplying balanced line-to-neutral loads where harmonics are present, it is possible for the neutral current to be as high as twice the level of line current. This can result in neutral conductor and conductor termination overheating. A K-rated transformer will not eliminate this type of problem. If the harmonic currents cannot be reduced, then it will be necessary to increase the size of the neutral bus and neutral conductor.

OVERCURRENT PROTECTION FOR TRANSFORMERS

Wiring a transformer circuit is one of the most difficult wiring tasks unless the installer understands transformer fundamentals. Rules for sizing overcurrent protection for a transformer operating at not more than 600 volts are covered in *450.3(B)* and *Table 450.3(B)*. It must be noted that these rules apply only to the transformer itself, and not necessarily to the input and output circuit wires. If one or both of the windings operate at more than 600 volts, *450.3(A)* and *Table 450.3(A)* will apply.

According to *Table 450.3(B)*, both the primary and secondary windings are permitted to be protected from overcurrent by one overcurrent device located on the primary side of the transformer and sized at not more than 125% of the transformer full-load current. If that primary overcurrent device has a rating greater than 125% of the transformer full-load primary current rating, then overcurrent protection not greater than 125% of the transformer secondary full-load current rating is required to protect the transformer secondary winding. Both situations are explained in the following two sections.

Overcurrent Protection Only on the Primary (600 volts or less)

A transformer is permitted to be protected by one overcurrent device on the primary side rated not more than 1.25 (125%) times the primary full-load current, as shown in Figure 8.10. If the calculation does not correspond with a standard rating of overcurrent device as listed in *240.6*, it is permitted to round up to the next standard fuse or circuit breaker rating. This overcurrent device may be a set of fuses in a panelboard or fusible switch, or a circuit breaker. The secondary winding is not required to have separate protection from overcurrent in this situation. When the secondary of the transformer is not single-voltage 2-wire, the secondary conductors are required to be protected according to *240.4(B)*, but the secondary winding is not required to be protected by other than the primary overcurrent device. *NEC® 240.21(C)(1)* applies to the secondary conductors, and not to the winding of the transformer. Example 8.2 will show how overcurrent protection is selected to protect the transformer using this rule, and how overcurrent protection for the conductors must be considered separately.

Example 8.2 A 37.5-kVA 3-phase transformer is to be installed to supply a 100-ampere 208Y/120-volt panelboard from a 480-volt, 3-phase power panel. The conductors are copper with 75°C insulation and terminations. The panelboard has a 100-ampere main circuit breaker, and it is located not more than 25 ft (7.5 m) from the transformer. The feeder and transformer are protected with time-delay fuses, and the feeder supplies only this transformer and panelboard. A diagram of the circuit is shown in Figure 8.10. Determine the maximum rating of the fuses permitted to protect the transformer when using the minimum size conductors supplying the primary of the transformer.

Answer: First calculate the primary full-load current of the transformer and obtain 45 amperes.

$$\text{Primary full-load current} = \frac{37.5\ \text{kVA} \times 1000}{1.73 \times 480\ \text{V}} = 45.1\ \text{amperes}$$

The rule is found in the first row of *Table 450.3(B)* for determining the maximum permitted rating of the primary overcurrent device. The transformer primary winding is permitted to be protected at

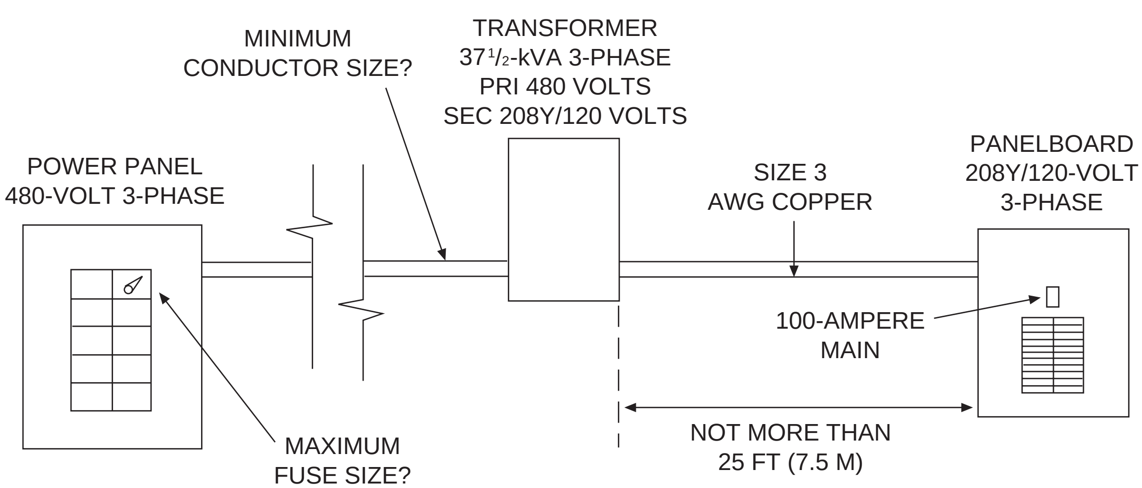


Figure 8.10 A 37.5-kVA, 3-phase, transformer supplies a 208Y/120-volt, 4-wire, 100-ampere panelboard from a 480-volt supply. Determine the minimum copper primary conductor size and the maximum permitted rating of fuse protecting the transformer and circuit.

1.25 times the full-load current of the transformer, which is 56 amperes. This value is permitted to be rounded up to the next standard rating, which is 60 amperes (see *Note 1*). If the conductors supplying the transformer are protected at 60 ampere, then *240.4* requires the conductor to have an allowable ampacity of 60 amperes, which is size 6 AWG. But if the primary full-load current of the transformer is only 45 amperes, it would seem more reasonable to use 50-ampere fuses and size the conductors at 8 AWG. The maximum fuse rating permitted assuming the minimum primary conductor size is 50 amperes.

The previous example points out the choices that can be made when sizing the overcurrent protection and the conductors for a transformer installation. For the previous example, the secondary full-load current is 104 amperes, and there is a 100-ampere overcurrent device installed on the secondary side of the transformer, which meets the requirement of protecting the transformer secondary within 125% of the transformer secondary full-load current. What this means is that it is actually permitted to size the primary overcurrent protection in Example 8.2 at 250% of the primary full-load current. This calculates to be 113 amperes, which must be rounded down to a 110-ampere overcurrent device rating. So actually, the maximum permitted rating of primary overcurrent protection for the transformer in Example 8.2 is 110 amperes. But this would not be practical since the primary conductors supplying the transformer would be required to be size 2 AWG when size 8 AWG is adequate to supply the load.

When there are several different secondary windings supplying the secondary conductors, an overload could occur on one or more secondary conductors and go undetected by the primary overcurrent protection. This can be prevented by properly sized overcurrent protection installed on the secondary side of the transformer. The primary overcurrent device can protect the secondary conductors, if properly sized, when the transformer secondary is single voltage and there are only two conductors leaving the transformer. This rule is found in *240.4(F),* and an example is shown in Figure 8.11. The overcurrent device on the primary side of the transformer is required to be sized to prevent an overload on the secondary conductors. Example 8.3 describes this process.

Example 8.3 Consider the case of a 3-kVA transformer used to step down 480 to 120 volts to supply one 20-ampere single-phase 2-wire circuit. There will be no secondary overcurrent protection as shown in Figure 8.11. Determine the maximum permitted overcurrent device rating on the primary circuit to protect the transformer and the secondary circuit wires.

Answer: First, determine the primary and secondary full-load current rating of the 3-kVA transformer using Equation 8.5.

$$\text{Primary Current} = \frac{3\ \text{kVA} \times 1000}{480\ \text{V}} = 6.25\ \text{A}$$

$$\text{Secondary Current} = \frac{3\ \text{kVA} \times 1000}{120\ \text{V}} = 25\ \text{A}$$

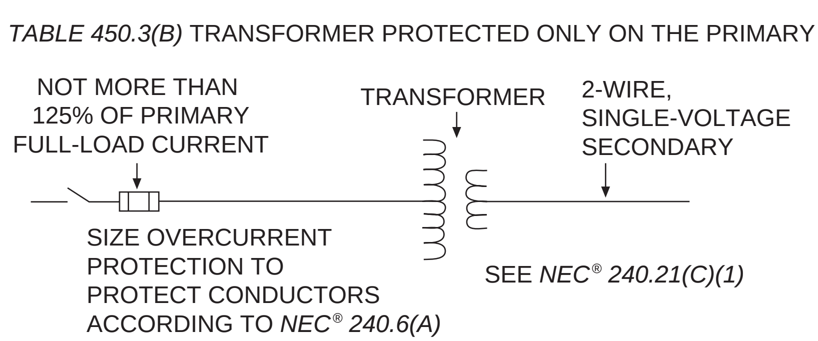


Figure 8.11 A transformer may be protected with one overcurrent device on the primary sized at not more than 125% of the primary full-load current.

Next, determine the maximum permitted overcurrent device rating for the primary using the rules of *Table 450.3(B)*. The primary overcurrent device rating is not to exceed 167% of the transformer primary full-load current.

$$\text{Maximum Overcurrent Device Rating} = 6.25\text{ A} \times 1.67 = 10.4\text{ A}$$

Note 1, which permits rounding up, does not apply in this case. Therefore, it will be necessary to round down to a 10-ampere standard overcurrent device rating as listed in *240.6(A)*. Circuit breakers are not generally available with small ratings. Therefore, time-delay fuses will be used to protect the primary of the transformer. The primary circuit conductors will be size 14 AWG copper.

The transformer is considered protected with a 10-ampere fuse on the primary, but are the conductors on the secondary side of the transformer protected? The purpose of the installation was to provide a 20-ampere circuit at 120 volts. This requires size 12 AWG copper conductors. Use Equation 8.8 to determine the current flow on the secondary circuit wires required to blow the 10-ampere fuses on the primary.

$$\text{Secondary current} = 10\text{ A} \times \frac{480\text{ V}}{120\text{ V}} = 40\text{ A}$$

If 10-ampere fuses are installed on the primary, the secondary conductors will be overloaded to 40 amperes. Use Equation 8.7 to determine the current on the primary side of the transformer when there is a 20-ampere current flow on the secondary. The maximum rating fuse that is permitted to be installed on the primary side of the transformer to prevent overloading of the secondary conductors is 5 amperes.

$$\text{Primary current} = 20\text{ A} \times \frac{120\text{ V}}{480\text{ V}} = 5\text{ A}$$

Primary and Secondary Overcurrent Protection (600 volts or less)

The overcurrent device protecting the primary of a transformer is permitted to be rated as large as 2.50 (250%) times the primary full-load current, provided the transformer secondary winding is protected. The transformer secondary overcurrent device rating is not permitted to be greater than 1.25 (125%) of the secondary full-load current. Protection for both the primary and the secondary of the transformer is illustrated in Figure 8.12.

This rule is very useful when a feeder is available in the area where the transformer is to be installed and has sufficient capacity to supply the load served by the transformer. The transformer circuit is permitted

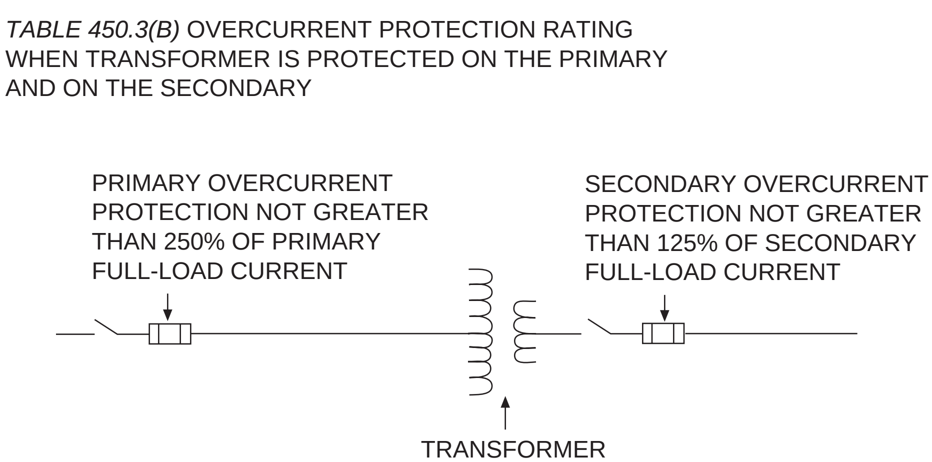


Figure 8.12 If the transformer is protected on the secondary with an overcurrent device rated not more than 125% of the secondary current, the primary overcurrent device is permitted to be sized as large as 250% of the primary current.

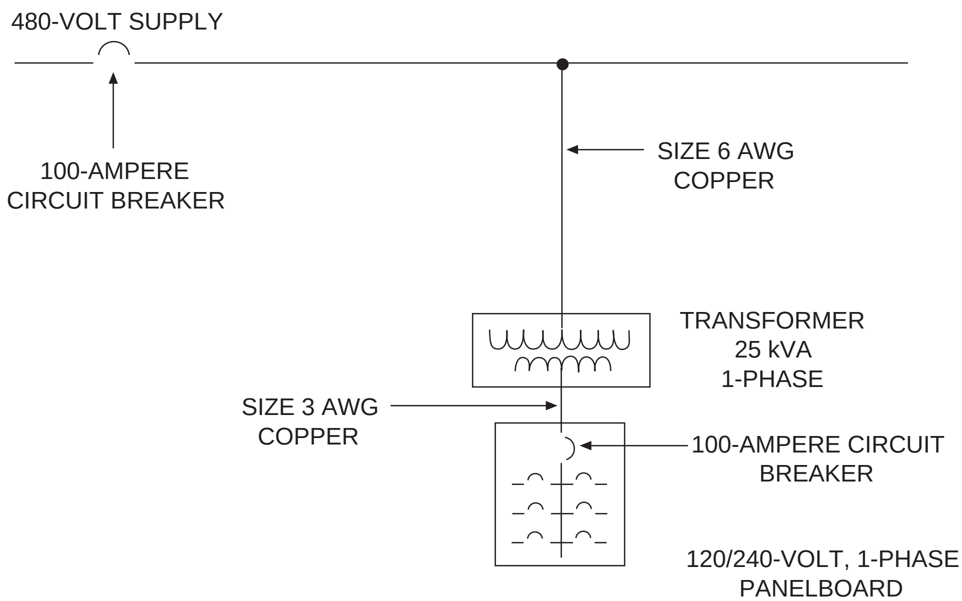


Figure 8.13 The primary overcurrent protection for a transformer is permitted to have a rating not exceeding 2.5 times the transformer primary full-load current provided overcurrent is provided on the secondary rated not higher than the transformer secondary full-load current.

to be tapped directly to the feeder and the feeder overcurrent device can serve as the transformer overcurrent protection provided the rating is not greater than 2.5 times the full-load current of the transformer primary. But the secondary winding of the transformer is now required to be provided with overcurrent protection not greater than 1.25 times the transformer secondary full-load current. This is illustrated in Figure 8.13 where a 25-kVA single-phase transformer is tapped to a 480-volt feeder protected by a 100-ampere circuit breaker. Example 8.4 shows how to determine the maximum rating of overcurrent protection permitted for the primary and secondary windings of the transformer. Rules in *Article 240* specify the minimum size of conductors and the locations of overcurrent devices. Those rules will be discussed later.

Example 8.4 A 25-kVA single-phase transformer is tapped to a 480-volt feeder protected with a 100-ampere circuit breaker. The transformer is supplying a 120/240-volt, 3-wire panelboard with a 100-ampere main circuit breaker. The circuit is illustrated in Figure 8.13. The total distance from the point of tap at the feeder, through the transformer to the 100-ampere circuit breaker in the panelboard is 25 ft (7.5 m). Determine the maximum rating of overcurrent device permitted to protect the primary and secondary of the transformer.

Answer: First determine the full-load current of the primary winding, which is 52 amperes. According to *Table 450.3(B)*, if overcurrent protection is provided on the secondary of the transformer at not more than 1.25 times the secondary full-load current, the overcurrent protection on the primary is permitted to be increased to 2.5 times the primary full-load current, which is 130 amperes (52 A × 2.5 = 130 A). There is no provision to round this value up to the next standard rating. Therefore, it is necessary to round the value down to the next standard rating as listed in *240.6*, which is 125 amperes. The feeder is protected with a 100-ampere circuit breaker, therefore, the feeder overcurrent device is less than the maximum permitted, and can serve as the transformer primary overcurrent protection.

$$\text{Primary full-load current} = \frac{25\ \text{kVA} \times 1000}{480\ \text{V}} = 52\ \text{A}$$

Next, determine the maximum permitted rating of the secondary overcurrent protection. The secondary full-load current is 104 amperes. The secondary overcurrent protection is permitted to have a rating of 1.25 times the full-load secondary current of the transformer, which is 130 amperes. *Note 1* permits this value to be rounded up to the next standard rating overcurrent device as listed in *240.6*, which is 150 amperes. Therefore, the secondary of this transformer is permitted to have an overcurrent device rated at 150 amperes. The panelboard has a 100-ampere main circuit breaker, which is well within the maximum permitted.

$$\text{Secondary full-load current} = \frac{25\text{ kVA} \times 1000}{240\text{ V}} = 104\text{ A}$$

If the overcurrent protection for the 480-volt feeder of Figure 8.13 had a rating greater than 125 amperes, then the situation is handled as a feeder tap, *240.21(B)(3)*, ending in an overcurrent device similar to Figure 8.14. Then the overcurrent device is sized as small as practical to handle the load as was the case with Example 8.2.

In the case where the primary overcurrent protection for the transformer is greater than 1.25 times the full-load current of the primary winding, the overcurrent protection for the secondary winding is permitted to consist of up to six individual overcurrent devices grouped together at the end of one set of feeder conductors. This is *Note 2* and applies in the case of *Table 450.3(A)* for transformers operating at more than 600 volts and *Table 450.3(B)* for transformers operating at 600 volts or less. The sum of the ratings of the overcurrent devices is not permitted to total more than the rating permitted for a single overcurrent device. This is illustrated in Figure 8.15 with the overcurrent device ratings worked out in Example 8.5.

Example 8.5 A 37.5-kVA 3-phase transformer is tapped to a 480-volt feeder and supplies three 208-volt 3-phase motors. The individual motor branch-circuit time-delay fuse ratings are 30, 50, and 60 amperes. Is it permitted to omit the single secondary overcurrent device and terminate the secondary conductors from the transformer at the three motor circuit disconnects grouped together at one location?

Answer: *Note 2 of Table 450.3(B)* permits this practice if the three motor circuit fuse ratings do not total more than the highest rated single overcurrent device permitted for the transformer. First, determine the transformer secondary full-load current of 104 amperes. Then multiply that value by 1.25 to get 130 amperes (104 A × 1.25 = 130 A). *Note 1* permits this value to be rounded up to the next standard rating which according to *240.6* is 150 amperes. The three individual motor branch-circuits total to 140 amperes (30 A + 50 A + 60 A = 140 A). This is less than 150 amperes. Therefore, the installation is permitted as shown in Figure 8.15. If the motor circuit overcurrent devices had totaled more than 150 amperes, then the feeder would have been required to terminate at a single overcurrent device rated not greater than 150 amperes.

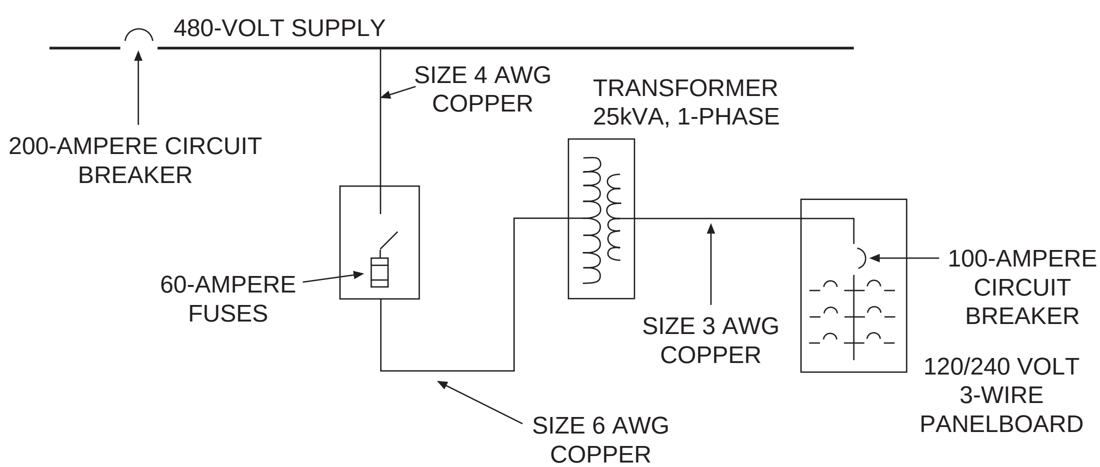


Figure 8.14 If a transformer circuit is tapped to a feeder with feeder overcurrent protection rated more than 2.5 times the transformer primary full-load current, then overcurrent protection will be required on the primary specifically sized for the transformer circuit.

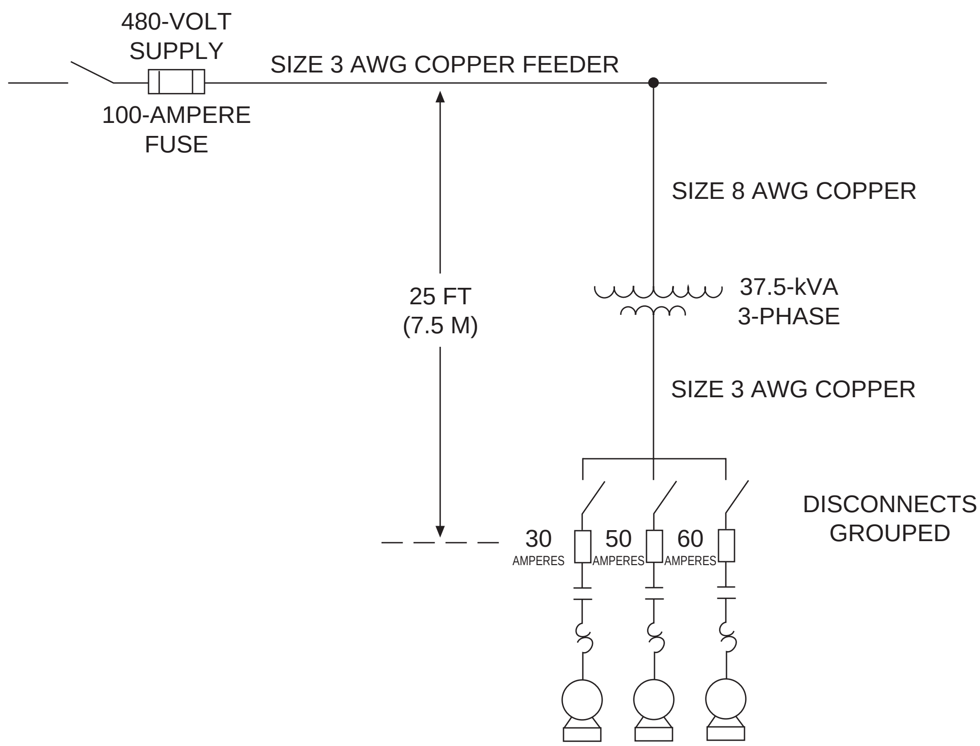


Figure 8.15 When overcurrent protection is required on the secondary of the transformer, such as this case of a feeder tap, the secondary is permitted to end in up to six overcurrent devices with ratings that do not total more than the rating required for a single overcurrent device.

$$\text{Secondary full-load current} = \frac{37.5\ \text{kVA} \times 1000}{1.73 \times 208\ \text{V}} = 104\ \text{A}$$

Boost and Buck Transformer Overcurrent Protection

The specific transformer, winding connections, kVA rating, and maximum load current for an application of voltage boosting or voltage bucking are determined with information from specific boost and buck transformer manufacturers. These are insulating transformers connected as autotransformers. *NEC® 450.4* gives the rules for installing autotransformers. Overcurrent protection for insulating transformers (*450.3*) is based upon the full-load current of the primary and secondary windings. For an autotransformer, the overcurrent protection is based upon the full-load **input** current. Figure 8.16 shows a boost and buck transformer connected to boost 208 volts up to 236 volts to power a 3-horsepower, single-phase, 230-volt motor. The boost and buck transformer suitable for this application is rated 0.75 kVA, with a primary rated 120/240 volts and the secondary rated 16/32 volts. When connected for maximum boosting, this transformer has a rated full-load output current of 23.4 amperes.

The first step in selecting the overcurrent protection for the transformer and the input and output conductor size is based upon knowing the input and output current. From *Table 430.248*, a 3-horsepower, 208-volt motor draws 18.7 amperes. Connected for maximum boosting, the transformer is capable of a maximum continuous current of 23.4 amperes. Overcurrent protection is based upon the full-load input current. Using Equation 8.7, determine the input current when the motor is drawing 18.7 amperes and the maximum input current when the transformer is delivering an output current of 23.4 amperes. The input current will be 21.2 amperes when the motor is operating at full-load. This transformer connection is capable of a maximum input current of 26.6 amperes.

$$\text{Input current} = 18.7\ \text{A} \times \frac{236\ \text{V}}{208\ \text{V}} = 21.2\ \text{A}$$

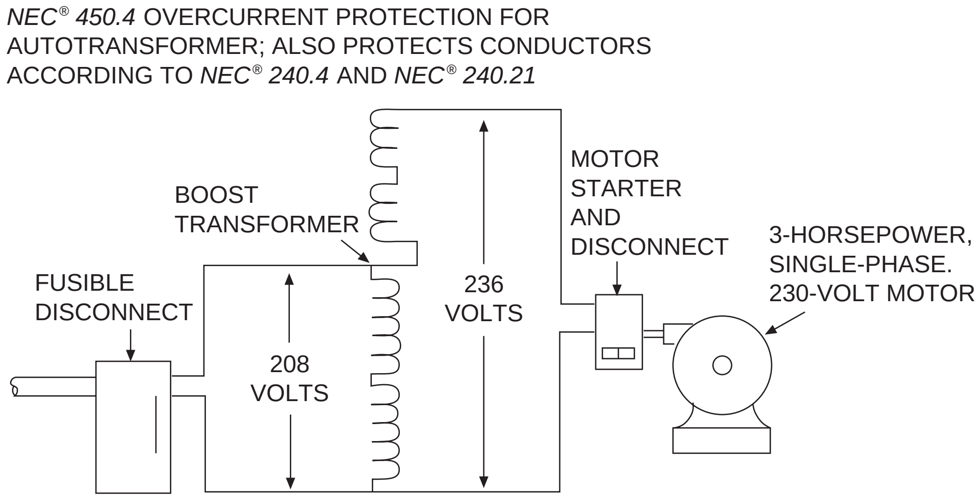


Figure 8.16 A boost and buck transformer is used to boost the 208-volt supply to 236 volts for a 3-horsepower, single-phase motor.

$$\text{Input current} = 23.4\text{ A} \times \frac{236\text{ V}}{208\text{ V}} = 26.6\text{ A}$$

It is recommended the overcurrent protection and conductors be based upon the full-load current of the load, which is 18.7 amperes. The full-load input current will then be 21.2 amperes. *NEC® 450.4* permits the boost and buck transformer overcurrent protection to be rated not more than 1.25 times the full-load input current, which gives an overcurrent device rating of 26.5 amperes. In this case, it is permitted to round this value up to the next standard rating of overcurrent device listed in *240.6,* which is a 30-ampere fuse or circuit breaker in each ungrounded input conductor. Because this transformer is slightly oversized for the load, the maximum input overcurrent device rating could be up to 35 amperes.

The circuit conductor size in most cases is based upon the rating of the overcurrent device. The input and output current are not the same. Therefore, an adjustment for voltage is necessary to properly size the conductors. If the transformer input overcurrent protection is 30 amperes, then using *Table 310.16* and *240.4(B),* size 10 AWG copper conductors are required for the input circuit to the transformer. Use Equation 8.8 to determine the output current that corresponds to an input current of 30 amperes. This value will be 26.4 amperes. Using *Table 310.16,* this also is a size 10 AWG copper conductor if insulation and terminations are assumed to be rated 75 °C.

$$\text{Output current} = 30\text{ A} \times \frac{208\text{ V}}{236\text{ V}} = 26.4\text{ A}$$

The conductors for the circuit in Figure 8.16 are permitted to be sized using the rules of *430.22.* The conductor is required to have an allowable ampacity not less than 1.25 times the full-load current. The full-load current to the motor is 18.7 amperes and the full-load input current to the transformer is 21.2 amperes. Multiply each of these values by 1.25 and select the minimum conductor size using *Table 310.16.* The minimum size copper input current to the transformer in Figure 8.16 is size 10 AWG, and the minimum size copper output conductor to the motor is 12 AWG.

TRANSFORMER TAPS

The overcurrent protection rules for a transformer in *450.3* do not provide for the protection of the conductors supplying a transformer or the conductors leading away from the transformer. The protection of conductors is covered in *240.4* and *240.21.* The most basic situation is where a circuit is installed to supply a specific load, such as shown in Figure 8.17, and a transformer is required to change the supply voltage to

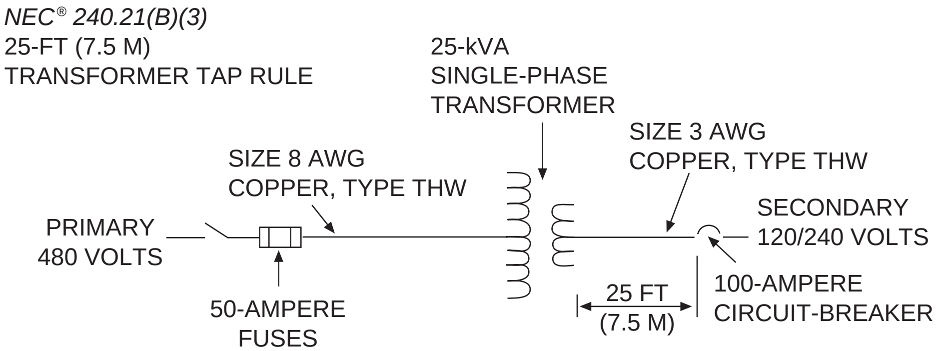


Figure 8.17 The secondary overcurrent protection is permitted to be located 25 ft (7.5 m) from the secondary winding when the primary circuit wire has overcurrent protection not exceeding the ampacity of the primary wire.

match the requirement of the load. In Figure 8.17, the purpose is to supply a 120/240-volt, 3-wire panelboard with a 100-ampere main circuit breaker from a 480-volt electrical supply. Assume for the purpose of this example that all conductors are copper with 75°C insulation and terminations. The conductors from the secondary of the transformer to the 100-ampere circuit breaker are size 3 AWG. The voltage is changed from 480 volts to 240 volts. Therefore, there will be 50 amperes flowing in the primary conductors when 100 amperes is flowing in the secondary conductors (Equation 8.7). The 480-volt conductors supplying the transformer are size 8 AWG protected with 50-ampere time-delay fuses. The overcurrent protection for this circuit is well within the limits set by *Table 450.3(B)*. The conductors supplying the transformer primary are protected, but the secondary conductors leading away from the transformer are only protected at their load end similar to service entrance conductors. A short circuit or ground fault that may occur between the transformer and the secondary overcurrent device can create a hazardous condition without opening the primary overcurrent device. As a result, special rules were developed to minimize the risk of a hazardous condition developing. These are the transformer tap rules and they are located in *240.21*. For an inside installation, the maximum distance permitted from the transformer to the overcurrent device is 25 ft (7.5 m). This rule is found in *240.21(C)(6)*.

NEC® 240.21(C)(6) does not restrict the number of conductors leading away from the transformer. Therefore, several sets of conductors are permitted to supply different loads. In the case of Figure 8.18, a 112.5-kVA, 3-phase transformer supplies two 208Y/120-volt panelboards, one with a 225-ampere main circuit breaker and the other with a 100-ampere main circuit breaker. The only restriction is that each set of

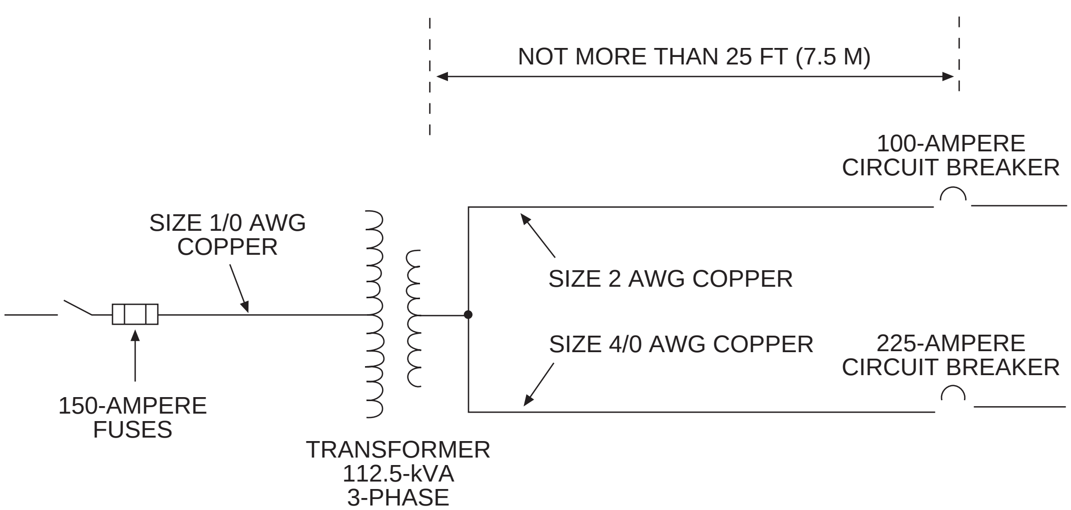


Figure 8.18 Multiple secondary conductors, not more than 25 ft (7.5 m) in length, are permitted to extend from a transformer and end in a single overcurrent device rated for the conductor, but the conductor is required to have an ampacity not less than one-third the rating of the primary overcurrent device adjusted for the voltage change.

conductors ends at a single circuit breaker or set of fuses, and there is a minimum size conductor specified. The secondary conductors leading away from the transformer are required to have an ampacity not less than one-third the ampacity of the primary overcurrent device when converted to equivalent current at the secondary voltage (Equation 8.8). The transformer shown in Figure 8.18 is connected to a 480-volt, 3-phase supply and is protected on the primary with 150-ampere fuses. This fuse rating is small enough, according to *Table 450.3(B),* that additional overcurrent protection for the secondary windings is not required. Divide the 150-ampere fuse rating by three and use Equation 8.8 to find the equivalent current at the secondary voltage, which is 115 amperes. This is the minimum ampacity permitted for any set of conductors leading away from this transformer. Note that instead of a size 3 AWG copper conductor to supply the 100-ampere panelboard, a size 2 AWG conductor is required.

$$\text{Secondary current} = 50\text{ A} \times \frac{480\text{ V}}{208\text{ V}} = 115\text{ A}$$

NEC® 240.21(C)(2) permits multiple sets of conductors leading away from a transformer secondary with only a small restriction upon the ampacity of the conductors relative to the primary overcurrent device, provided the length of conductor from the transformer to the overcurrent device does not exceed 10 ft (3 m). This is illustrated in Figure 8.19. The conductors are required to be run in raceway from the transformer to the panelboard or other device containing the overcurrent device. The 10 ft (30 m) tap conductors are required to have an ampacity not less than 10% of the rating of the primary overcurrent device corrected for the change in voltage using Equation 8.8, which in this case is only 10 amperes.

It is frequently desirable to tap a transformer from a feeder as shown in Figures 8.13 and 8.20 without overcurrent protection between the tap point and the transformer. This is permitted by *240.21(B)(3).* The restriction in this case is that the total distance from the point where the primary conductor taps the feeder to the overcurrent device on the secondary is not permitted to exceed 25 ft (7.5 m). The feeder overcurrent device protects the primary and secondary tap conductors and the primary winding of the transformer. If the feeder overcurrent device has a rating higher than 1.25 times the transformer full-load current, then a single overcurrent device is required to protect the transformer secondary subject to the conditions of *Note 2* of *Table 450.3(A)* and *Table 450.3(B).* The transformer installation of Figure 8.20 has a primary full-load current of 104 amperes, and a secondary full-load current of 208 amperes.

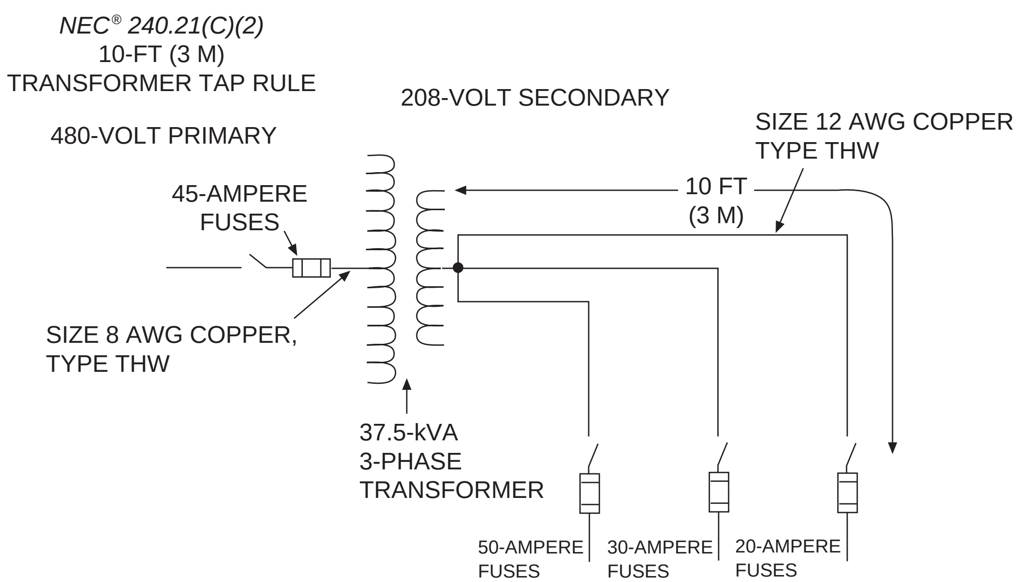


Figure 8.19 The size of the secondary tap conductors is permitted to be sized to supply the load with no relation to the rating of the primary overcurrent device when the tap length does not exceed 10 ft (3 m).

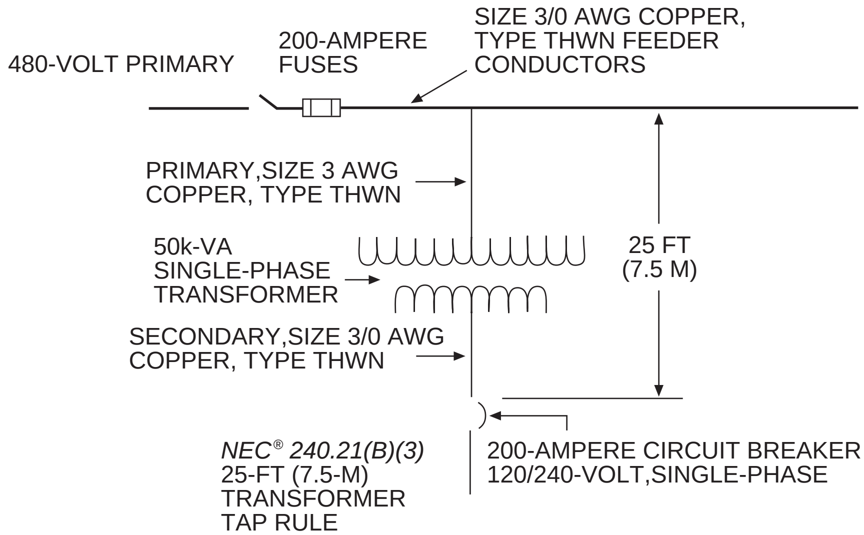


Figure 8.20 When the primary circuit wire is tapped from a feeder, the secondary winding overcurrent protection shall be located not more than 25 ft (7.5 m) from the point of the primary tap.

$$\text{Primary full-load current} = \frac{50\ \text{kVA} \times 1000}{480\ \text{V}} = 104\ \text{A}$$

$$\text{Primary full-load current} = \frac{50\ \text{kVA} \times 1000}{240\ \text{V}} = 208\ \text{A}$$

Table 450.3(B) permits the primary overcurrent device to have a rating of up to 250 amperes and a secondary overcurrent device of up to 300 amperes. The secondary overcurrent device rating is only 200 amperes. The conductor between the transformer and the 200-ampere circuit breaker is sized according to *240.4* which requires a minimum size 3/0 AWG copper conductor. The primary tap conductor must have an allowable ampacity not less than required to supply the load on the secondary of the transformer. Use Equation 8.7 to determine how much current will flow on the primary conductor when 200 amperes is flowing on the secondary conductors. The result will be 100 amperes, which requires a size 3 AWG copper conductor to supply the transformer.

Primary overcurrent device = 104 A × 2.5 = 260 A (must round down to 250 A)

Secondary overcurrent device = 208 A × 1.25 = 260 A (permitted to round up to 300 A)

NEC® 240.21(C)(3) is a special case of the 25-ft (7.5-m) transformer secondary tap rule that applies only for industrial installations. The difference between this tap rule and the others is that the secondary conductor is permitted to end in multiple overcurrent devices provided they are grouped together in one location. There are several conditions that must be satisfied. The secondary conductor is not permitted to have an allowable ampacity less than the secondary full-load current of the transformer. For example, assume a 75-kVA, 3-phase transformer supplies 208Y/120-volt power from a 480-volt supply. The secondary full-load current is 208 amperes. The secondary conductor is not permitted to be smaller than size 4/0 AWG copper. According to *Table 310.16*, this conductor is rated for 230 amperes. The secondary conductor is permitted to terminate at multiple overcurrent devices, but in this case, they are not permitted to total to more than 260 amperes (208 A × 1.25 = 260 A).

NEC® 240.21(C)(4) is a transformer secondary conductor tap rule that only applies if the conductors are run outside a building. Multiple tap conductors are permitted to be run outdoors from a transformer secondary to individual loads such as disconnects in individual buildings. The tap conductors are permitted to

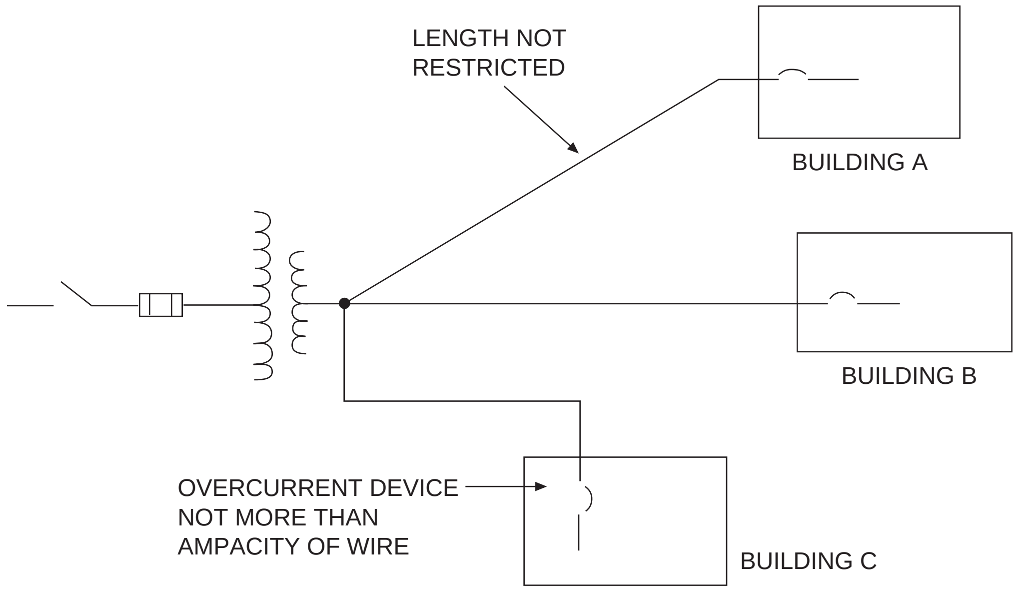


Figure 8.21 Multiple outside secondary taps are permitted to a transformer with no restriction in length or conductor size except that the taps are to end at a single overcurrent device with a rating not exceeding the ampacity of the conductors.

be sized for the load to be served and they are permitted to be of any length. The conductors are required to end at a single circuit breaker or set of fuses with a rating not higher than the ampacity of the conductors. This type of installation is illustrated in Figure 8.21.

TRANSFORMER GROUNDING

An electrical system derived from a transformer is required to have noncurrent-carrying metal parts and equipment grounded the same as any other part of the electrical system. In addition, the electrical system produced by the transformer also may be required to be grounded according to *250.20(B). NEC® 250.26* specifies the wire that shall be grounded. The method of grounding the grounded circuit conductor is specified in *250.30* for separately derived systems. A separately derived system is defined in *Article 100.* A transformer installed at some point in an electrical system is considered to be a separately derived system if a derived grounded-circuit conductor is not electrically connected to a grounded-circuit conductor of the building electrical system. Further information about separately derived systems is found in *250.20(D).* Most transformer installations are considered to be separately derived systems, and the grounding is covered in *250.30.* The rules of grounding are illustrated in Figure 8.22.

It is important to understand the purpose for grounding a separately derived system. If a ground fault should occur, the current attempts to return to the source, which in this case is the separately derived system. An adequate low impedance path must be provided back to the grounded conductor of the separately derived system in order for fault current to flow. In the case of an ungrounded system, a low impedance path must be provided back to the grounding point at the main disconnect for the separately derived system. Therefore, it is important the grounding electrode be located as close as practical to the separately derived system. Most insulating transformer installations are considered to be separately derived systems.

The requirement for a grounding electrode for a separately derived system is found in *250.30(A)(7).* The grounding electrode is required to be the closest of either an effectively grounded structural metal member in the building or an effectively grounded metal water pipe. If the transformer is located near or adjacent to the service equipment, then it is probably most convenient and effective to ground the separately derived system to the same grounding electrode as the service equipment. Assume a transformer is installed in a building a considerable distance from the service equipment. Also, assume there is a metal water pipe in the building but the transformer is located a distance from the point where the water pipe enters the building. If the steel frame of the building is effectively grounded and closer to the transformer, then the transformer

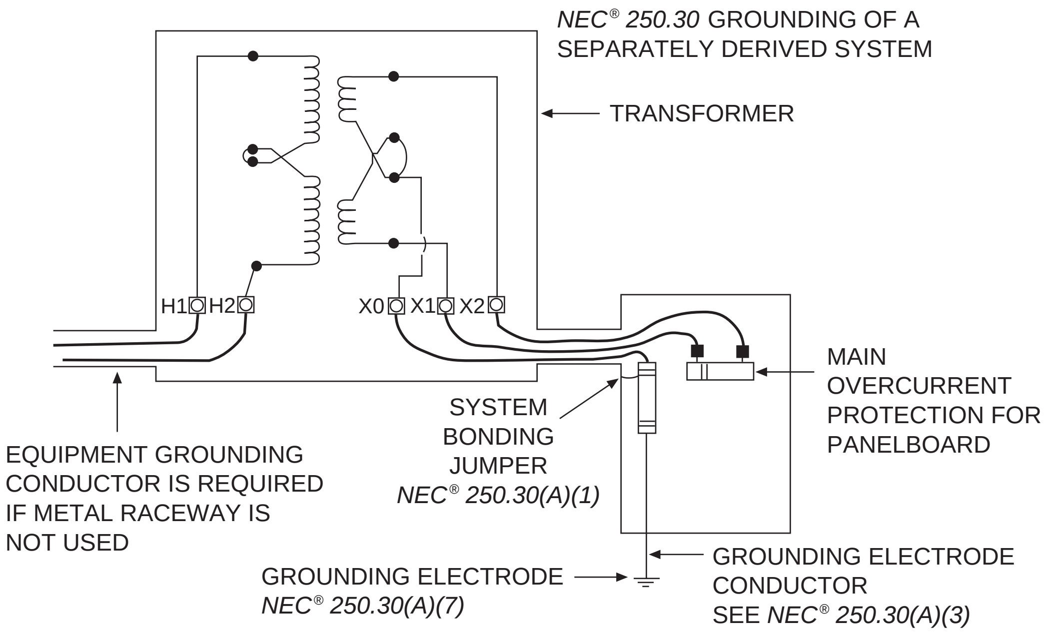


Figure 8.22 Grounding and bonding for a transformer are permitted to be at the first disconnect with overcurrent protection, or it can be at the transformer.

should be grounded to the building steel as close to the transformer as practical. In this case it is not required to run a grounding electrode conductor back to a point within 5 ft (1.5 m) of the point where the metal water pipe enters the building. But if the metal water pipe serves the same area as the separately derived system, it is required according to *250.104(D)(1)* to bond to the metal water pipe in the local area. This is a bonding requirement not a grounding requirement, although the conductors are the same size. If there is no metal building steel available that is effectively grounded, then the transformer is required to be grounded to the metal water pipe within 5 ft (1.5 m) of the point where it enters the building. For industrial or commercial buildings, the connection to the water pipe may be permitted to be made a distance from the point where it enters the building if the conditions of the *Exception* to *250.52(A)(1)* are satisfied. If there is no effectively grounded metal water pipe or effectively grounded building structural steel, then any one of the other grounding electrodes described in *250.50* or *250.52* is required to serve as the grounding electrode for the separately derived system.

For a building where a number of transformers will be installed and finding a satisfactory grounding electrode may be difficult, it is permitted to run a common grounding electrode conductor through the building to which several transformers can be grounded. This method of grounding separately derived systems is permitted in *250.30(A)(4)* and is illustrated in Figure 5.18 in *Unit 5*. This common grounding conductor can be connected to the grounding electrode for the building. The size of the common grounding conductor is required to be not smaller than 3/0 AWG copper according to *250.30(A)(4)(a)*. If there is an exposed metal building frame and metal water pipe in the area served by the circuits from the separately derived system, they are to be bonded to the common grounding electrode conductor as required by *250.104(D)*.

The size of the grounding electrode conductor for any one transformer is based upon the largest size ungrounded secondary conductor from the transformer using *Table 250.66*. Any bonding conductor required by *250.104(D)* is also sized using *Table 250.66*. The grounding electrode conductor connection to the grounded conductor is permitted to be made at the transformer or at the first overcurrent device supplied by the transformer. In Figure 8.22, the grounding electrode conductor connection is made at the first disconnect. It is also required to bond to the disconnect enclosure in a manner similar to that of a service. If this bond is made at the transformer, usually a wire will be used as a bonding jumper from the grounded conductor terminal in the transformer to the enclosure. A grounding electrode conductor must be run from the transformer enclosure to the grounding electrode. Grounding at the transformer and at the first disconnecting means is not permitted if a parallel path is created for grounded conductor current. It is required that the transformer enclosure and the enclosure of the first disconnecting means be effectively bonded together.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 450 Transformers and Transformer Vaults

450.5(B)(2) Exception: In the case of a high-resistance grounded electrical system, a resistor installed in the grounding conductor limits the ground-fault current to less than 10 amperes. These systems are often installed as an alternative to a ungrounded 3-phase electrical system. A zig-zag grounding autotransformer is generally installed as a part of the alarm system to indicate when a ground-fault occurs. The exception permits the overcurrent device protecting this zig-zag transformer to be rated as high as 20 amperes, rather than the 1.25 times the phase current to the transformer. The reason for this change is that circuit breakers are not manufactured that are small enough in rating to meet the Code requirements for this application.

WORKSHEET NO. 8—BEGINNING TRANSFORMERS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A single-phase transformer has a rating of 25 kVA with a primary winding rated 480 volts and the secondary winding rated 120/240 volts. The full-load current of the primary winding of the transformer is:
   A. 30 amperes.
   B. 52 amperes.
   C. 104 amperes.
   D. 130 amperes.
   E. 208 amperes.

   Code reference No code reference

2. A single-phase, 5-kVA transformer is connected to a 480-volt supply to provide power at 120 volts. The current draw in the 120-volt, 2-wire secondary circuit supplied by the transformer is 40 amperes as shown in Figure 8.23. The current flowing in the 480-volt circuit supplying the transformer, assuming minimal losses, is approximately:
   A. 10 amperes.
   B. 20 amperes.
   C. 40 amperes.
   D. 80 amperes.
   E. 160 amperes.

   Code reference No code reference

3. Information that is not required to be provided on the nameplate of a dry-type transformer from the following list is:
   A. full-load current of the primary and secondary.
   B. frequency.
   C. rated kilovolt-amperes.
   D. primary and secondary voltage.
   E. impedance if rated 25 kVA or larger.

   Code reference ________________

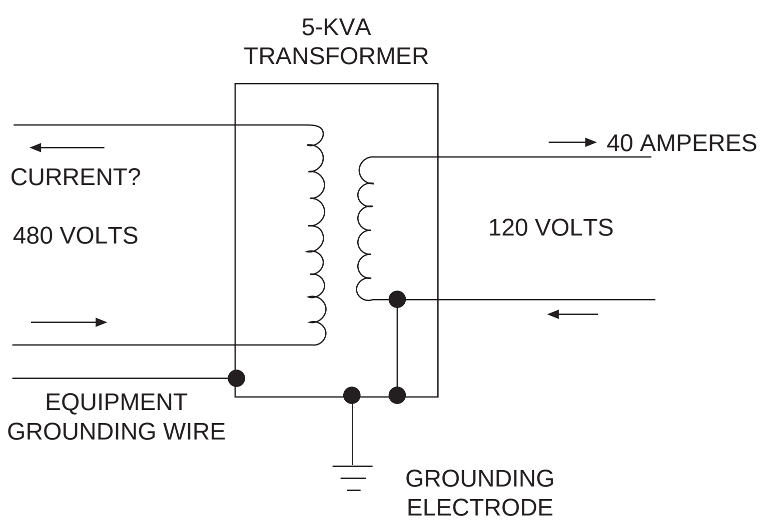


Figure 8.23 Determine the current flowing in the primary conductors of this insulating transformer.

4. Transformers are required to be installed where they are readily accessible. In the case of a 10-kVA dry-type transformer operating at not over 600 volts and installed in the open on the wall of an industrial space, the transformer is permitted to be installed:
   A. not more than 6 ft 7 in. (2 m) above the floor.
   B. not more than 8 ft (2.5 m) above the floor.
   C. not more than 10 ft (3 m) above the floor.
   D. not more than 20 ft (6.1 m) above the floor.
   E. at any height as long as a ladder or other portable elevating device is capable of providing direct access to the transformer without removal of obstacles.

   Code reference ________________

5. A transformer installed within a building to change the voltage to create a new electrical system such as a transformer connected to a 480-volt supply to create a 120/240-volt 3-wire system, shown in Figure 8.24, is considered to be:
   A. a secondary service.
   B. an alternate power source.
   C. an isolated electrical system.
   D. a separately derived system.
   E. a premises electrical system.

   Code reference ________________

6. A 5-kVA dry-type transformer, with both windings operating below 600 volts, has an outer metal covering in direct contact with the core and no ventilation openings to the inside of the transformer. The transformer is installed in a room with walls constructed of a combustible material. If no fire resistant, thermal insulating material is installed between the transformer and the wall, the minimum separation distance permitted between the transformer and the wall, as shown in Figure 8.25, is:
   A. of no concern and the transformer can be mounted directly to the wall.
   B. 3 in. (75 mm).
   C. 6 in. (150 mm).
   D. 12 in. (300 mm).
   E. 18 in. (450 mm).

   Code reference ________________

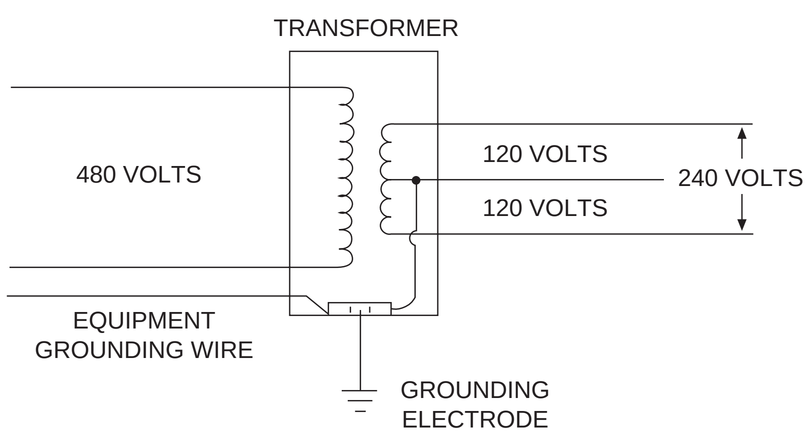


Figure 8.24 What is the name used in the Code for a transformer that changes the voltage and creates a new electrical system within a building?

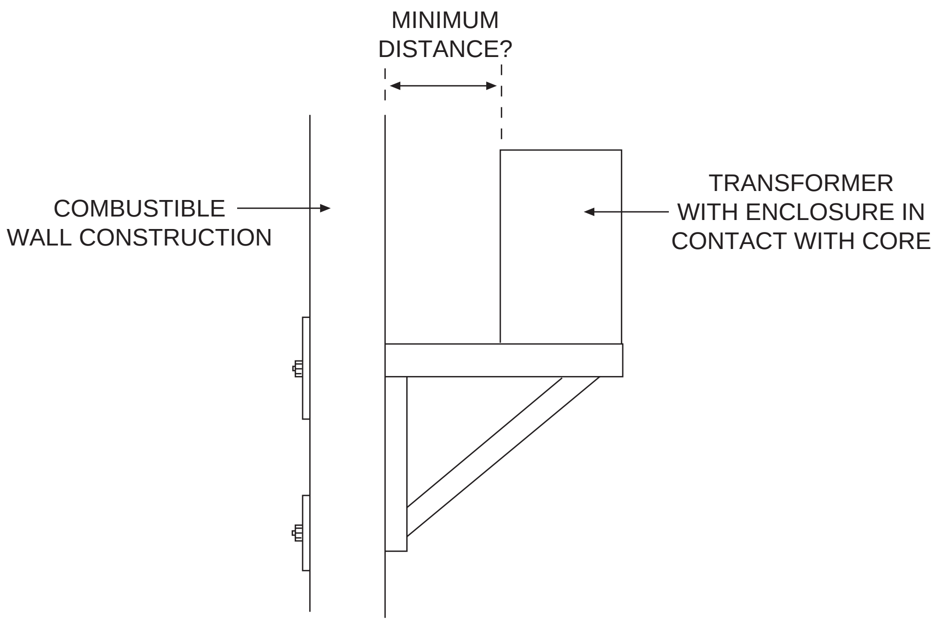


Figure 8.25 Determine the minimum distance between a wall of combustible construction and a transformer with the core in contact with the enclosure and no ventilation openings.

7. A 480-volt, single-phase circuit protected with time-delay fuses supplies only one 50-kVA dry-type transformer. The purpose of the transformer is to supply a single-phase, 120/240-volt panelboard which is provided with a 200-ampere main circuit breaker as shown in Figure 8.26. The distance from the fuses protecting the transformer primary to the circuit breaker in the panelboard is 40 ft (12.19 m), and the distance from the transformer to the panelboard is 15 ft (4.57 m). All conductors are copper with 75°C insulation and terminations. The conductor supplying the primary is size 2 AWG and the conductor on the secondary to the panelboard is size 3/0 AWG. The maximum rating time-delay fuse permitted to protect this transformer circuit is:
   A. 100 amperes.
   B. 125 amperes.
   C. 150 amperes.
   D. 200 amperes.
   E. 250 amperes.

Code reference ________________

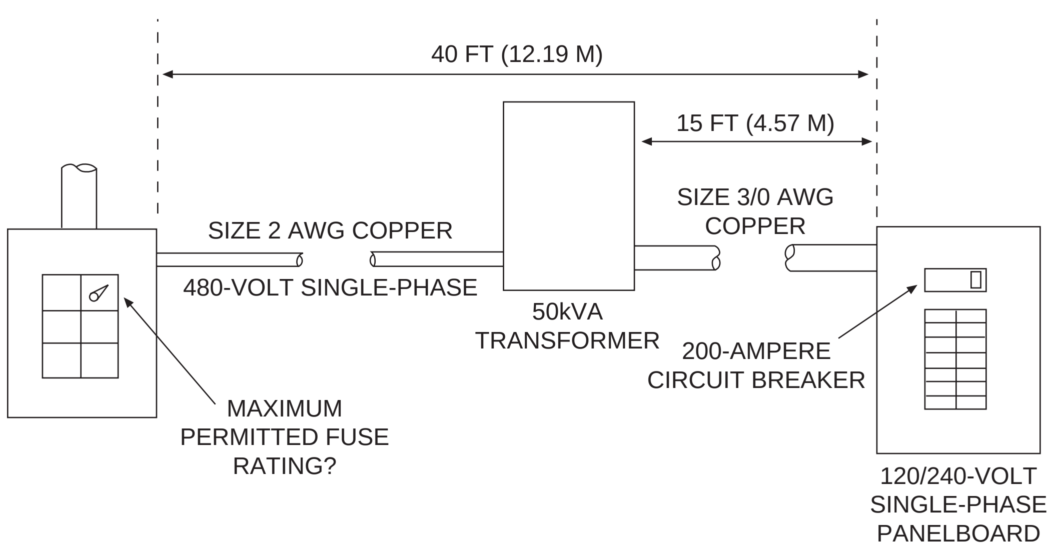


Figure 8.26 Determine the maximum permitted primary fuse rating for this transformer and the maximum distance permitted from the transformer to the 120/240-volt panelboard.

8. Refer to the transformer installation of Figure 8.26 which is in a commercial building. The distance from the transformer to the panelboard is permitted to be increased from 15 ft to a maximum distance of:
   A. 25 ft (7.5 m).
   B. 50 ft (15 m).
   C. 75 ft (22.5 m).
   D. 100 ft (30 m).
   E. not limited to a specific distance.

   Code reference ________________

9. A 15-kVA, single-phase dry-type transformer is installed to supply a 240-volt load from a 480-volt supply. All conductors are copper with 75°C insulation and terminations. The primary circuit conductor is size 10 AWG 2-wire at 480 volts, and the secondary conductor is size 6 AWG 2-wire at 240 volts. The primary is protected with 30-ampere time-delay fuses, and a disconnect switch with 60-ampere time-delay fuses is installed on the secondary circuit as shown in Figure 8.27. The maximum distance from the transformer to the secondary disconnect switch is:
   A. 25 ft (7.5 m).
   B. 50 ft (15 m).
   C. 75 ft (22.5 m).
   D. 100 ft (30 m).
   E. not limited to a specific distance.

   Code reference ________________

10. An autotransformer:
   A. has two separate windings not electrically connected to each other.
   B. has a winding common to both the primary and secondary circuits.
   C. is only permitted to be used in electric cars.
   D. is required to have overcurrent protection installed on both the primary and secondary.
   E. installation is not permitted to any input conductor connected directly to an output conductor.

   Code reference ________________

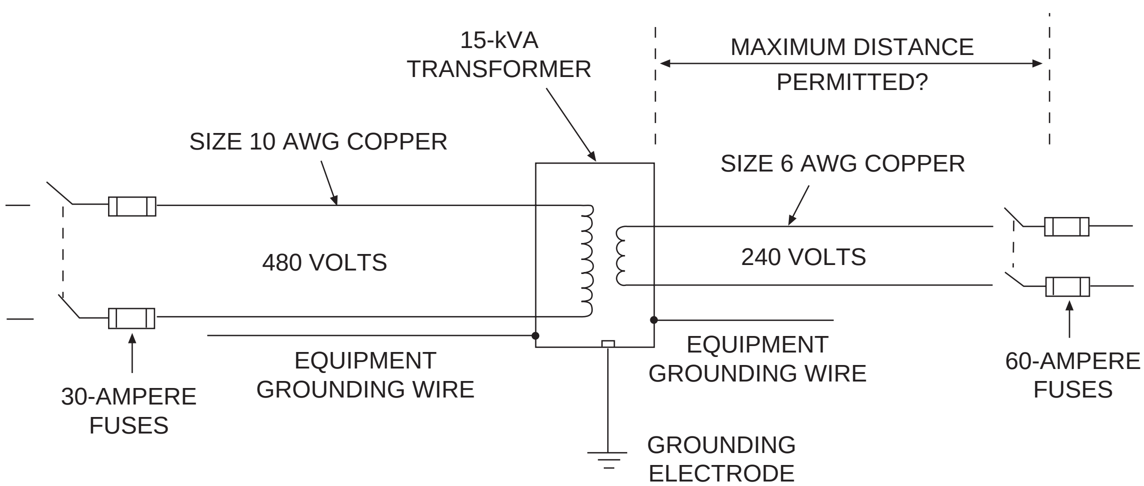


Figure 8.27 For this transformer installation with a single-voltage 2-wire secondary, determine the maximum distance permitted from the transformer to the secondary overcurrent device.

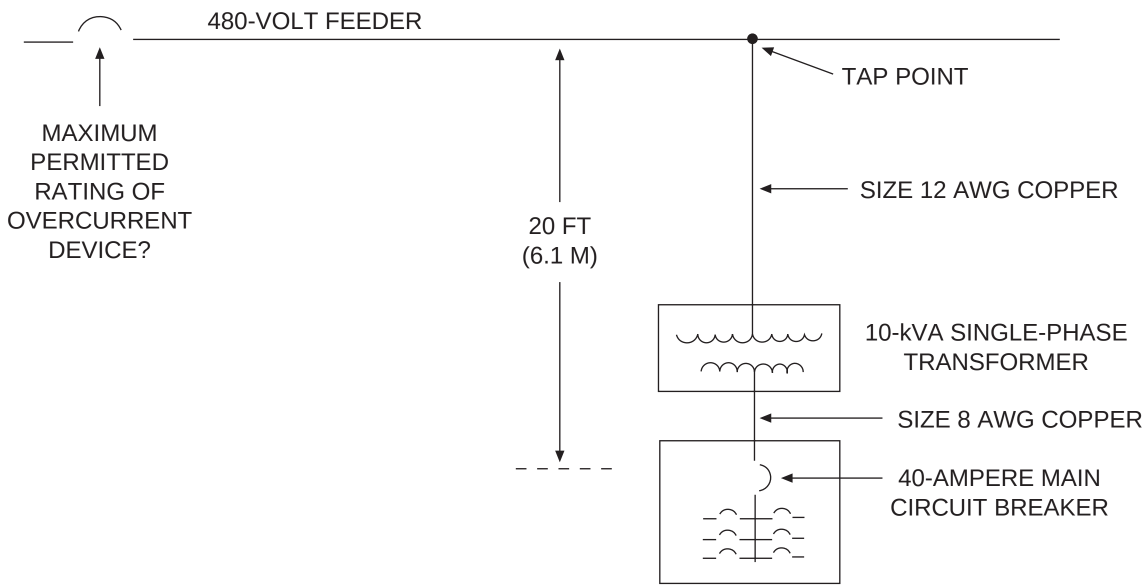


Figure 8.28 Determine the maximum rating feeder overcurrent device permitted where the overcurrent device also serves as the transformer overcurrent protection.

11. A 10-kVA single-phase transformer supplies a 120/240-volt, 3-wire panelboard with a 40-ampere main circuit breaker. The conductors between the transformer and the panelboard are size 8 AWG copper and the tap conductors supplying the primary of the transformer are size 12 AWG copper. The primary conductor is tapped to a 480-volt feeder with the distance from the tap point to the feeder being 20 ft (6.1 m) as illustrated in Figure 8.28. If the feeder overcurrent device serves as the primary protection for the transformer, the maximum rating feeder overcurrent device permitted is:
    A. 20 amperes.
    B. 40 amperes.
    C. 50 amperes.
    D. 125 amperes.
    E. 160 amperes.

    Code reference ________________

12. A 75-kVA, 3-phase transformer supplies a 200-ampere, 208Y/120-volt, 4-wire panelboard from a 480-volt supply. The panelboard is supplied with size 3/0 copper conductors terminating at a 200-ampere circuit breaker within 10 ft of the transformer. The primary is supplied with size 3 AWG copper conductors protected by a 100-ampere circuit breaker. All conductors have 75°C insulation and terminations, and are run in Rigid Metal Conduit. The installation is shown in Figure 8.29. A metal water pipe enters the building and is used as a grounding electrode for the service, but the water pipe is not visible at all points between the point of entry to the building and the area of the transformer installation. The building has a structural steel frame, which is considered effectively grounded. The grounding electrode required for this installation is:
    A. the structural steel frame of the building and the metal water pipe.
    B. the metal water pipe with a connection made within 5 ft of the point where it enters the building.
    C. the metal water pipe, but permitted to have the connection made at the point nearest the transformer.
    D. the structural steel because it is closer to the transformer than the point where the water pipe enters the building.
    E. a ground rod driven to earth at the point closest to the transformer.

    Code reference ________________

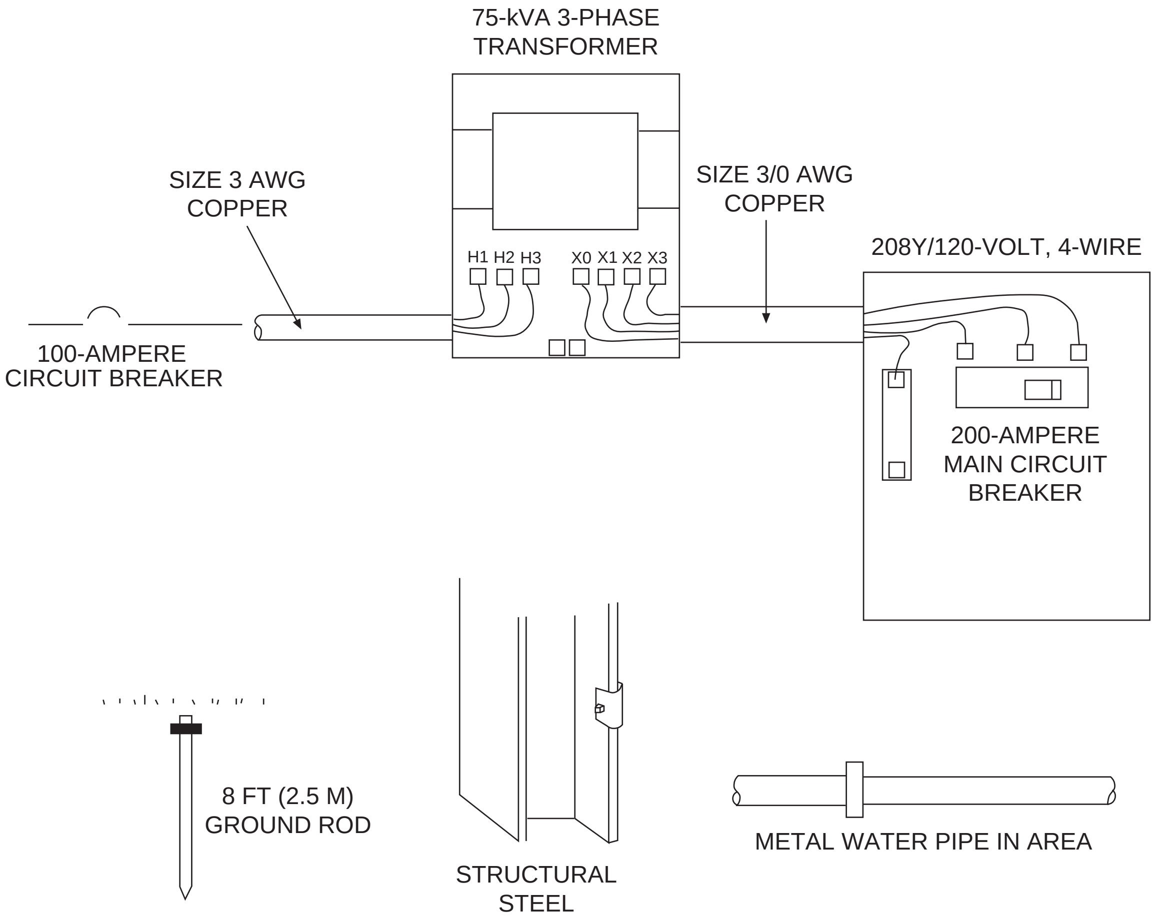


Figure 8.29 Determine the grounding electrode required for this transformer installation as well as the minimum size copper grounding electrode conductor. Also determine the permitted location for the bonding jumper, and the minimum size bonding jumper and the minimum size bonding jumper to the metal water pipe serving the area served by the transformer circuits.

13. Refer to the transformer installation of Figure 8.29. If the grounding electrode conductor is copper, the minimum size permitted is:
    A. 6 AWG.
    B. 4 AWG.
    C. 3 AWG.
    D. 2 AWG.
    E. 2/0 AWG.

Code reference ________________

14. The system bonding jumper for the transformer installation shown in Figure 8.29, which connects the grounded circuit conductor to the equipment grounding conductor, is:
    A. required to be at the transformer.
    B. required to be at the first disconnect supplied by the transformer.
    C. required to be made at both the transformer and the first disconnect supplied by the transformer.
    D. required to be made back at the main service equipment.
    E. permitted to be at the first disconnect or overcurrent device supplied by the transformer.

Code reference ________________

15. The metal water pipe in an area supplied power from a transformer is not effectively bonded back to the point where the metal water pipe enters the building. Assuming the same transformer installation as Figure 8.29, the minimum size copper conductor required to bond the metal water pipe in the area to the grounded conductor of the separately derived system is:
    A. 8 AWG.
    B. 6 AWG.
    C. 4 AWG.
    D. 3 AWG.
    E. 1 AWG.

Code reference ________________

WORKSHEET NO. 8—ADVANCED TRANSFORMERS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A 3-phase transformer has a rating of 112.5 kVA with a primary winding rated 480 volts and the secondary winding rated 208Y/120 volts. The full-load current of the secondary winding of the transformer is:
   A. 243 amperes.
   B. 293 amperes.
   C. 313 amperes.
   D. 390 amperes.
   E. 541 amperes.

   Code reference No code reference

2. A 3-phase transformer is connected for 480 volts on the primary and 208 volts on the secondary. If 200 amperes are flowing on the secondary conductors, the current in the primary conductors, assuming minimal losses, is approximately:
   A. 87 amperes.
   B. 108 amperes.
   C. 200 amperes.
   D. 400 amperes.
   E. 462 amperes.

   Code reference No code reference

3. A transformer, which is intended to be connected to a 3-phase 3-wire ungrounded electrical system for the purpose of creating a 3-phase 4-wire grounded electrical system, is called a:
   A. boost and buck transformer.
   B. insulating transformer.
   C. isolation transformer.
   D. shielded transformer.
   E. zig-zag transformer.

   Code reference ________________

4. The door sill at the entrance of a vault, as shown in Figure 8.30, for an oil-insulated transformer is required to have sufficient height to contain all of the liquid in the largest transformer and in no case shall the height be less than:
   A. 4 in. (100 mm).
   B. 6 in. (150 mm).
   C. 8 in. (200 mm).
   D. 10 in. (250 mm).
   E. 12 in. (300 mm).

   Code reference ________________

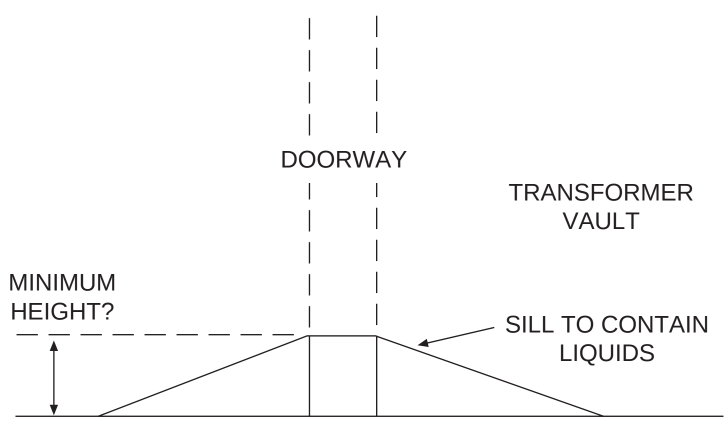


Figure 8.30 Determine the minimum height of the doorway sill required at the entrance to a liquid-insulated transformer vault.

5. A 500-kVA oil-insulated transformer is installed in a vault inside a building. The vault is ventilated to the outside of the building using natural circulation of air. After deducting the area for screens, gratings, and louvers, the minimum cross-sectional area of the ventilation opening shall be not less than:
   A. 375 in^2 (237,500 mm^2 or 2375 cm^2).
   B. 500 in^2 (316,500 mm^2 or 3165 cm^2).
   C. 750 in^2 (475,000 mm^2 or 4750 cm^2).
   D. 1000 in^2 (633,300 mm^2 or 6333 cm^2).
   E. 1500 in^2 (950,000 mm^2 or 9500 cm^2).

Code reference ________________

6. A building contains one large 480-volt, 3-phase pump motor. One 20-ampere, 120-volt general-purpose circuit is installed to provide lighting outlets and receptacles for maintenance. The circuit is provided with a 3-kVA dry-type transformer and connected to the 480-volt supply. The conductors are copper with 75°C insulation and terminations. The conductor supplying the transformer is size 14 AWG and the conductors on the secondary side of the transformer are size 12 AWG. The installation is shown in Figure 8.31. If time-delay fuses in a disconnect switch protect all circuit conductors and the transformer, the maximum rating fuses permitted are (see Table 7.2 for typical fuse ratings):
   A. 3 amperes.
   B. 5 amperes.
   C. 10 amperes.
   D. 15 amperes.
   E. 20 amperes.

Code reference ________________

7. A 45-kVA 3-phase transformer supplies a 208Y/120-volt, 4-wire panelboard with a 125-ampere main circuit breaker. The transformer is tapped from a 480-volt, 3-phase feeder with the feeder fuses also protecting the tap conductors and the transformer. The distance from the tap point through the transformer to the panelboard is 25 ft (7.5 m) with size 4 AWG primary and size 1 AWG secondary copper conductors run in Rigid Metal Conduit as shown in Figure 8.32. This installation is only permitted if the fuses protecting the feeder have a standard rating not exceeding:
   A. 125 amperes.
   B. 150 amperes.
   C. 200 amperes.
   D. 225 amperes.
   E. 400 amperes.

Code reference ________________

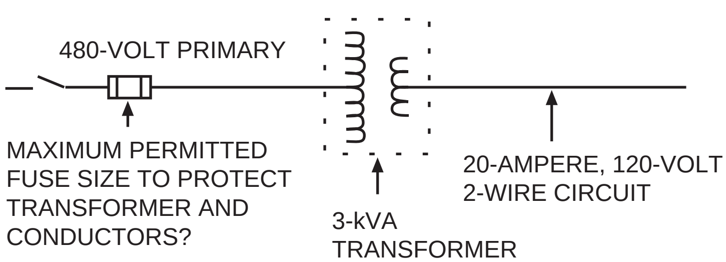


Figure 8.31 Determine the minimum rating primary overcurrent device required to protect the transformer and the secondary circuit conductors for a 2-wire, single-voltage secondary.

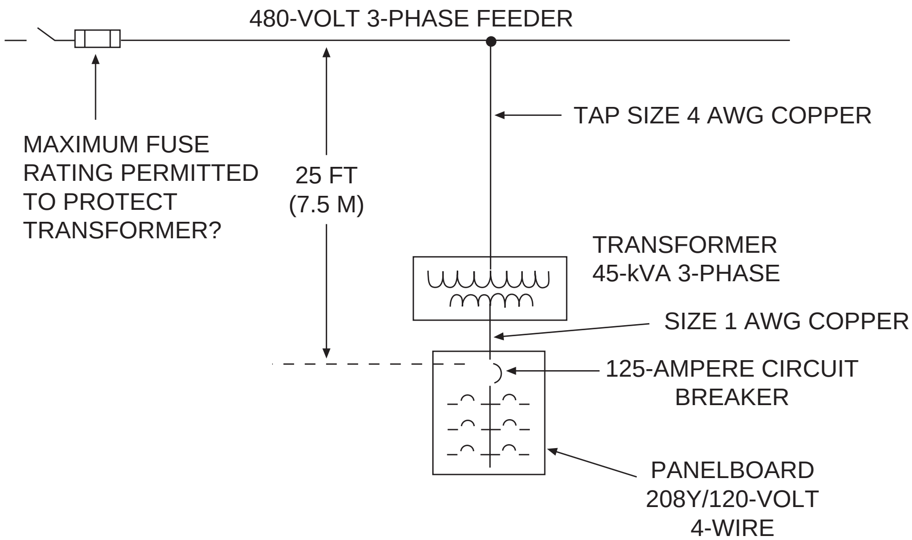


Figure 8.32 Determine the maximum rating feeder overcurrent device permitted where the overcurrent device also serves as the transformer overcurrent protection and the distance from the tap point to the secondary overcurrent device does not exceed 25 ft (7.5 m).

8. A 50-kVA dry-type single-phase transformer is installed outdoors on a concrete pad and supplies 120/240-volt single-phase power to panelboards with 100-ampere main circuit breakers in each of two separate buildings. The secondary conductors are size 1 aluminum Type USE run underground to each building. The conductors terminate at the panelboards immediately upon entering the buildings. The transformer is connected to a 480-volt supply with size 1 copper conductors protected by 150-ampere time-delay fuses. The maximum length of secondary conductors permitted to each buildings is:
   A. 10 ft (3 m).
   B. 25 ft (7.5 m).
   C. 50 ft (15 m).
   D. 100 ft (30 m).
   E. not restricted.

   Code reference ________________

9. A 45-kVA 3-phase transformer supplies a 208Y/120-volt, 4-wire panelboard with a 125-ampere main circuit breaker. The distance from the transformer to the panelboard is 25 ft (7.5 m) with size 1 AWG copper conductors run in Rigid Nonmetallic Conduit. The transformer circuit is tapped from a 400-ampere, 480-volt, 3-phase feeder with the tap ending at a fusible disconnect switch as shown in Figure 8.33. The primary conductors supplying the transformer are 6 AWG copper. The maximum standard rating time-delay fuses permitted for this transformer circuit is:
   A. 60 amperes.
   B. 70 amperes.
   C. 100 amperes.
   D. 125 amperes.
   E. 175 amperes.

   Code reference ________________

10. The 45-kVA 3-phase transformer in Figure 8.33 with size 1 AWG copper secondary conductors feeding a panelboard with a 125-ampere main circuit breaker is grounded to a steel building support. The minimum size copper grounding electrode conductor permitted to be run from the panelboard to the steel support is:
   A. 8 AWG.
   B. 6 AWG.
   C. 4 AWG.
   D. 2 AWG.
   E. 1 AWG.

   Code reference ________________

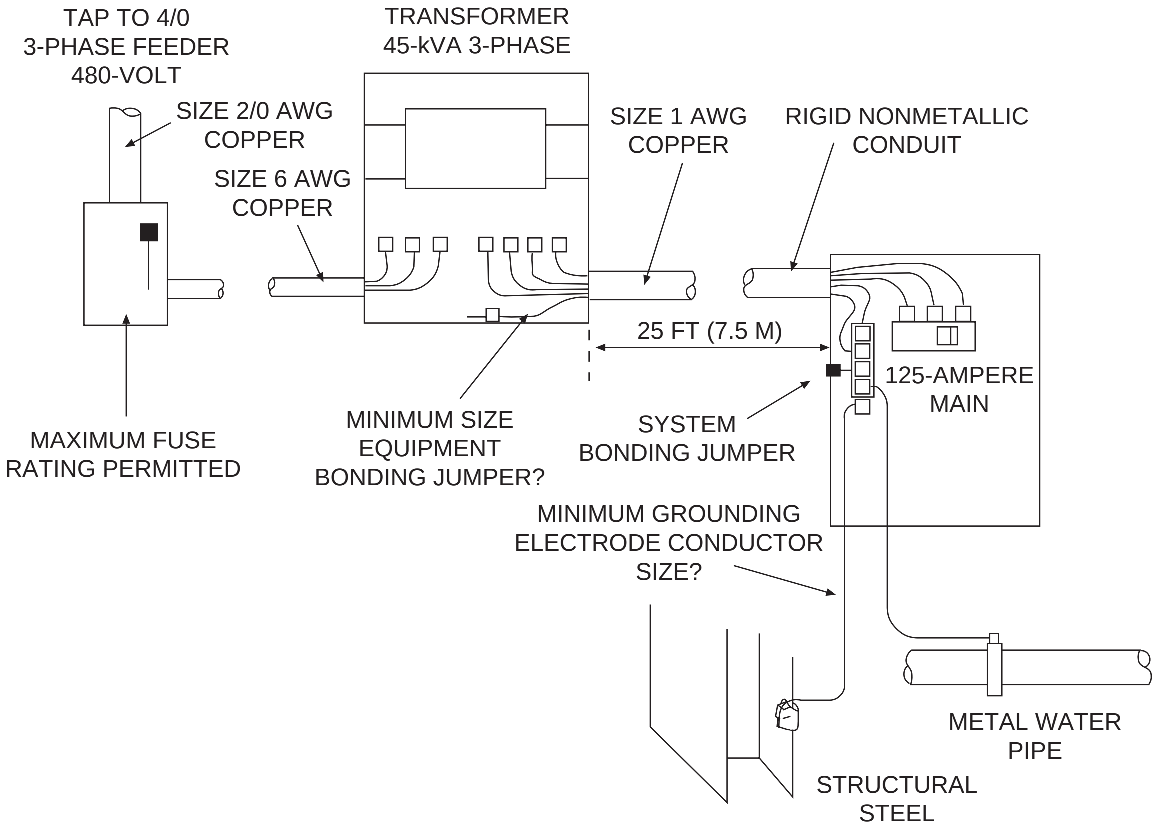


Figure 8.33 Determine the maximum permitted rating primary overcurrent device for a transformer where the primary conductors are size 6 AWG copper. Also determine the minimum size copper grounding electrode conductor for the transformer installation as well as the equipment bonding jumper in the section of Rigid Nonmetallic Conduit between the transformer and the panelboard.

11. The 45-kVA 3-phase transformer in Figure 8.33 with size 1 AWG copper secondary conductors feeding a panelboard with a 125-ampere main circuit breaker has the grounding electrode conductor connection to the grounded-circuit conductor at the panelboard. Because the conductors between the transformer and the panelboard are run in Rigid Nonmetallic Conduit, a bonding jumper is run from the panelboard grounding bus back through the conduit to the transformer enclosure. The minimum size equipment bonding jumper permitted for this purpose is:
    A. 12 AWG.
    B. 10 AWG.
    C. 8 AWG.
    D. 6 AWG.
    E. 4 AWG.

    Code reference ________________

12. A 75-kVA 3-phase transformer is supplied with size 3 AWG copper conductors and protected on the primary by 100-ampere time-delay fuses. The transformer is connected to a 480-volt supply and provides power for two 208Y/120-volt, 4-wire panelboards as shown in Figure 8.34. One panelboard has a 150-ampere main circuit breaker and the other has a 50-ampere main circuit breaker. All conductors are copper and have 75°C insulation and terminations, and the maximum length of conductors from the transformer to either panelboard is not more than 10 ft (3 m). The minimum size conductors permitted to supply the panelboard with the 50-ampere main circuit breaker is:
    A. 8 AWG.
    B. 6 AWG.
    C. 4 AWG.
    D. 1/0 AWG.
    E. 3/0 AWG.

    Code reference ________________

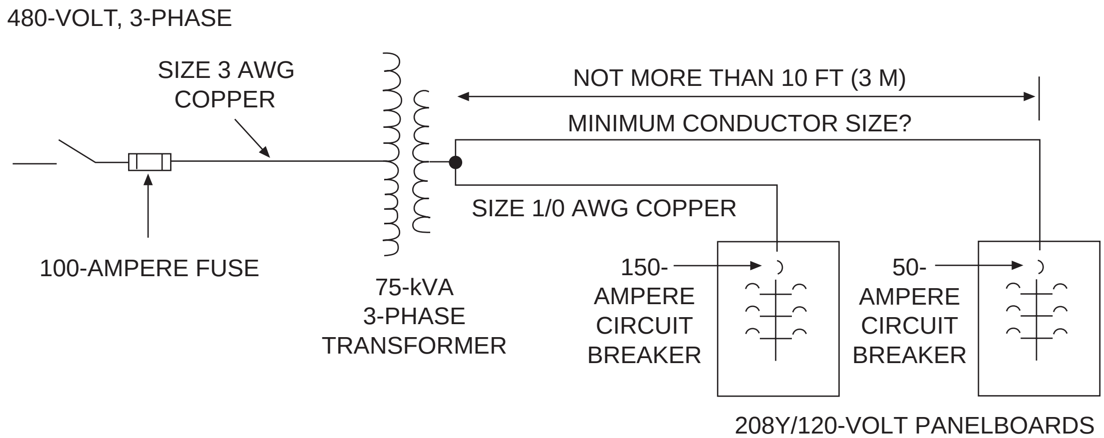


Figure 8.34 Determine the minimum size copper conductors supplying the panelboard with the 50-ampere main circuit breaker when the length of the conductor is 10 ft (3 m), and when the length of the conductor is 25 ft (7.5 m).

13. A 75-kVA 3-phase transformer in a commercial building is supplied with size 3 AWG copper conductors and protected on the primary by 100-ampere time-delay fuses. The transformer is connected to a 480-volt supply and provides power for two 208Y/120-volt, 4-wire panelboards as shown in Figure 8.34. One panelboard has a 150-ampere main circuit breaker and the other has a 50-ampere main circuit breaker. All conductors are copper and have 75°C insulation and terminations. The installation is the same as shown in Figure 8.34 except the length of conductors from the transformer to both panelboards is more than 10 ft (3 m) but not more than 25 ft (7.5 m). The minimum size conductors permitted to supply the panelboard with the 50-ampere main circuit breaker is:
    A. 8 AWG.
    B. 6 AWG.
    C. 4 AWG.
    D. 1/0 AWG.
    E. 3/0 AWG.

    Code reference ________________

14. A 5-horsepower single-phase motor is to be operated at 240 volts, but the building only has 208 volts available. A 1-kVA boost and buck transformer with a primary winding rated 120/240 volts and the secondary winding rated 16/32 volts is selected to boost from 208 volts to 240 volts. This transformer, connected in this manner, has a maximum continuous load current rating of 31.2 amperes (1000 VA/32 V = 31.2 A). The circuit is shown in Figure 8.35. It will be assumed the motor is powering an easy starting load, and the circuit conductors are properly sized. The maximum standard rating time-delay fuses permitted to provide overcurrent protection for the transformer and circuit is:
    A. 25 amperes.
    B. 30 amperes.
    C. 35 amperes.
    D. 40 amperes.
    E. 45 amperes.

    Code reference ________________

15. A 5-horsepower single-phase motor is to be operated at 240 volts, but the building only has 208 volts available. A 1-kVA boost and buck transformer with a primary winding rated 120/240 volts and the secondary winding rated 16/32 volts is selected to boost from 208 volts to 240 volts as shown in Figure 8.35. The transformer, connected in this manner, has a maximum continuous load current rating of 31.2 amperes. All conductors

are copper with 75°C insulation and terminations, and the conductors from the transformer to the motor are size 10 AWG. The minimum size conductors permitted to supply the transformer from the 208-volt source is:

A. 12 AWG.
B. 10 AWG.
C. 8 AWG.
D. 6 AWG.
E. 4 AWG.

Code reference ________________

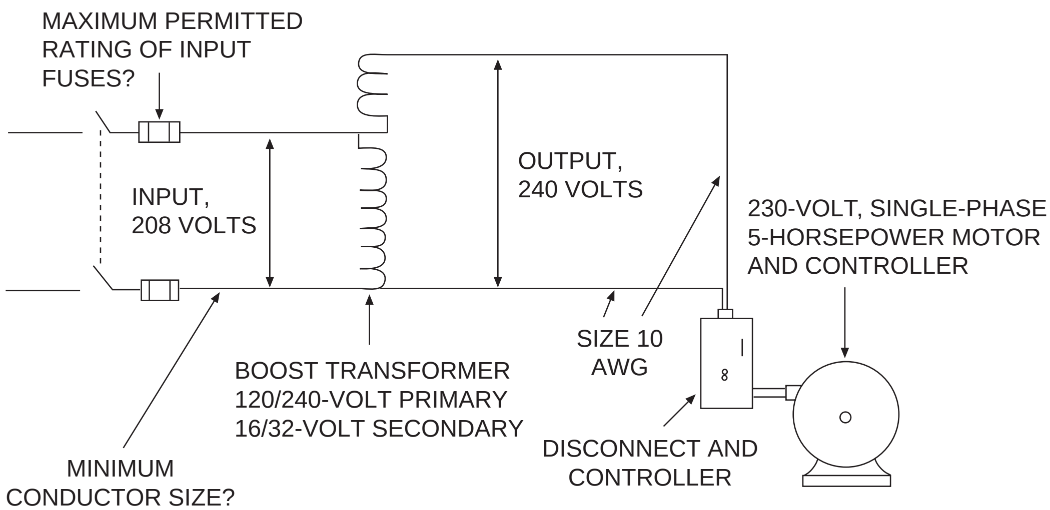


Figure 8.35 Determine the maximum permitted standard rating of the input conductor fuses, and the minimum size input conductors for this boost and buck transformer installation supplying a single-phase 230-volt motor from a 208-volt supply.

UNIT 9

Hazardous Location Wiring

OBJECTIVES

After completion of this unit, the student should be able to:

- explain the difference between a Division 1 and a Division 2 (or a Zone 0, Zone 1, and Zone 2), Class I hazardous location.
- explain the difference between a Division 1 and a Division 2, Class II hazardous location (or Zone 20, Zone 21, and Zone 22).
- describe the conditions that constitute a Class III hazardous location.
- explain the function of an explosion-proof enclosure.
- select the proper atmospheric group when given the name of a common flammable vapor or dust.
- explain a wiring method permitted for use in a Class I hazardous location.
- explain a wiring method permitted for use in a Class II, Division 1 and Division 2 hazardous location.
- explain the special bonding requirements when double locknuts are used at an enclosure feeding a circuit in a hazardous location.
- state the minimum number of threads required on a piece of Rigid Metal Conduit or IMC to be used in a Class I hazardous location for field-made fittings.
- answer wiring installation questions relating to electrical installations in hazardous locations, as described in *Articles 500*, *501*, *502*, *503*, *504*, *505*, and *506*, including the special occupancies described in *Articles 510*, *511*, *513*, *514*, *515*, and *516*.
- state at least four significant changes that occurred from the 2005 to the 2008 Code for *Articles 500*, *501*, *502*, *503*, *504*, *505*, *506*, *510*, *511*, *513*, *514*, *515*, or *516*.

CODE DISCUSSION

An area is considered hazardous because of the highly flammable nature of a vapor, gas, dust, or solid material that may be easily ignited to cause fire or an explosion. Classification of the type of hazardous material, and the boundaries of the hazardous area, is covered in *Article 500*, with general requirements for wiring in these areas. *Articles 501, 502, 503, 504, 505,* and *506* cover specific wiring requirements for the type of hazardous area involved. *Article 504* covers the installation of intrinsically safe wiring systems in any classified location. Intrinsically safe wiring systems are designed such that even if a fault or a short circuit occurs, sufficient energy is not available to ignite the hazardous vapor, dust, or material in the surrounding area. *Article 505* describes an alternate method to *Article 501* of classifying Class I hazardous locations into zones, and describes the wiring methods permitted to be used for Zone 0, Zone 1, and Zone 2. In the case of flammable dusts, fibers, and flyings, wiring and equipment is permitted to be installed according to the rules of *Article 506* where materials and extent of hazard are organized into Zone 20, Zone 21, and Zone 22. This is an alternative using *Article 502* or *Article 503* for the installation of equipment and wiring. *Articles 510* through *516* deal with specific types of occupancies where hazardous conditions exist. These articles bring about uniformity of installations. Many occupancies are unique, and therefore, it is necessary to depend on *Articles 500* through *506* to make decisions about the wiring. There are other National Fire Protection Association (NFPA) documents that may be necessary to determine the wiring requirements or to decide the boundaries of the hazardous area. It may be necessary to involve an expert, such as a registered professional engineer, with knowledge of the process and materials to decide the boundaries of the hazardous area, as well as to determine when a material constitutes a hazard.

Article 500 covers some explanation of the nature of the conditions in a hazardous location as far as electrical equipment is concerned. The types of hazardous vapors, gases, and dusts are categorized into Groups A through G. Flammable vapor and gas can also be categorized into Groups IIA, IIB, and IIC when installed under the zone system of *Article 505*. The markings required on electrical equipment for use in a hazardous location are covered. Hazardous locations are arranged into Class I, Class II, and Class III. Class I hazardous locations are described in *500.5(B)*. Class II locations are described in *500.5(C)*, with Class III locations described in *500.5(D)*.

Article 501 covers the specific requirements and wiring methods permitted in a Class I hazardous location, which is one where flammable vapors or gas are or may be present in sufficient concentration to be ignited. The wiring methods permitted are covered in *501.10*, and some common methods are illustrated in Figure 9.1. The wiring methods permitted in a Class I, Division 1 location are threaded Rigid Metal Conduit, threaded Intermediate Metal Conduit, and Type MI Cable. Some additional cables and raceways are permitted in a Class I, Division 2 location. These are covered in *501.10(B)*. The requirements for providing seals in the wiring system are covered in *501.15*. The types of motors permitted to be installed in a Class I area are covered in *501.125*, and luminaire (lighting fixture) markings and installation are covered in *501.130*. *NEC® 501.30* covers the requirements for grounding and bonding, which in some ways are different from the general requirements of *Article 250*. Refer to *500.8(E)* for a caution about preventing sparking during fault conditions by making sure threaded fittings are wrench-tight. This, as well as adequate grounding and bonding of the equipment, can reduce the chances of sparking.

Article 502 gives the wiring requirements for a Class II hazardous location where combustible dust is present in the air or may become suspended in the air. The wiring methods permitted are given in *502.10*. It should be noted there are differences in requirements for a Division 1 and a Division 2 hazardous area. Sealing the wiring system is covered in *502.15*. The type of motors permitted for use in a Class II location and the ventilation of the motor are covered in *502.125* and *502.128*. Luminaire (lighting fixture) installation is covered in *502.130*. The bonding and grounding requirements are similar to those of the Class I hazardous location and are covered in *502.30*.

Article 503 deals with wiring in areas where there will be flammable fibers and flyings. The key here is flammable. A woodworking area where wood flyings that are easily ignitable and collect on surfaces and equipment is a typical example. A sawmill, on the other hand, usually involves wood particles that are heavy in weight and have a high moisture content. This material is generally not considered to be easily ignitable, and thus would not be considered to be a Class III hazardous location. Wiring methods permitted for use in a Class III area are stated in *503.10*. Motors are covered in *503.125*, and *503.128* and luminaires (lighting fixtures) in *503.130*. Grounding and bonding are covered in *503.30*.

Article 504 covers the requirements for the installation of intrinsically safe wiring systems in hazardous classified locations. *NEC® 504.2* provides definitions important for the application of this article, such as the definition of intrinsically safe circuits. *NEC® 504.20* states that any wiring method suitable for similar conditions in unclassified locations is permitted to be used as a wiring method for intrinsically safe wiring systems in classified locations. *NEC® 504.30* specifies separation requirements for intrinsically safe wiring from power and light wiring systems. The minimum separation is 2 in. (50 mm) if the wiring of both systems is fixed in place. There are exceptions, stated in *504.30*. It is necessary to maintain the 2 in. (50 mm) separation everywhere in the building, not just in the classified area. This is illustrated in Figure 9.2. *NEC® 504.80* specifies that terminals shall be identified to prevent accidental interconnection of normal power circuits and intrinsically safe wiring systems. The intrinsically safe wiring system shall be identified with a

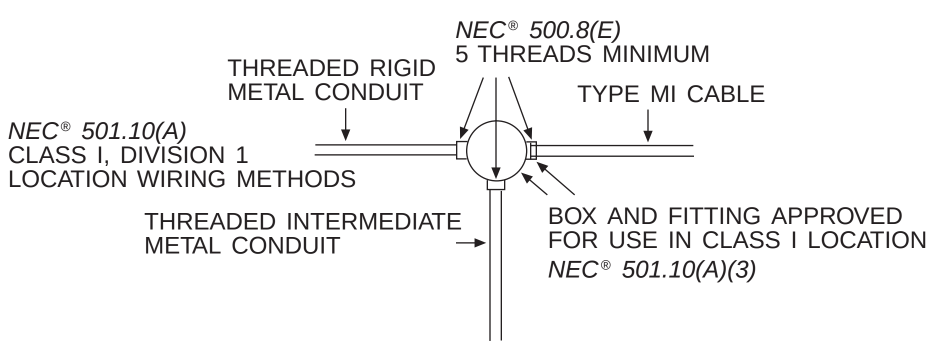


Figure 9.1 Common wiring methods permitted in a Class I, Division 1 location are threaded Rigid Metal Conduit, threaded Intermediate Metal Conduit, and Type MI Cable with approved fittings.

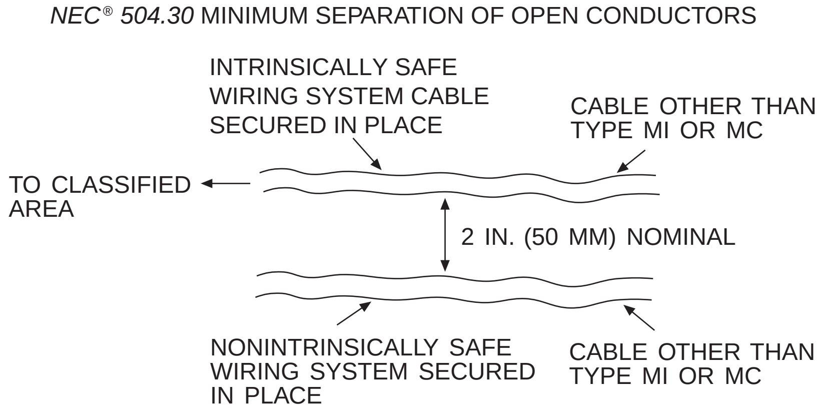


Figure 9.2 The intrinsically safe wiring shall be separated a minimum distance of 2 in. (50 mm) from lighting, power, and Class I circuits everywhere in the building—not just in the classified location.

permanent label affixed to the wiring at intervals with a minimum spacing of 25 ft (7.5 m). If a label is not visible in every separated section of the building, a label must be attached. For example, if intrinsically safe wiring passes through a room and there is no label visible in that room, a label must be attached. The label shall read "Intrinsic Safety Wiring," *504.80(B).*

Article 505 provides an alternative method of classifying Class I hazardous locations as well as specifying the wiring methods. This article separates the Class I area into three zones, Zone 0, Zone 1, and Zone 2. As described in *505.5(B)(1),* in a Zone 0 of a Class I location, an ignitable concentration of gas or vapor is present continuously or is normally present for extended periods of time. The rules for wiring in Zone 0 are provided in *505.15(A),* but essentially the only wiring permitted is intrinsically safe wiring, nonincendive circuits, nonconductive optical fiber cable, or similar systems with an energy-limited electrical supply that has been approved for the purpose. *NEC® 505.5(B)(2)* describes Zone 1 of a Class I location as one where an ignitable concentration of gas or vapor is likely to be present for limited periods of time during normal operation, system breakdown, or repair. In general, a Class I, Division 1 location, as described in *500.5(B)(1),* is separated into Zone 0 and Zone 1 when the rules of *Article 505* are applied. The wiring methods permitted in Zone 0 are permitted in Zone 1 are in *505.15(B).*

In Zone 2 of a Class I location, an ignitable concentration of gas or vapor is not likely to exist during normal operation, and if an ignitable mixture becomes present, it will only exist for a short period of time. Usually the short-duration ignitable gas or vapor concentration in Zone 2 is the result of an accident or an unexpected system component rupture or failure. For Zone 2, the wiring methods used in more hazardous Class I, Division 1 or Zone 0 or 1 are permitted, as well as those wiring methods described in *505.15(C)* location.

Typical equipment intended for use in classified hazardous locations is required to be marked to show the class, group, operating temperature, and ambient temperature range. But equipment to be installed in a Class I location in accordance with *Article 505* is required to be marked with the class, zone, and symbol indicating the equipment is built to American standards (AEx), the type of protection designation, gas classification group, ambient temperature range, and temperature classification. An example is shown in Figure 9.3. The types of protection system designations are listed in Code *Table 505.9(C)(2)(4)* and are described later. Temperature classifications are described in *Table 505.9(D)(1).* The gas groups as applied to *Article 505* are labeled differently than as applied to *Article 501.* As applied to *Article 505,* an ignitable concentration of gas or vapor is labeled Group II. But Group II is subdivided into Group IIA (same as Group D), Group IIB (same as Group C), and Group IIC (same as Groups A and B).

Different methods of preventing ignition of a flammable vapor in the area are used when wiring is installed according to *Article 505.* Intrinsically safe equipment cannot release enough energy to ignite a flammable vapor, and it would have a protection system designation of **ia** or **ib.** The term **explosion proof** is not generally used with respect to wiring installed according to *Article 505.* The corresponding term is **flameproof,** which carries a protection system designation **d.**

Flameproof protection is identified by the letter **d.** Type **d** equipment is permitted to be installed in Zone 1 areas and is designed to withstand an internal explosion without causing the ignition of the vapors surrounding the equipment.

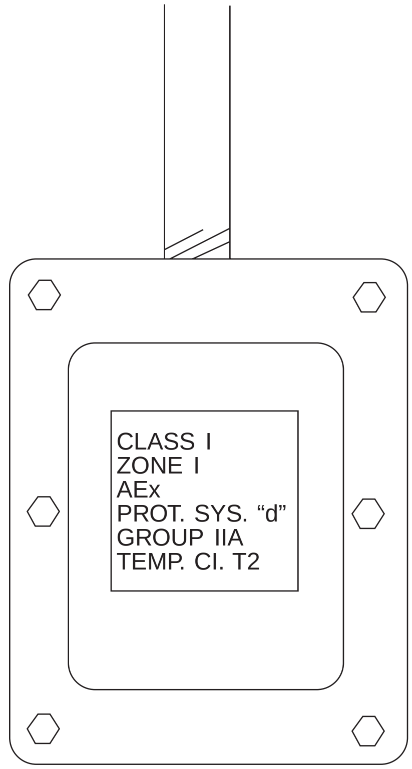


Figure 9.3 Markings on equipment suitable to be installed in a Class I hazardous location under the zone system shall be marked with the class, zone, United States specification symbol, protection system designation employed, vapor group, and temperature classification.

Equipment type known as **p** is purged and pressurized. This type of equipment reduces the chance of the possible ignition of the surrounding flammable gases such as with the ventilation of air from an unclassified location. Purged and pressurized equipment is permitted to be installed in Zone 1 and 2 hazardous locations.

Intrinsic safety equipments are identified by two different designations. Type **ia** is an intrinsically safe equipment, which is intended for use in a Zone 0 location, while type **ib** is the intrinsically safe equipment but is designed for Zone 1 locations. Equipment identified with the designation **ia** or **ib** is an associated apparatus such as a barrier which is connected to their respective intrinsically safe equipment but is generally not installed in the classified area.

Equipment that is provided with type **n** protection is permitted to be installed in Zone 2 locations. This type of equipment is designed in a manner such that it is not capable of igniting a surrounding hazardous vapor. Furthermore, type **n** equipment is broken down into three subcategories—**nA, nC,** and **nR.** The subcategories represent different design characteristics of the equipment or enclosures.

Protection provided by oil immersion is identified by the letter **o.** Through the use of this type of protection, the electrical equipment or part of the equipment is immersed in a nonflammable liquid. Any spark or arc from this type of equipment cannot ignite the surrounding vapors or gases. This type of equipment is intended to be installed in a Zone 1 location.

Type **e** equipment is known as increased safety equipment. This type of equipment can be installed in Zone 1 hazardous locations. This type of equipment is characterized by those not producing any arcs or sparks under normal operating conditions. Also, measures are taken to reduce the likelihood of surface temperatures of the equipment being of a level that would ignite the surrounding hazardous vapors or gases.

Encapsulation, type **m** equipment, is approved for Zone 1 locations. With this type of protection, arc producing contacts are encased in a compound so that any resultant arc could in no way ignite gases or vapors surrounding the enclosure.

Powder-filled protection, type **q,** is very similar to encapsulation except that a filling powder surrounds the spark producing contacts rather than a rigid compound. Type **q** equipment is for installation in Zone 1 locations.

NEC® 501.1 is the key for wiring in a Class I hazardous location. An area described as Class I, Division 1 or 2 according to *500.5(B)* is to be wired in accordance with the rules of the Code and as modified by

Article 501. As pointed out in the fine print note to *501.1*, if the Class I area is subdivided into zones rather than divisions, then the rules of *Article 505* shall apply. Therefore, wiring in a Class I location is permitted to be selected and installed in accordance with either *Article 501* or *Article 505*. *NEC® 505.7(B)* is a precaution for instances when a structure or location is classified by both the zone and division system. Class I, Zone 0 or Zone 1 classified areas are not permitted to border Class I, Division 1 or Division 2 locations. It is permitted for a Class I, Zone 2 location to border, but not overlap, a Class I, Division 2 location. This is illustrated in Figure 9.4. There is an additional requirement if the class location is to be installed according to *Article 505*. A qualified person is required to supervise the definition of zone boundaries, equipment selection, and wiring system selection according to *505.7(A)*.

Article 506 is an alternate method of installing wiring and electrical equipment in a Class II or a Class III hazardous location. This is an installation method that can be used in place of *Article 502* for Class II wiring or *Article 503* for Class III wiring. When using this alternate method, flammable dusts, fibers, and flyings are treated the same with respect to rules for wiring. Combustible metallic dusts (Group E) are not covered by this alternate method, and for those areas it will be necessary to apply the rules of *Article 502*. Types of materials are not subdivided into groups as they are with dusts of different characteristics for *Article 502*. With *Article 506*, dusts, fibers, and flyings are categorized according to degree of hazard. If a condition will occur where a combustible concentration of the material exists all of the time or for extended periods of time, that condition is considered a Zone 20. If a combustible accumulation or suspension is likely to occur, then those areas are considered Zone 21. In areas where a condition of combustible accumulation is not likely to occur, but is possible under unusual or accidental circumstances, then that area is considered to be a Zone 22. Classification of Zones with examples is discussed in *506.5*.

Wiring and electrical equipment installation in areas where there is a combustible dust or a combustible fiber and flying accumulation is treated differently in *Article 502* from *Article 503*. Equipment such as motor controllers is required to have a marking similar to that shown in Figure 9.3 with the difference that the Class I is not present and a safe temperature operating range is required to be listed on the equipment, such as – 20°C to +40°C. The ambient temperature of the area where the equipment is to be installed is required to be within the listed range. It

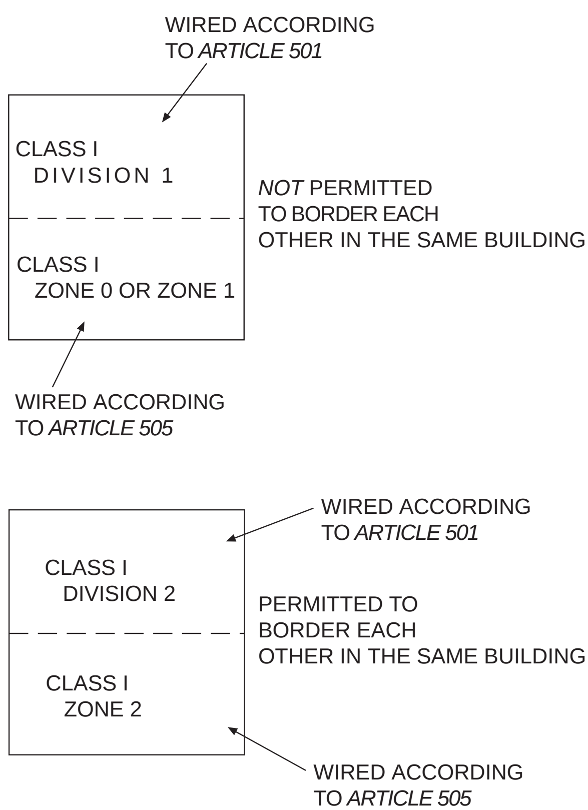


Figure 9.4 When some Class I wiring in a facility is wired according to *Article 501* and other areas are wired to *Article 505*, Division 1 and Zone 0 and 1 locations are not permitted to border each other, but Division 2 and Zone 2 areas are permitted to border each other.

is required in *506.6(A)* that design of the equipment layout and wiring system, selection of equipment and materials, installation, and inspection is to be performed by qualified personnel. In the case of a Zone system applied to a Class I area, the design, selection of equipment and materials, and installation are to be performed under the supervision of a Registered Professional Engineer. Wiring and equipment installed in a facility using *Article 502* or *Article 503,* according to *506.6(B),* are not permitted to overlap with or even adjoin wiring installed according to *Article 506* except that a Class II, Division 2 or a Class III, Division 2 area is permitted to be located next to a Zone 22 area. This is a similar rule as shown in Figure 9.4.

The rules for the selection and installation of equipment such as motors, luminaires (lighting fixtures), controllers, heaters, transformers, and the like are much more detailed in *Article 502* and *Article 503* than in *Article 506,* and the rules are not necessarily equivalent. Wiring methods and materials are also different. For example, Electrical Metallic Tubing is permitted to be used as a wiring method in a Class III, Division 1 location using *Article 503,* but is not permitted in that same location if classified into Zone 20 or Zone 21 using *Article 506*. If sealing of the wiring system is judged to be necessary, the seal shall be identified. No such requirement applies when installing wiring using *Article 503*. The rules for grounding and bonding are the same for wiring installed using *Article 502, Article 503,* or *Article 506.*

Article 510 is a short article that states that *Articles 511* through *516* apply to special occupancies where hazardous areas exist. It also states that the general provisions of the Code apply, unless specific requirements are given in the article that apply to the type of occupancy.

Article 511 applies to commercial garages where repair is done to automobiles and other combustion motor equipment. The hazardous locations are defined, and the wiring methods permitted in those hazardous areas are described in *Article 501.* Special requirements are placed on the installation of luminaires (lighting fixtures) above a hazardous area. When wiring is installed in these facilities, as much wiring as possible is located outside of the hazardous area to reduce the cost of the installation.

Article 513 covers the requirements for installing wiring in an aircraft hangar. There are similarities in the requirements for a commercial garage. The hazardous area includes a larger portion of room because of the height of aircraft and the location of fuel tanks in the wings. The wiring methods permitted for the hazardous areas are described in *Article 501.* Raceways within or beneath a hangar floor are considered to be a part of the Class I area above the floor by *513.8* and *514.9.* This means conduits emerging up through the floor into the Class I area above are not considered to be crossing a classification barrier and are, therefore, not required to be sealed. If, however, those conduits leave the classified area and emerge into an area of a different division or an unclassified area, those conduits are required to be sealed.

Article 514 covers the classification and specific wiring requirements for gasoline dispensing and service stations. It is important to be familiar with the type of equipment used in these areas. *NEC® 514.3(B)(1)* describes the boundaries of the hazardous areas for Class I, liquids. Flammable gases such as compressed natural gas or liquified petroleum have the limits of the boundaries described in *514.7(B)(2).* For example, in the case of a gasoline dispenser, the space within the dispenser is considered to be a Class I, Division 1 hazardous location. The space in all directions horizontally from the dispenser and down to the grade level is considered to be a Class I, Division 2 location. This Division 2 location extends outward from the dispenser 20 ft (6 m) in all directions and up to a height of 18 in. (450 mm) above grade level. This is illustrated in Figure 9.5. For a

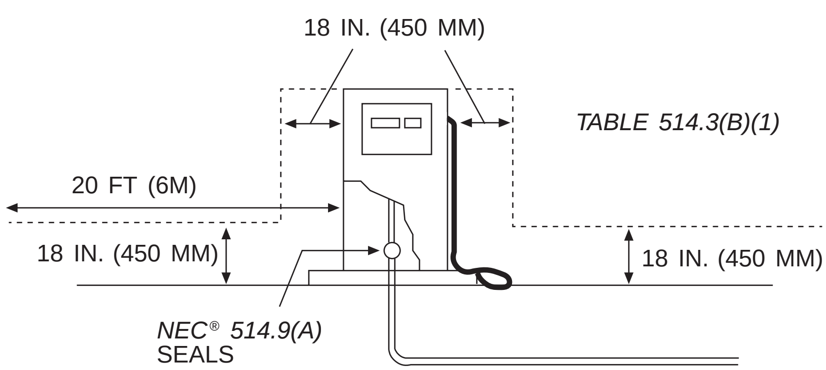


Figure 9.5 The limits of the hazardous locations for a gasoline dispensing unit are found in Code *Table 514.3(B)(1)*.

dispensing unit, *514.11(A)* requires that each circuit conductor be wired so that the disconnecting means opens all of the wires, including a neutral conductor.

Article 515 covers wiring installed in hazardous areas around bulk storage plants. This is an area where gasoline or other volatile flammable liquids are stored in tanks or distributed by container, rail car, tank vehicle, or ship. The boundaries of the hazardous area are described in *Table 515.3.*

Article 516 applies to the wiring installed in the area of spray application, dipping, and coating processes. A paint spray area is a typical application. The boundaries of the hazardous location are described in *516.3.* All dimensions are described in this section and shown in *Figure 516.3(C)(1), Figure 516.3(C)(2),* and *Figure 516.3(C)(4)* of this *Article 516.* In the case of a dipping process, it is important to make a determination of the point where the object that was dipped is no longer considered to be a vapor source. The definition of a vapor source is found in *516.3(C)(4).* The limits of the hazardous location for an open tank dipping process are shown in an illustration of an open tank dipping process in *Figure 516.3(C)(5).* Frequently, it is possible to locate wiring, controls, motors, and lighting fixtures outside of the hazardous area.

HAZARDOUS LOCATION WIRING FUNDAMENTALS

The first step for wiring in a hazardous location is to determine the type of material that makes the area hazardous. Next, determine if the type of facility is considered to be a special occupancy, which is described in one of the articles of the Code, for example, a paint spray booth or a motor vehicle fuel-dispersing station. Then it will be possible to determine the areas classified as hazardous. Achieving a safe and low-cost wiring system is the result of locating as much electrical equipment as possible out of the hazardous area. In the case of an industrial process, chemicals may be involved that require the assistance of officials or engineers other than the electrical inspector to determine the type of hazard. The National Fire Protection Association has additional publications that deal with most materials that would result in an area being classified as a hazardous location.

Types of Hazardous Locations

The types of hazardous materials are described in *Article 500, Article 505,* or *Article 506* with specific wiring requirements for each class covered in *Articles 501, 502, 503, 504, 505,* and *506.*

- Class I Groups A, B, C, and D, ignitable gas or vapor
- Class I Groups IIC, IIB, and IIA, ignitable gas or vapor
- Class II Groups E, F, and G, combustible dust
- Class III Easily ignitable fibers or flyings

Explosion characteristics of different air mixtures of flammable vapors are different; therefore, flammable vapors are separated into Groups A, B, C, and D when the wiring is installed according to *Article 501,* and the same vapors are separated into Groups IIA, IIB, and IIC when the wiring is installed according to *Article 505.* The Code does not provide a list of typical vapors that fall into each group. Instead, the Code gives one typical example of a vapor in each group. For Groups B, C, and D, vapors are placed according to ignition performance tests. The Code uses maximum experimental safe gap (MESG) and minimum ignition current (MIC) ratio to place vapors into the groups. Pressure of the vapor air mixture is an important factor with respect to flammability. One criteria is the maximum experimental safe gap under test conditions between adjacent metal parts. Another criteria is the minimum current to cause ignition. The ignition characteristics of some common materials such as gasoline are well-known, and specific requirements can be established for the installation of wiring. For other materials, special training may be needed. A summary of the Groups A, B, C, and D is shown in Table 9.1, along with the MESG and MIC ratio for each group.

Once the hazardous material has been identified, the degree of hazard must be determined. A Division 1 area is one in which the hazardous material is likely to be present. A Division 2 area is one in which, under normal operating conditions, a hazardous material is present in dangerous quantities only under accidental spills or other unusual circumstances. The final condition is the nonhazardous area. The division line between hazardous and nonhazardous may be a physical barrier, or it may simply be a distance limit. Class I zones were discussed earlier in this unit.

Table 9.1 Group designations for flammable vapor air mixtures that apply when wiring is installed according to *Article 501*.

Group	MESG	MIC ratio	2005 Code vapor list	1996 Code vapor list
A or IIC	NA	NA	Acetylene	Acetylene
B or IIC	Less than or equal to 0.45 mm	Less than or equal to 0.4	Hydrogen	Gases containing more than 30% hydrogen by volume: butadiene, ethylene oxide, propylene oxide, and acrolein
C or IIB	Greater than 0.45 mm, but less than or equal to 0.75 mm	Greater than 0.4, but less than or equal to 0.8	Ethylene	Ethyl, ether, ethylene
D or IIA	Greater than 0.75 mm	Greater than 0.8	Propane	Acetone, ammonia, benzene, butane cyclopropane, ethanol, gasoline, hexane, methanol, methane, natural gas, naphtha, and propane.

Ratings of Equipment

Electrical equipment other than conduit, wire, and some fittings will be marked if suitable for hazardous locations. The equipment shall be marked with the class and the group of hazardous material. The National Electrical Manufacturers Association (NEMA) has established a numbering system for different types of enclosures. Typical motor and control enclosure designations for hazardous locations are listed as follows:

- Class I — Hazardous gas or vapor
  NEMA 7 explosion-proof enclosure
- Class II — Flammable dust
  NEMA 9 dust-ignition-proof enclosure
  Motors are permitted to be totally enclosed pipe-ventilated
- Class III — Flammable flyings and fibers
  NEMA 4, and NEMA 12 dusttight enclosure
  Motors are permitted to be rated totally enclosed, totally enclosed pipe-ventilated, or totally enclosed fan-cooled

Objectives of Explosionproof Enclosures

An explosionproof wiring system is installed in Class I hazardous locations. The wiring system is installed with the assumption that it is impossible to prevent the entry of the hazardous gas or vapor into the wiring system. A flammable mixture of gas or vapor and oxygen may accumulate in a heat-producing or an arc-producing portion of the wiring system, such as a switch. The distance from the enclosure to the seal is not permitted to be greater than 18 in. (450 mm). If the raceway is trade size 2 (53) or larger in diameter, and the enclosure contains splices, taps, or terminations, then it is also required to provide a seal within 18 in. (450 mm) of the box or enclosure. Seals installed in conduit entries to enclosures limit the internal combustion to a small portion of the wiring system, as shown in Figure 9.6.

It is, therefore, assumed that an internal explosion cannot be prevented. The explosion produces extreme internal pressure. The enclosure, seals, conduit, and fittings shall have sufficient strength to

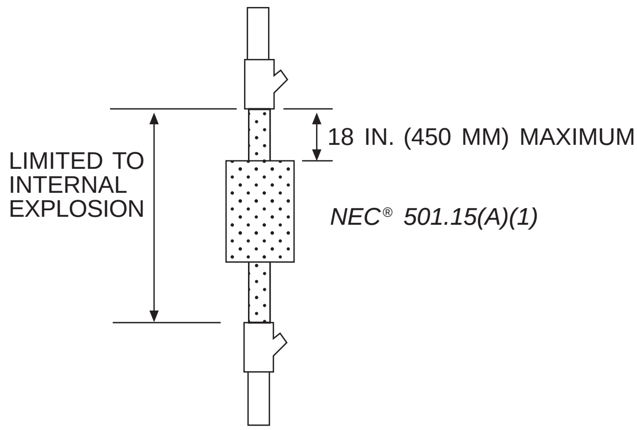


Figure 9.6 Seals confine combustion in the wiring system to a limited portion of the electrical system.

withstand the pressure of the internal explosion. This is why Rigid Metal Conduit or Intermediate Metal Conduit (IMC) is required, and why joints must have a minimum of five threads fully engaged. This is also why explosionproof enclosures are so massive. Therefore, it is absolutely necessary to install all bolts and screws on enclosure covers.

Heat is produced during an internal explosion, and this heat will raise the outside surface temperature of the enclosure. This surface temperature shall be kept below the ignition temperature of the gas or vapor on the outside, or an explosion is likely to occur. This is another reason why explosionproof enclosures are so massive. There must be enough metal mass to absorb the heat of the internal explosion.

The high pressure developed during an internal explosion will cause the ignition gases to eventually escape through joints and threads. The covers and threads shall be tight enough to retard the leakage of products of combustion. If leakage is too fast, the escaping gas will be hot enough to ignite the vapor on the outside. Therefore, slowly escaping gas will cool before it gets to the outside, as shown in Figure 9.7. All threaded joints must be tight, with at least five threads engaged. Machined metal surfaces must be clean with no scratches. A grain of sand on the machined surface of a cover, or a scratch, will allow hot gas to escape, and an external explosion may occur.

Sealing Fittings

The thickness of the compound in a Class I sealing fitting is specified in *501.15(C)(3)*. The minimum thickness of the sealing compound is not permitted to be less than the trade size of the sealing fitting. The minimum thickness under any circumstances is 5/8 in. (16 mm). If a sealing fitting is made for trade size 3/4 (21) conduit, then the minimum sealing compound thickness in the sealing fitting is trade size 3/4 (21). This is illustrated in Figure 9.8. If a trade size 1 (27) sealing fitting is used with trade size 3/4 (21) conduit, using a reducer at the fitting, the minimum thickness of sealing compound in the fitting is now trade size 1 (27).

It is also important to make sure the conductors are separated so that the sealing compound will flow around each conductor, leaving no voids for vapor to pass. To help in the separation of conductors in the

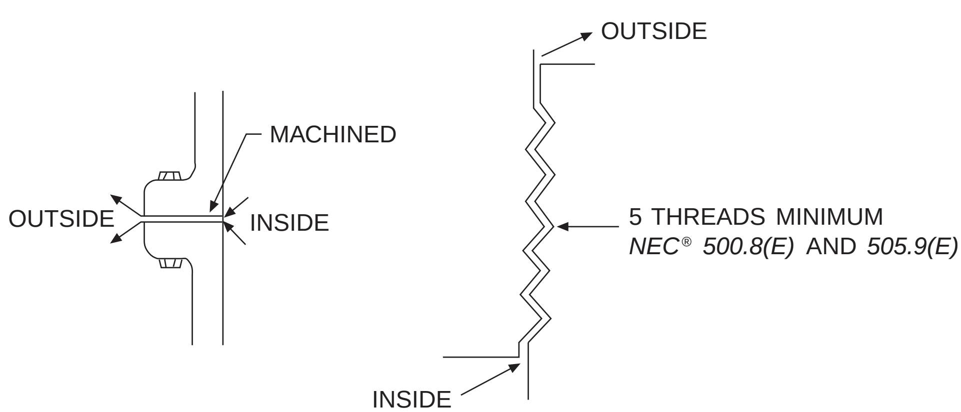


Figure 9.7 Explosionproof equipment is designed to absorb the heat from escaping combustion vapors through the threads or a metal surface machined to a specified clearance.

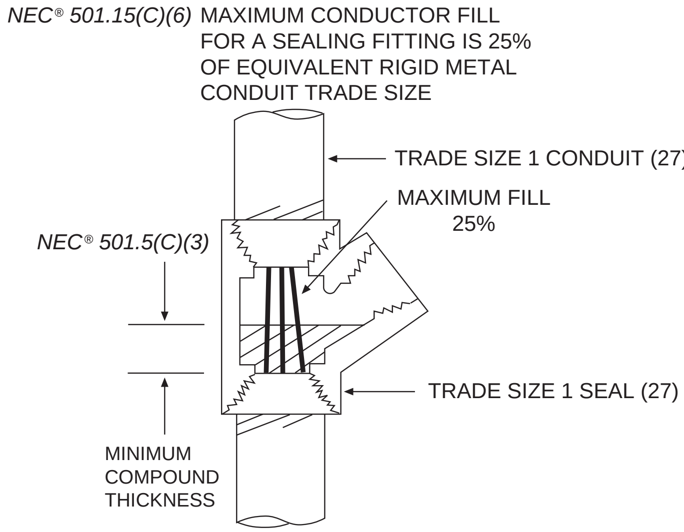


Figure 9.8 Standard Class I sealing fittings are rated for 25% fill and the thickness of the sealing compound is not permitted to be less than 5/8 in. (16 mm) or the trade size of the sealing fitting.

sealing fitting, standard fittings are listed for only 25% fill. This means that the total cross-sectional area of the conductors is not permitted to exceed 25% of the cross-sectional area of the sealing fitting based on the cross-sectional area of Rigid Metal Conduit as listed in *Table 4* in *Chapter 9*. This would mean that the IMC or Rigid Metal Conduit is permitted to be filled to only 25% of the conduit cross-sectional area. There are some ways around this problem. There are sealing fittings rated for 40% fill. Another solution is to use an oversized sealing fitting with reducers. The following example will show how to determine the minimum size of sealing fitting required for a particular installation.

Example 9.1 Four size 6 AWG, Type THWN conductors are run to an explosion-proof enclosure where a sealing fitting is required to be installed within 18 in. (450 mm) of the enclosure. Determine the minimum trade diameter sealing fitting required for this installation.

Answer: Look up the cross-sectional area of size 6 AWG, Type THWN conductors in *Table 5* in *Chapter 9* and find 0.0507 sq. in. Next, multiply the individual conductor cross-sectional area by 4 to get the total cross-sectional area of the conductors (4×0.0507 in.^{2} = 0.2028 in.^{2}). There is no 25% cross-sectional area column in *Table 4* in *Chapter 9*, so divide the cross-sectional area of the wires by 0.25 to get the minimum total cross-sectional area of the fitting required, which in this case is 0.8112 sq. in. (523.2 mm^2) ($0.2028 \div 0.25 = 0.8112$ in.^{2}). Now go to the 100% cross-sectional area column of the Rigid Metal Conduit section of *Table 4* in *Chapter 9* and find a size that is not smaller than 0.8112 sq. in. (523.2 mm^2), which is trade size 1 (27).

4×0.0507 in.^{2}	=	0.2028 in.^{2}
(4×32.71 mm^2	=	130.8 mm^2)
0.2028 in.^{2} / 0.25	=	0.8112 in.^{2}
(130.8 mm^2 / 0.25	=	523.2 mm^2)

The conduit is permitted to be sized according to a 40% fill. The total cross-sectional area of the conductors in this example is 0.2028 sq. in. Look up the minimum trade size conduit from the 40% fill column of *Table 4* and find trade size 3/4 (21). It is permitted to use trade size 3/4 (21) Rigid Metal Conduit in this case with a trade size 1 (27). sealing fitting and an explosion-proof reducer from trade size 1 to 3/4 (27 to 21).

Since the maximum permitted cross-sectional area of the wires passing through a sealing fitting is based upon the cross-sectional area of Rigid Metal Conduit of the same trade size, Table 9.2 was created showing 25% of the cross-sectional area of the sealing fitting. Referring to Example 9.1, the four wires have a total cross-sectional area of 0.2028 sq. in. Using Table 9.2, it is easy to see that a trade size 1 in. sealing fitting is required.

Table 9.2 Allowable wire fill area for standard sealing fittings (based on RMC trade size area)

Sealing Fitting Trade Size	Cross-Sectional Area 25% sq. in.	sq. mm	100% sq. in.	sq. mm
3/4 (21)	0.137	88	0.549	353
1 (27)	0.222	143	0.887	573
1 1/4 (35)	0.382	246	1.526	984
1 1/2 (41)	0.518	333	2.071	1333
2 (53)	0.852	550	3.408	2198
2 1/2 (63)	1.217	784	4.866	3137
3 (78)	1.875	1210	7.499	4840
3 1/2 (91)	2.503	1615	10.010	6461
4 (103)	3.221	2079	12.882	8316
5 (129)	5.053	3263	20.212	13050
6 (155)	7.290	4705	29.158	18821

Equipment Grounding and Bonding

Grounding is extremely important in hazardous locations. Extra care must be taken to make sure the grounding path is of low impedance. An adequate grounding system will conduct current without allowing the enclosure of the equipment to develop a voltage above ground. This is important to prevent the case of the electrical equipment from arcing to ungrounded metal equipment and structural supports. A normally harmless static or small fault-induced arc can cause an explosion in a hazardous location.

It is also important that all threaded connections be made wrenchtight to prevent arcing at the joint in the event the conduit and metal enclosures are needed to conduct fault current. An arc at a loosely joined conduit connection can cause an explosion. Special bonding requirements are also required at certain areas of hazardous locations, as shown in Figure 9.9. Double locknuts are not permitted to serve as the equipment grounding for a circuit in a hazardous location. It is necessary to bond directly from conduit entries into an enclosure even if the enclosure is not in the hazardous area. Code *Articles 501.30(A), 502.30(A), 503.30(A), 505.25(A)* and *506.25(A)* cover the special bonding requirements for wiring to hazardous locations.

Dust-Ignitionproof Equipment

The principle of installing wiring in a Class II area is to prevent the entry of flammable dust. Dust is a solid material that is heavier than air. Gaskets will prevent the entry of dust particles. In calm air, dust will settle. If dust is prevented from entering heat- and arc-producing parts of the wiring system, a fire or explosion will be prevented.

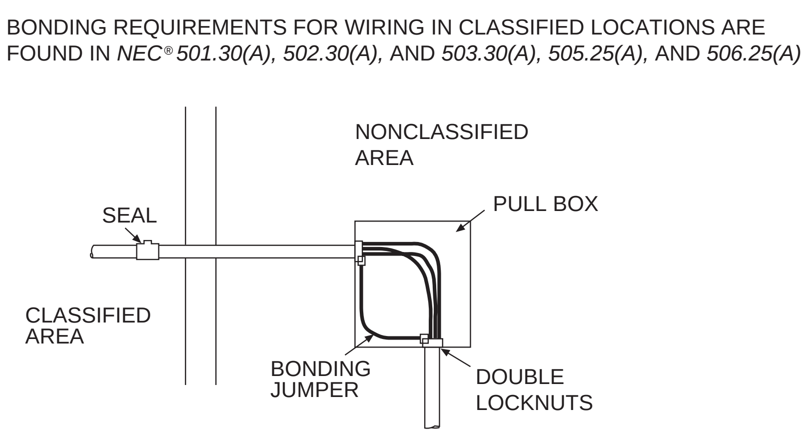


Figure 9.9 Double locknuts are not considered adequate bonding for conduit systems supplying wiring in a hazardous location and, therefore, special bonding is required even in the nonhazardous area.

Enclosures for Class II areas are not required to be of equally heavy construction as Class I enclosures. Seals are not required to isolate arc- and heat-producing components. Sealing is required simply to prevent the entry of dust. The same extra care taken to ensure a good grounding system is required because arcs, due to poor bonding, can set off a general explosion if a fault occurs.

Flammable Fibers and Flyings

The primary problem in these types of facilities is to prevent the entry of heavier-than-air fibers and flyings such as cotton, textile fibers, and dry wood fibers. Enclosures generally have hinged doors with a latch and a gasket around the edges of openings. Enclosures and equipment must be selected to prevent the surface temperature from rising above the ignition temperature of the fibers or flyings that may collect on the enclosure. This temperature limitation must be achieved even when fibers and flyings have accumulated in layers on wiring and equipment.

Special Occupancies

The general wiring requirements for hazardous locations are provided in Code *Articles 501, 502, 503, 504,* and *505.* Later articles provide special wiring requirements and rules for determining the hazardous classified area. An example of a special occupancy with rules to define the extent of the hazardous locations is an automobile repair facility that also serves motor vehicles that run on compressed natural gas or other lighter-than-air fuels. In such an area, according to *511.3(B)(4),* the area 18 in. (450 mm) down from the ceiling, as well as the area 18 in. (450 mm) above the floor, is considered to be a Class I, Division 2 hazardous location as illustrated in Figure 9.10.

The local electrical inspector, building code, or other organizations or agencies will provide additional requirements for types of hazardous facilities not specifically covered in the Code. Some manufacturers of electrical equipment and wiring materials for installation in hazardous locations publish excellent literature that is helpful when installing wiring in hazardous areas.

The earth below a Class I hazardous location of a motor fuel-dispensing facility is no longer considered to be a Class I hazardous location. There is, however, a requirement that any conduit emerging from the ground be sealed within 10 ft (3.05 m) of the point of emergence, as illustrated in Figure 9.11. Also, there shall be no coupling, fitting, box, or union between the point of emergence and the seal, except that a listed explosion-proof reducer at the seal is permitted. The wiring is required to be threaded Rigid Metal Conduit or threaded steel Intermediate Metal Conduit. *Exception 2* of *514.8* does permit Rigid Nonmetallic Conduit for the portion of the run that is at least 2 ft (600 mm) below grade.

In the case of a commercial garage, a raceway embedded in a masonry wall adjacent to a Class I area, or buried under a concrete floor above which is a Class I, Division 2 area is not considered to be in the Class I

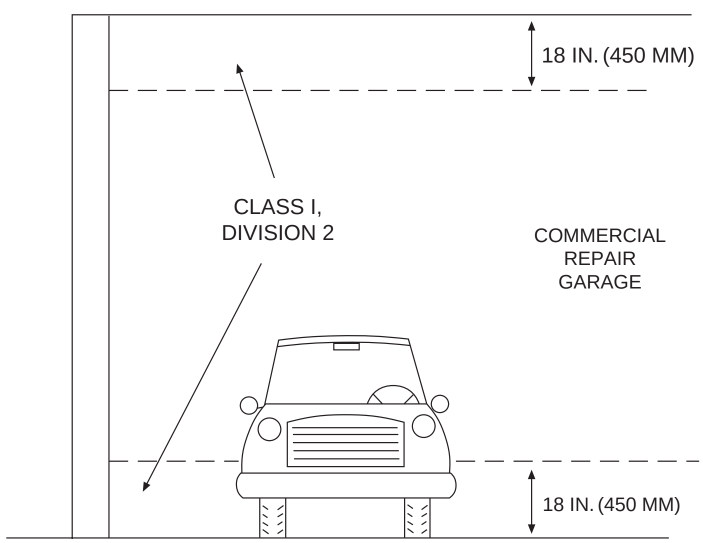


Figure 9.10 Commercial garages that repair vehicles using compressed natural gas or other lighter-than-air fuels have the area 18 in. (450 mm) down from the ceiling in the service area classified as a Class I, Division 2 location.

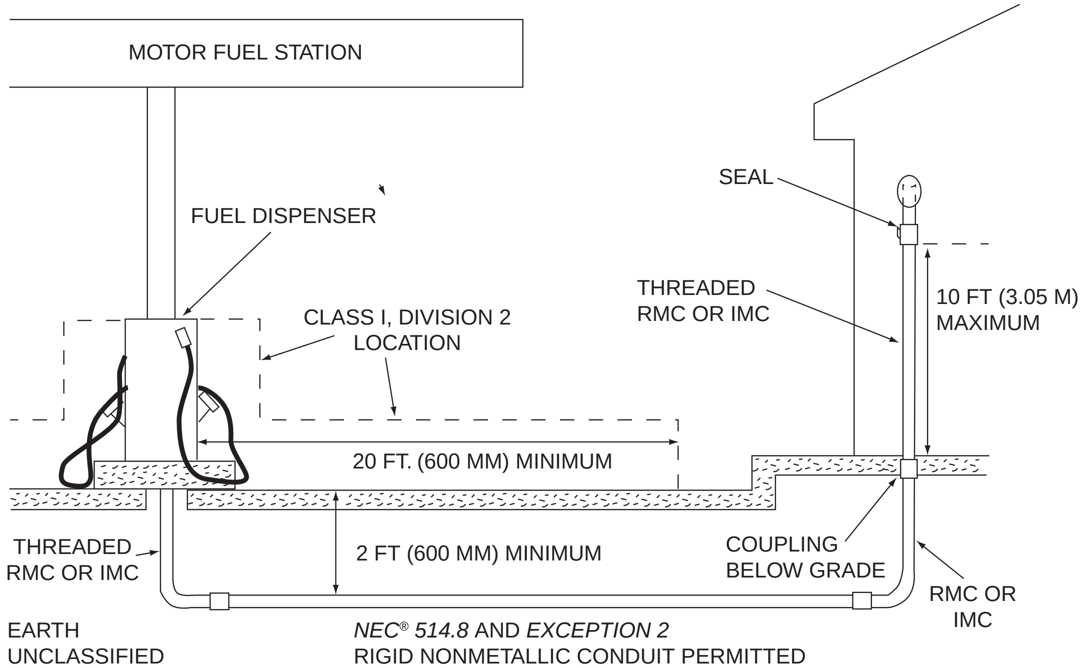


Figure 9.11 The earth beneath the Class I, Division 2 area of a motor-fuel–dispensing station is considered an unclassified area; however, there are requirements placed on the sealing of any conduit passing through the earth beneath the classified area.

area. Rigid nonmetallic conduit is permitted to be run under the floor of the auto repair area of a commercial garage, and there is no depth requirement. Rigid Nonmetallic Conduit is not permitted to be installed in a Class I, Division 2 hazardous area. If a run of Rigid Nonmetallic Conduit emerges up through the concrete floor above which is a Class I, Division 2 area, Rigid Nonmetallic Conduit is not permitted to be within 2 ft (600 mm) of grade, and that portion of the conduit run less than 2 ft (600 mm) must be Rigid Metal Conduit or Intermediate Metal Conduit.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 500 Hazardous Locations, Classes I, II, and III, Divisions 1 and 2

When a rule in this *Article* is derived from another NFPA standard, the specific reference in that other standard is listed at the end of the section.

500.7(K): When combustible gas detection equipment is used as a protection technique, it is now required to be listed for Class I and the appropriate Division for which it is intended to be used in addition to being listed for the specific gas for which it is intended to detect.

500.8(A): This is a new section that gives a recommendation as to the criteria for judging the suitability of equipment for installation in a particular classified location. Some equipment suitable for use may not be listed and labeled.

Article 501 Class I Locations

501.10(B)(7): Schedule 80 PVC and reinforced thermosetting resin conduit (RTRC) with suffix -XW is now permitted for some Class I, Division 2 locations where corrosion of metallic conduits can be an issue. These installations are limited to industrial locations with limited public access, and the facility is maintained only

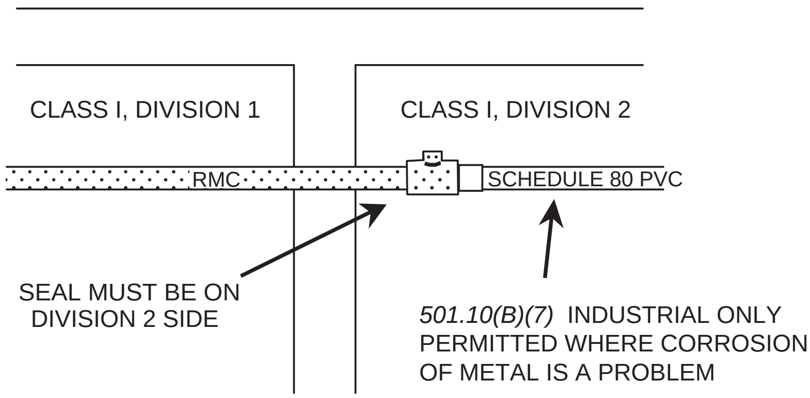


Figure 9.12 In an industrial area with restricted access to the public and a supervised staff to maintain the wiring, where corrosion is a problem with metal conduit, it is now permitted to use schedule 80 PVC and RTRC rigid nonmetallic conduit with suffix – XW in Class I, Division 2 areas and Zone 2 areas where the seal is installed on the Division 2 or Zone 2 side of the boundary.

by supervised qualified personnel. When a conduit run extends from a Division 1 to a Division 2 area, the wiring method used in the Division 1 area shall extend into the Division 2 area up to the point of the required sealing fitting. The sealing fitting shall be located in the Division 2 area, as shown in Figure 9.12.

Article 502 Class II Locations

502.120(B)(2): Effective January 1, 2011, transformers and resistors installed in a Class II, Division 2 location will be required to be mounted in a dusttight enclosure. Present enclosures are not required to be dusttight; they must be tight metal housings without ventilation openings.

502.150(B)(1): Meters, instruments, and relays used with signaling, alarm, remote-control, and communications systems presently are only required to be installed in enclosures that minimize entrance of dust and have no openings through which sparks or burning materials can escape. After January 1, 2011, these meters, instruments, and relays will be required to be housed in dusttight enclosures.

Article 504 Intrinsically Safe Systems

504.2: There is a new sentence added to the fine print note for the definition of simple apparatus. This is important because something considered a simple apparatus is one that produces too little energy to be considered a hazard and therefore is not required to be listed for use as a part of an intrinsically safe system. Simple single-component electrical devices that are capable of storing energy such as a capacitor or inductor are permitted to be used as a part of an intrinsically safe system as a simple apparatus, provided their ability to store energy is considered into the design of the system.

504.10(A) FPN No. 2: This new fine print note is a reminder that components of an intrinsically safe system that are not rated for a maximum shot circuit input test of 250 volts may in some systems require additional over-voltage protection. The issue is that if a high voltage fault is introduced at the input of an apparatus such as a barrier, the output terminals of the device will not reach a voltage that could result in an ignition condition in an intrinsically safe circuit.

504.30(A)(1) Exception 2 & 3: These are two new exceptions to the rule that intrinsically safe circuits are not permitted to be installed in the same raceway or cable tray with circuits that are not intrinsically safe. These exceptions point out that if the rules of separation stated in *504.30(B)* are followed, in a Division 2 or Zone 2 location these intrinsically safe circuits are permitted to share the same raceway, cable tray, or cable with circuits that are not intrinsically safe.

504.30(A)(2): Within an enclosure, there are likely to be both circuits that are intrinsically safe and some that are not intrinsically safe. The previous edition of the Code required that these conductors be kept separated by a distance of not less than 2-in. (50 mm). That is not always practical. The change is that now there are several alternative methods of maintaining separation of conductors without requiring a 2-in. (50 mm) separation. These methods are by use of a metal partition, an approved insulating barrier, or one of the sets of conductors, intrinsically safe or non-intrinsically safe, be run in metal clad or shielded cable where the cable sheath is capable of acting as a fault current path.

504.50(B): In the previous edition of the Code, it was required that cable shields be grounded. It was the intent that associated apparatus be grounded, but that was never stated. Now it is stated that associated apparatus must be grounded.

504.70: Since intrinsically safe circuits are not capable of causing an ignition in a classified area, the seal that is required is not required to be explosion-proof when these circuits pass from a Division 1 to a Division 2, a Division 2 to an unclassified area, or from a Division 1 to an unclassified area. The purpose of the seal is to prevent the passage of flammable vapors or dust. A new requirement was added stating that the seal is required to be accessible and identified for the purpose.

Article 505 Class I, Zone 0, 1, and 2 Locations

505.7(A): Area classification, installation design, selection of wiring methods and equipment, installation, and inspection are to be performed by persons who are qualified, but no longer does the Code require that they be Registered Professional Engineers. However, local ordinances, or even the facilities owner, may require that some of these tasks be performed by a licensed engineering firm. This *Article* applies to Class I areas installed using the Zone system.

505.8(H): Equipment that is encapsulated and marked **"ma"** is permitted to be installed in a Class I, Zone 0, Zone 1, or Zone 2 location. The encapsulation prevents any internal arcing or any internal heating from reaching the flammable vapor to cause an ignition.

505.8(I): Equipment that is encapsulated and marked **"mb"** is permitted to be installed in a Class I, Zone 1, or Zone 2 location. The encapsulation prevents any internal arcing or any internal heating from reaching the flammable vapor to cause an ignition.

505.8(K): A combustible gas detection system is permitted in certain cases to serve as a means of protection, but now there is the requirement that the detection equipment be listed for the particular gas to be detected.

505.9(F): This section recognizes fiber optic cable assemblies that contain conductors capable of carrying current and specifies how these cable assemblies are to be installed in a classified area.

505.15(C)(1)(g): Schedule 80 PVC and reinforced thermosetting resin conduit (RTRC) with suffix -XW is now permitted for some Class I, Zone 2 locations where corrosion of metallic conduits can be an issue. These installations are limited to industrial locations with limited public access, and the facility is maintained only by supervised qualified personnel. When a conduit run extends from a Zone 1 to a Zone 2 area, the wiring method used in the Zone 1 area shall extend into the Zone 2 area up to the point of the required sealing fitting. The sealing fitting shall be located in the Zone 2 area in a similar manner as shown in Figure 9.12.

505.17(6): In a Class I, Zone 1, and Zone 2 area, flexible cords are permitted, and they can be terminated at an enclosure rated as "e" increased safety. There were no rules on how this flexible cord was to be terminated, and now it is required that the termination be also rated as "e" increased safety.

Article 506 Zone 20, 21, and 22 Locations for Combustile Dusts or Ignitible Fibers/Flyings

506.2: Several new definitions of protection types are provided; they are protection by encapsulation **"mD,"** protection by enclosure **"tD,"** protection by intrinsic safety **"iD,"** and protection by pressurization **"pD."**

506.8(E): An encapsulation system of protection marked **"maD"** is permitted for equipment installations in Zone 20, Zone 21, and Zone 22 locations.

506.8(F): An encapsulation system of protection marked **"mbD"** is permitted for equipment installations in Zone 21 and Zone 22 locations.

506.8(I): A protection by enclosure system of protection marked **"tD"** is permitted for equipment installations in Zone 21 and Zone 22 locations.

506.8(J): A protection by pressurization system of protection marked **"pD"** is permitted for equipment installations in Zone 21 and Zone 22 locations.

506.8(K): A protection by intrinsic safety system of protection marked **"iD"** is permitted for equipment installations in Zone 20, Zone 21, and Zone 22 locations.

506.9(C)(2): This section is new, and it specifies the markings that are required on equipment intended to be installed in Zone 20, Zone 21, and Zone 22 locations. It is to be marked AEx to indicate it is built to American standards, the protection technique from *Table 506.9(C)(2)(2),* the Zone for which it is permitted to be installed, the temperature classification from *Table 500.8(C),* and if the ambient temperature range is other than −20ºC to +40ºC, then state the upper and lower ambient temperature limits for which it is suitable. An example of these markings on an enclosure is shown in Figure 9.13.

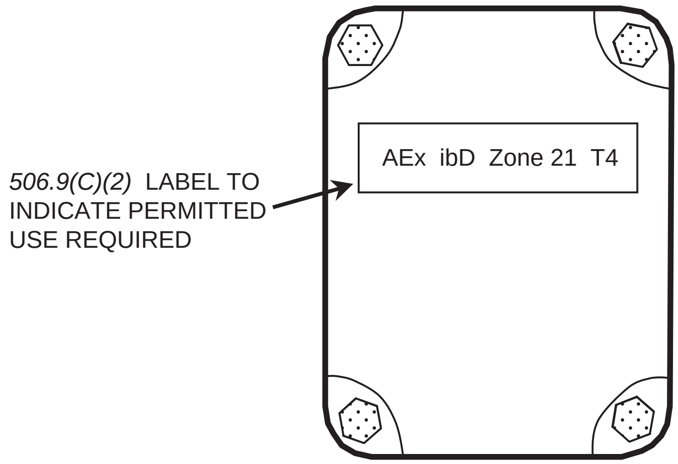


Figure 9.13 In an area designated as Zone 20, Zone 21, or Zone 22, it is required to provide markings on equipment that indicate protection technique, Zone, and temperature limitation.

Table 506.9(C)(2)(2): This new table lists protection techniques, their designations, and the Zone for which each it permitted to be installed.

506.9(F): This section recognizes fiber optic cable assemblies that contain conductors capable of carrying current and specifies how these cable assemblies are to be installed in a classified area.

Article 511 Commercial Garages, Repair and Storage

When a rule in this *Article* is derived from another NFPA standard, the specific reference in that other standard is listed at the end of the section.

511.2: Two new definitions were added to distinguish between a major automotive repair facility and a minor repair facility. A major difference is that for a major repair facility, there may be painting and draining of fuel tanks. These definitions are used in the following section that defines the extent of the classified hazardous areas within the building.

511.3: This section specifies the limits of the Class I, Division 1 and Division 2 areas of a commercial garage or facility where lubrication and minor repairs are performed on motor vehicles. The entire section was reorganized and basically separated into descriptions of facilities that perform major repairs and those that perform minor repairs. There are actually no changes in the rules.

Article 513 Aircraft Hangars

513.2: There are aircraft hangars that are used exclusively for painting aircraft and are provided with unique ventilation systems. This is a new definition to separate such a facility from other types of aircraft hangars. The building is basically a giant spray booth for uniquely shaped objects, and there is considerable space inside the facility that is not near the aircraft and the spraying operation.

513.3(C)(2): This new section defines the limits of the classified hazardous area within the aircraft painting hangar. The dimensions would be determined based upon the largest aircraft that would be placed into the facility. Any area horizontally within 10 ft (3 m) of the aircraft from the floor up to a height of 10 ft (3 m) above the aircraft is considered to be a Class I, Division 1 or Zone 1 classified area. The Class I, Division 2 or Zone 2 classified area extends out an additional 20 ft (6 m) horizontally and vertically from the boundary of the Division 1 or Zone 1 area. Large portions of the interior of the hangar are not considered to be within the classified hazardous area.

Article 514 Motor Fuel Dispensing Facilities

When a rule in this *Article* is derived from another NFPA standard, the specific reference in that other standard is listed at the end of the section. There were no significant changes to these rules.

Article 515 Bulk Storage Plants

When a rule in this *Article* is derived from another NFPA standard, the specific reference in that other standard is listed at the end of the section. There were no significant changes to these rules.

Article 516 Spray Application, Dipping, and Coating Processes

When a rule in this *Article* is derived from another NFPA standard, the specific reference in that other standard is listed at the end of the section. There were no significant changes to these rules.

WORKSHEET NO. 9—BEGINNING HAZARDOUS LOCATION WIRING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. In a Class I, Division 1 area, Rigid Metal Conduit or Intermediate Metal Conduit is required to be installed into hubs or fittings with the number of threads fully engaged not less then:
   A. 3.
   B. 5.
   C. 7.
   D. 8.
   E. 10.

   Code reference__________________

2. A duplex receptacle is installed on a masonry wall in the service area of a commercial garage to provide power for portable tools and ventilation is not provided at a level to render the area unclassified. The commercial garage is used for the major repair of gasoline, hybrid, and diesel-powered engines. The receptacle is installed in a surface-mounted metal masonry box and supplied with EMT using set screw connectors. This installation is permitted provided the distance from the service area floor to the bottom of the box is not less then:
   A. 12 in. (300 mm).
   B. 18 in. (450 mm).
   C. 24 in. (600 mm).
   D. 3 ft (900 mm).
   E. 5 ft (1.5 m).

   Code reference__________________

3. Current-interrupting contacts of a motor starter for an installation are not enclosed within a hermetically sealed chamber or immersed in oil. In a Class I, Division 1 hazardous location as shown in Figure 9.14, conduit seals are required to be installed in each conduit within a distance from the motor starter of not more than:
   A. 6 in. (150 mm).
   B. 10 in. (200 mm).
   C. 12 in. (300 mm).
   D. 18 in. (450 mm).
   E. 24 in. (600 mm).

   Code reference__________________

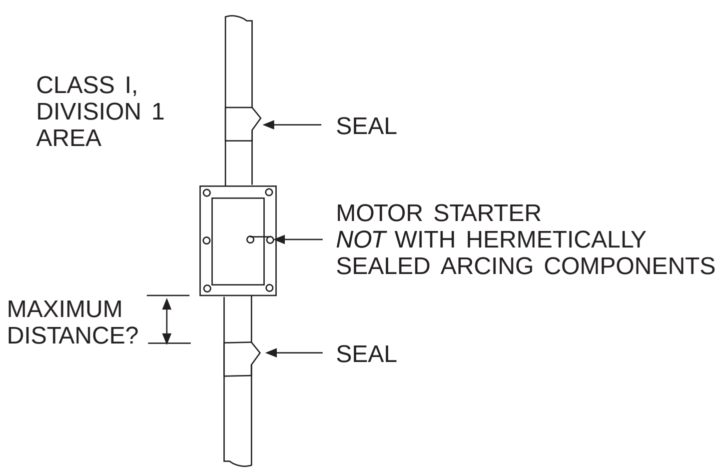


Figure 9.14 This motor starter is installed in a Class I hazardous location.

4. The wiring method permitted to be used in a Class I, Division 1 industrial hazardous location with restricted access to the public is threaded Rigid Metal Conduit, Type MI Cable, Type MC-HL Cable, Type ITC Cable, or:
   A. Electrical Metallic Tubing.
   B. enclosed gasketed busways.
   C. threaded Steel Intermediate Metal Conduit.
   D. Liquidtight Flexible Metal Conduit.
   E. Flexible Metal Conduit.

   Code reference ___________________

5. An area within a textile manufacturing building containing electrical operated equipment where combustible cotton fibers are frequently in the air is considered to be a:
   A. Class III, Division 1 location.
   B. Class II, Division 2 location.
   C. Class I, Division 2 location.
   D. Class II, Division 1 location.
   E. Class I, Division 1 location.

   Code reference ___________________

6. An area of a feed processing facility is considered a Class II, Division 1 location. A dust-ignitionproof motor starter is supplied with Rigid Metal Conduit where the last 10 ft (3.05 m) is a horizontal run with no fittings as shown in Figure 9.15. The fittings in the run of conduit do not contain splices and are listed as dusttight. A seal in the conduit run is:
   A. shall be placed within 18 in. of the dust-ignitionproof enclosure.
   B. required to be listed as explosionproof.
   C. required to be installed within 10 ft (3 m) of the dust-ignitionproof enclosure.
   D. not required because the horizontal conduit is considered an adequate seal.
   E. required to be any permanent compound installed in either end of the last portion of the conduit run.

   Code reference ___________________

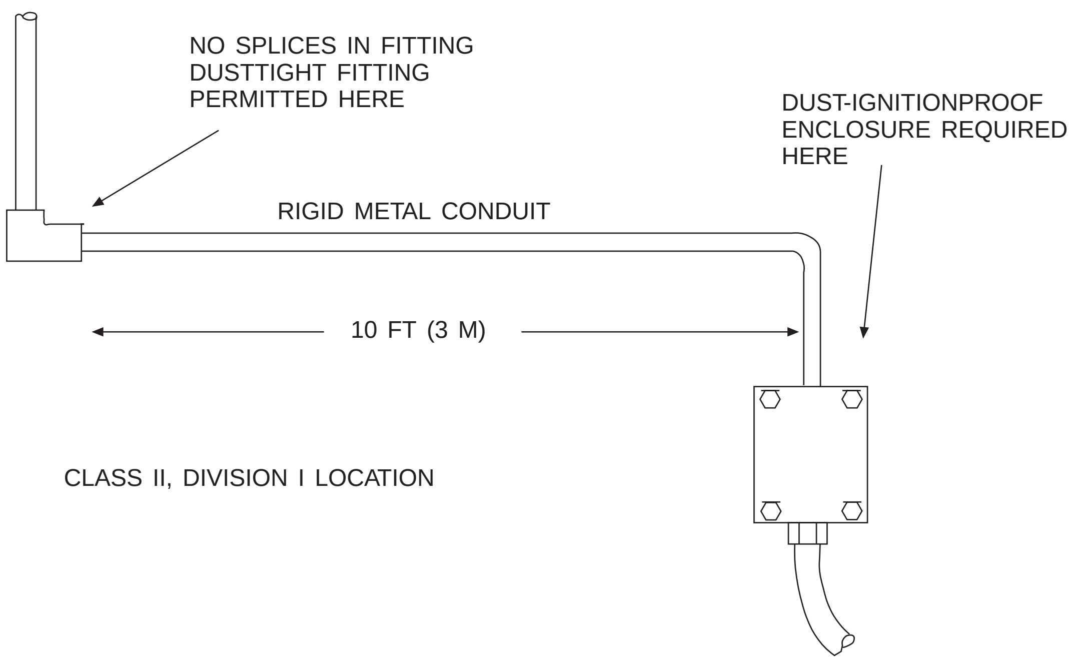


Figure 9.15 A 10-ft (3.05 m) horizontal length of Rigid Metal Conduit connects an unclassified fitting to a NEMA 9 enclosure in a Class II hazardous location.

7. Intrinsically safe wires in route to a Class I, Division 1 classified hazardous location are installed in Electrical Metallic Tubing. A power circuit not serving a hazardous location is run in Rigid Nonmetallic Conduit parallel with the intrinsically safe circuits. The minimum separation distance required to be maintained between the two raceway runs is:
   A. not specified in the Code.
   B. 1/2 in. (13 mm).
   C. 3/4 in. (19 mm).
   D. 1.97 in. (50 mm).
   E. 6 in. (152 mm).

   Code reference ___________________

8. A conduit run supplies wiring in a Class III, Division 1 classified hazardous location. In route to the Class III area the conduit enters and leaves a metal pull box. Bonding at the pull box is considered adequate:
   A. if a locknut is installed on the inside and outside and made up tight with no concentric knockouts in place.
   B. if a locknut is installed on the inside and outside and is made up tight.
   C. only if the pull box has threaded hubs.
   D. if bonding bushings are installed on the conduit entries and a bonding conductor connects the two bonding bushings together.
   E. if a locknut is installed on the inside and a metal bushing is installed on the outside.

   Code reference ___________________

9. To prevent sparking when fault current flows, all threaded conduit installed in classified hazardous locations shall have:
   A. all threaded connections treated with a conductive sealing compound.
   B. a copper bonding conductor run either inside or on the outside of the conduit.
   C. all threaded connections made up wrench tight.
   D. bonding jumpers installed when circuits operate at less than 250 volts.
   E. exposed threads coated with corrosion protection after installations in wet locations.

   Code reference ___________________

10. Oil immersion is a protection technique that is permitted to be used in areas classified as:
   A. Class II, Zone 1 or 2.
   B. Class I, Zone 0, 1, or 2.
   C. Class I, Zone 1 only.
   D. Class I, Zone 0 or 1.
   E. Class I, Zone 1 or 2.

   Code reference ___________________

11. Examine the seal shown in Figure 9.16. Unless specifically approved for a higher fill, the cross-sectional area of the conductors in a sealing fitting installed in a Class I hazardous location shall not exceed the cross-sectional area of a Rigid Metal Conduit of the same trade size by more than:
   A. 20%.
   B. 25%.
   C. 40%.
   D. 60%.
   E. 80%.

   Code reference ___________________

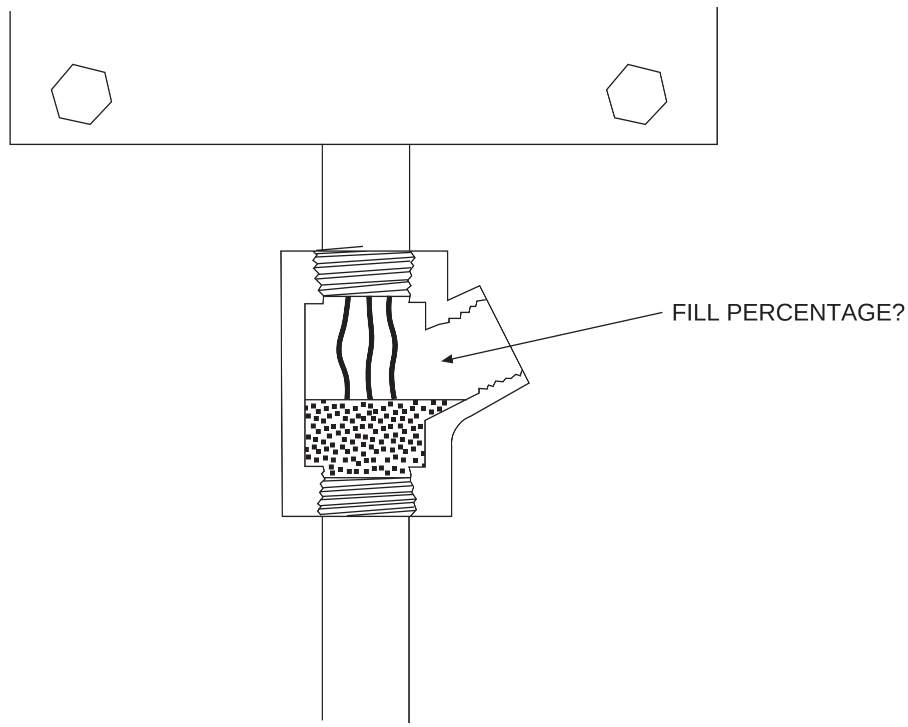


Figure 9.16 A standard Class I sealing fitting installed in a hazardous location.

12. Conductors supplying a gasoline-dispensing unit are run underground in Rigid Metal Conduit from the service station building to the dispenser. A seal is required to be installed in this conduit run:
    A. only at the dispenser where the conduit emerges from the concrete.
    B. only if the service station area where the conduit emerges from the earth is not under positive ventilation.
    C. only at the service station where the conduit emerges from the concrete.
    D. within 10 ft (3 m) of the boundary where the conduit leaves the Class I, Division 2 area.
    E. both at the dispenser and at the service station where the conduit emerges from the concrete.

Code reference ___________________

13. Equipment installed in classified hazardous locations shall be marked to show the class, operating temperature or temperature class, ambient temperature range, and the flammable material classification:
    A. name.
    B. classification.
    C. division.
    D. zone.
    E. group.

Code reference ___________________

14. A roof is installed above an area containing gasoline dispensers. High-intensity discharge luminaires (lighting fixtures) are connected to boxes with a short length of flexible wiring. A wiring method not permitted to be installed for this purpose in this location is:
    A. Flexible Metal Conduit.
    B. Type MC Cable.
    C. Type AC Cable.
    D. Electrical Nonmetallic Tubing.
    E. Nonmetallic-Sheathed Cable, Type NM.

Code reference ___________________

15. Paint spraying is conducted in a factory in an open-front booth that is equipped with a ventilation system that is interlocked with the spray application equipment. Luminaires (lighting fixtures) are installed outside of the spray booth and 2 ft (600 mm) in front of the opening to illuminate the interior of the booth. Luminaires (lighting fixtures) suitable for installation in an unclassified area are permitted for this application provided they are mounted a minimum height above the top edge of the booth opening a distance not less than:

A. 3 ft (914 mm).
B. 5 ft (1.525 m).
C. 8 ft (2.438 m).
D. 10 ft (3.048 m).
E. 12 ft (3.658 m).

Code reference ___________________

WORKSHEET NO. 9—ADVANCED HAZARDOUS LOCATION WIRING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. Equipment that is supplied having metric threaded entries:
   A. shall not be permitted to be installed.
   B. shall be provided with an adapter for connection to NPT threads.
   C. shall be installed only with conduits with metric threads.
   D. is permitted to be installed with conduits having metric threads.
   E. is only required to be identified as having metric threads.

   Code reference ___________________

2. Luminaires (lighting fixtures) installed in a Class II, Division 1 location where grain dust that can dehydrate and carbonize is present shall have a surface temperature classification not exceeding the ignition temperature or:
   A. T1.
   B. 500°C.
   C. 165°C.
   D. T2C.
   E. T3A.

   Code reference ___________________

3. A gasoline dispenser at a service station is supplied with 120-volt power from a circuit breaker panelboard where the circuit breaker will act as the disconnecting means for the dispenser. A locking mechanism that stays in place with or without a lock is installed at each circuit breaker supplying a fuel dispenser. The circuit breaker permitted to serve as the dispenser disconnect is:
   A. a single-pole circuit breaker.
   B. a single-pole, ground-fault circuit-interrupter breaker.
   C. a single-pole, arc-fault interrupter.
   D. an instantaneous-trip circuit breaker.
   E. a switched-neutral circuit breaker.

   Code reference ___________________

4. Unless specifically stated otherwise, intrinsically safe wiring installations are:
   A. permitted as open conductors without a cable jacket or raceway protection.
   B. required to be installed in Rigid Metal Conduit or steel Intermediate Metal Conduit.
   C. required to be installed in metal raceway or as metallic sheathed cable.
   D. permitted to be run in Electrical Metallic Tubing.
   E. required to be Type MI or Type MC when run as cable wiring.

   Code reference ___________________

5. Rigid Metal Conduit or steel Intermediate Metal Conduit is required to be installed into hubs or fittings with 5 threads fully engaged for field wiring in a hazardous location classified as:
   A. Class I, Division 1 or 2.
   B. Class I, Division 1.
   C. Class I, Division 1 or 2, or Class II, Division 1.
   D. Class I, Division 1 or 2, or Class II, Division 1 or 2.
   E. Class I, Class II, or Class III, both Divisions 1 or 2.

   Code reference ___________________

6. A conduit run supplies wiring for a Class III, Division 1 hazardous location, as shown in Figure 9.17. The conduit contains size 8 AWG, Type THWN copper conductors, which are protected by a 50-ampere overcurrent device in a 200-ampere panelboard. The minimum size of copper bonding jumper required to be installed in this pull box is:
   A. 12 AWG.
   B. 10 AWG.
   C. 8 AWG.
   D. 6 AWG.
   E. 4 AWG.

   Code reference ________________

7. A magnetic motor starter in a NEMA 1 enclosure is to be installed on a wall near the open end of a paint spray booth. The paint spray booth is equipped with ventilation that is interlocked with the sprayer such that the sprayer will not operate unless the ventilation is operating. The minimum horizontal distance permitted from the edge of the paint spray booth opening to the NEMA 1 enclosure is:
   A. 3 ft (900 mm).
   B. 5 ft (1.5 m).
   C. 10 ft (3 m).
   D. 20 ft (6 m).
   E. not specified.

   Code reference ________________

8. A parking garage with no mechanical ventilation provided is used for the parking and storage of gasoline and other fuel powered vehicles. If no maintenance is performed in this garage, the space up to a height of 18 in. (457 mm) above the floor is considered to be:
   A. an unclassified location.
   B. a Class I, Division 1, location.
   C. a Class I, Division 2, location.
   D. a Class I, Zone 1, location.
   E. a nonspecified area.

   Code reference ________________

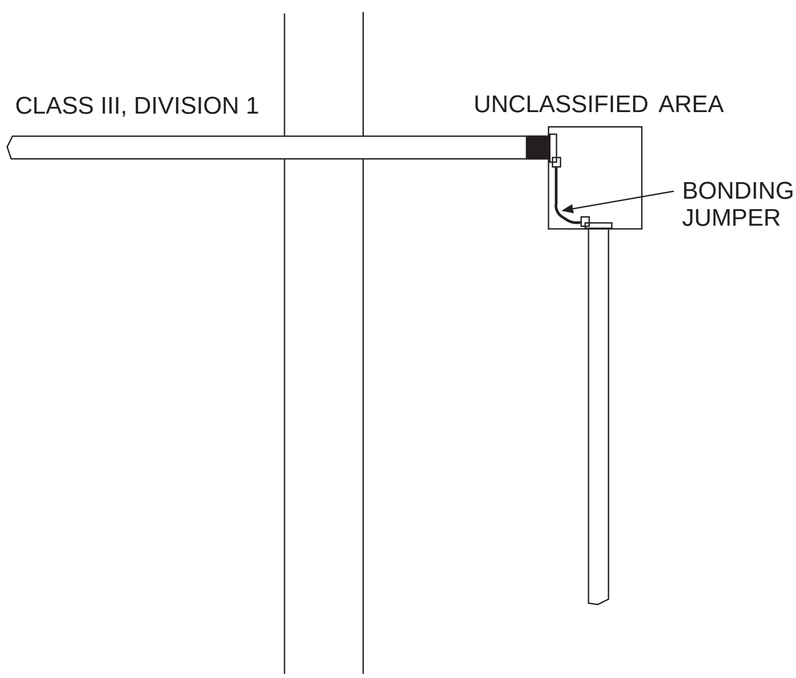


Figure 9.17 A pull box placed outside of a Class III Division 1 hazardous location.

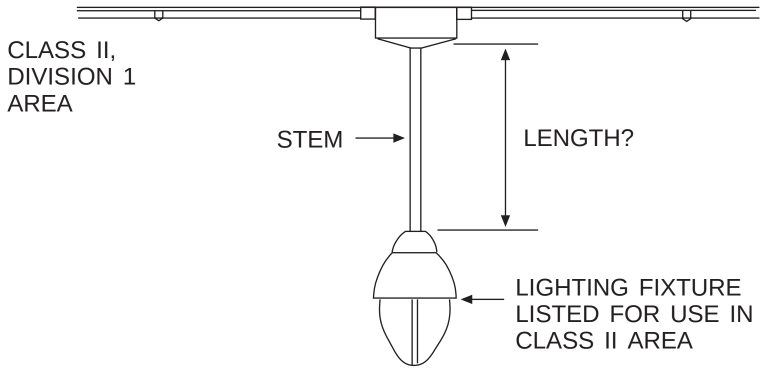


Figure 9.18 The Class II listed luminaire (lighting fixture) is installed in a Class II hazardous location with a Rigid Metal Conduit stem from the box to the luminaire (lighting fixture).

9. A luminaire (lighting fixture) is installed in a Class II, Division 1 area of a grain elevator, as shown in Figure 9.18. The box is properly supported and listed for use in a Class II location. A Rigid Metal Conduit stem is threaded into the cover of the box and is used as the sole support for the luminaire (lighting fixture). There is no flexible connection between the stem and the box, and there is no lateral support for the stem. The maximum length of stem permitted is:
   A. 6 in. (150 mm).
   B. 12 in. (300 mm).
   C. 18 in. (450 mm).
   D. 24 in. (600 mm).
   E. 3 ft (900 mm).

   Code reference ___________________

10. Refer to the illustration of the wiring to the outdoor gasoline dispenser in Figure 9.19. The Class I, Division 2, hazardous location is from the ground level to a height of 18 in. (450 mm) and extends outward from the edge of the gasoline dispenser in all directions a minimum distance of:
   A. 3 ft (900 mm).
   B. 10 ft (3 m).
   C. 20 ft (6 m).
   D. 25 ft (7.5 m).
   E. 50 ft (15 m).

   Code reference ___________________

11. Refer to Figure 9.19 for the wiring supplying the gasoline dispenser where condensed gasoline vapors may collect on the conductors. For the wires inside of the dispenser and run in the underground conduit to the dispenser, electrical conductors:
   A. shall not be smaller than size 10 AWG.
   B. are only required to have a moisture-resistant type of insulation.
   C. shall be marked on the insulation suitable for use in a Class I location.
   D. are required to have lead covering over the insulation.
   E. shall be identified for these conditions such as being gasoline resistant.

   Code reference ___________________

12. Fixed wiring installed above a Class I hazardous area of a bulk storage plant is not permitted to be run as:
   A. Intermediate Metal Conduit.
   B. Electrical Metallic Tubing.
   C. Schedule 80 PVC Rigid Nonmetallic Conduit.
   D. Liquidtight Flexible Nonmetallic Conduit.
   E. Metal Clad, Type MC Cable.

   Code reference ___________________

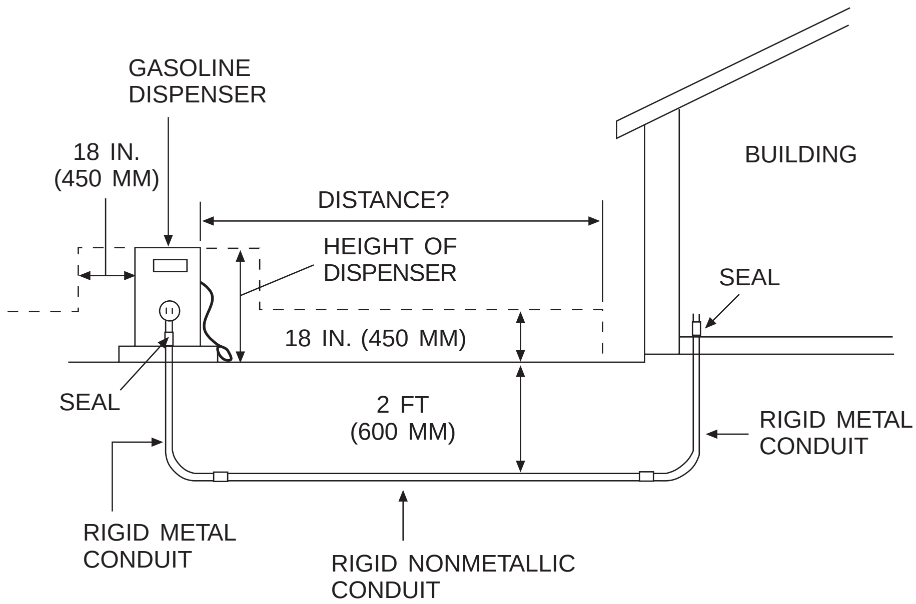


Figure 9.19 Wiring is run underground from the service station to a gasoline dispenser using Rigid Nonmetallic Conduit in direct contact with the earth.

13. A trade size 3/4 (21), Rigid Metal Conduit passes from a Class I, Division 1, hazardous location to an unclassified location. A sealing fitting listed for only a 25% fill is installed on the nonhazardous side of the boundary. The maximum number of size 10 AWG, Type THWN copper conductors that are permitted to be installed in the fitting is:
    A. 4.
    B. 5.
    C. 6.
    D. 7.
    E. 8.

    Code reference ___________________

14. For instances when a structure or location is classified by both the Zone and Division system, it is permitted to have Class I, Division 2 locations border, but not overlap a:
    A. Class I, Zone 1 or 2 location.
    B. Class I, Zone 0 location.
    C. Class I, Zone 1 location.
    D. Class I, Zone 2 location.
    E. any location installed using the Zone system.

    Code reference ___________________

15. During the construction process of an aircraft hangar it is deemed necessary to install a conduit under the floor of the hangar. The proposed conduit would be buried 24 in. (600 mm) below grade level and would be encased in concrete with a thickness of 2 in. (50 mm). The conduit would pass under the hangar from one unclassified location to another unclassified location, as shown in the Figure 9.20. The conduit:
    A. is permitted to be Rigid Nonmetallic Conduit for the below grade installation and Rigid Metal Conduit or steel Intermediate Metal Conduit where it emerges from the earth.
    B. is only permitted to be installed in this manner by use of Rigid Metal Conduit or Steel Intermediate Metal Conduit.
    C. is required to be relocated so it does not pass under the hangar.
    D. system is not permitted to be installed in this location if the raceway is Rigid Nonmetallic Conduit.
    E. is permitted to be installed as Rigid Nonmetallic Conduit for the entire run including the points where the conduit emerges from the ground in the unclassified locations.

    Code reference ___________________

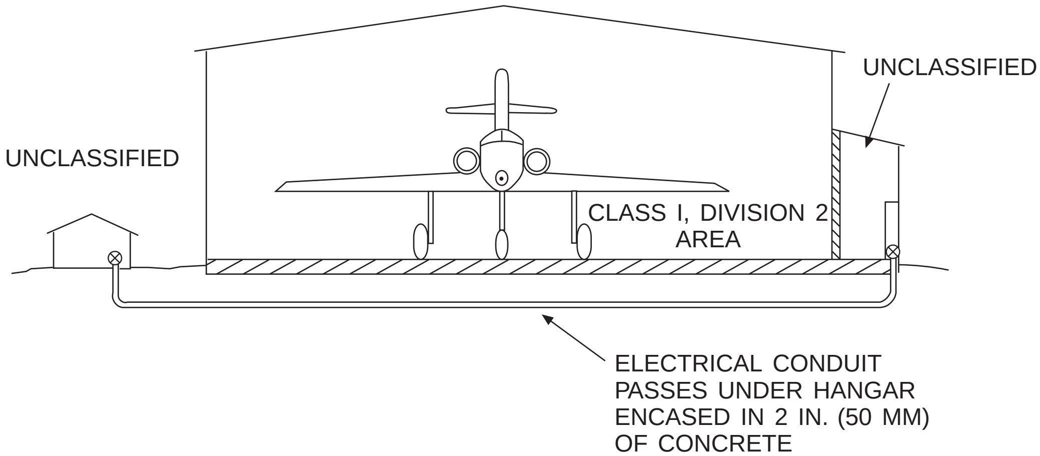


Figure 9.20 An electrical conduit passes completely under an aircraft hanger and emerges from the ground outside of the hazardous location.

UNIT 10

Health Care Facilities

OBJECTIVES

After completion of this unit, the student should be able to:

- name two types of patient care areas of a health care facility.
- describe when an anesthetizing location is also considered to be a hazardous location.
- give examples of the types of electrical equipment to be supplied by the life safety branch of the essential electrical system of a health care facility.
- give an example of the type of electrical equipment to be supplied by the critical branch of the essential electrical system of a health care facility.
- explain the purpose of a reference grounding point for a patient care area of a health care facility.
- name a specific location of a health care facility where a receptacle outlet is required to be listed for hospital use.
- describe how equipment grounding is required to be installed from a receptacle outlet at a bed location of a critical care area to the service panel that supplies the receptacle.
- state the minimum number of receptacle outlets required at the bed location of a general care area of a hospital.
- state the minimum number of circuits required at a patient bed location of a critical care area to be supplied by the critical branch of the essential electrical system.
- answer wiring questions about installations in health care facilities from Code *Articles 517* or *660.*
- state at least three significant changes that occurred from the 2005 to the 2008 Code for *Articles 517* or *660.*

CODE DISCUSSION

An essential step to understanding the wiring requirements of a health care facility is knowledge of the definitions at the beginning of *Article 517*. This article addresses the following types of health care facilities: (1) clinics, medical offices, dental offices, and outpatient facilities; (2) nursing homes and residential custodial care facilities; and (3) hospitals. Other articles also are essential to the wiring installation for health care facilities. These are *Article 700*, which covers emergency systems and illumination for building egress, *Article 701*, covering legally required standby electrical systems, and *Article 760* on fire alarm systems.

Article 517 covers specific electrical wiring requirements for health care facilities that are not covered elsewhere in the Code. *Part I* of this article provides definitions necessary for the understanding and uniform application of the Code to health care facilities. In a multifunction building, the appropriate part of this article shall apply to an area with a specific function.

Part II specifies the wiring methods that can be used in health care facilities. *NEC®517.13(A)* specifies that branch-circuits supplying patient care areas shall be run in metal raceway such as Rigid Metal Conduit, Intermediate Metal Conduit, Electrical Metallic Tubing, or cable assemblies such as Type AC, Type MI Cable, or Type MC where the outer metal jacket is an approved grounding means. Grounding and bonding requirements for receptacles and equipment in patient care areas are also covered in *Part II. NEC® 517.13(B)* requires that all receptacles supplying power at over 100 volts to patient locations shall be grounded with an insulated copper equipment grounding conductor run with the circuit conductors in metal raceway. The insulated copper equipment grounding conductor is also permitted to be run in Type AC, Type MC, or Type MI

Cable that has a metal sheath that is approved for grounding. With electrical equipment frequently attached to patients, redundant grounding is important. The insulated copper conductor acts as a path for fault current as well as the metal conduit or approved metal sheath of the cable. This redundancy in the grounding also reduces the resistance of a ground fault path which helps keep voltages during a fault at extremely low levels.

Generally a patient location is served by branch-circuits from more than one panelboard. It is likely that a patient could be connected to electrical equipment that is supplied from at least two separate panelboards. It is necessary that the equipment grounding bus in each panelboard be at the same potential. This is accomplished by bonding together of the equipment grounding bus of any panelboard that serves receptacles in the same patient location. *NEC® 517.14* specifies a minimum size 10 AWG copper bonding conductor be used between equipment grounding terminals in panelboards serving the same patient location.

The patient vicinity is defined in *517.2* as the area within 6 ft (1.8 m) of the patient bed. In a general care area, a minimum of four receptacles is required to serve the patient bed location. These may be single receptacles, or they may be multiple receptacles on the same yoke. For example, a duplex receptacle would count as two receptacles. The receptacles are required to be listed as hospital grade. A minimum of two branch-circuits is required to serve a patient bed location in a general care area. At least one of the branch-circuits is required to be supplied by the normal electrical system and one from the emergency system, as stated in *517.18*, unless the room is supplied from two separate emergency power sources. These branch-circuit and receptacle requirements are illustrated in Figure 10.1. *Exception 3* of *517.18(A)* permits both required circuits of a general care area to be supplied from the emergency system. The stipulation is that the two circuits be supplied from two completely separate emergency systems with separate transfer switches and panelboards. An installation meeting these requirements for a general care area is illustrated in Figure 10.2.

A critical care area is required to have six receptacles at the patient bed location, as shown in Figure 10.3. At least two circuits are required, one of which is required to be supplied from the emergency electrical system, as stated in *517.19*. The receptacles are required to be listed as hospital grade. At least one receptacle at the patient bed location is required to be supplied from the normal power system or other emergency system.

Part III provides the requirements for the types of electrical systems for a health care facility. There is a normal power system providing power for various circuits throughout the health care facility. An emergency electrical system is required in certain types of health care facilities, such as hospitals. This emergency electrical system is permitted to consist of a life safety branch and a critical branch. These systems are illustrated in Figure 10.4 for a hospital with an essential electrical system demand load not exceeding 150 kVA.

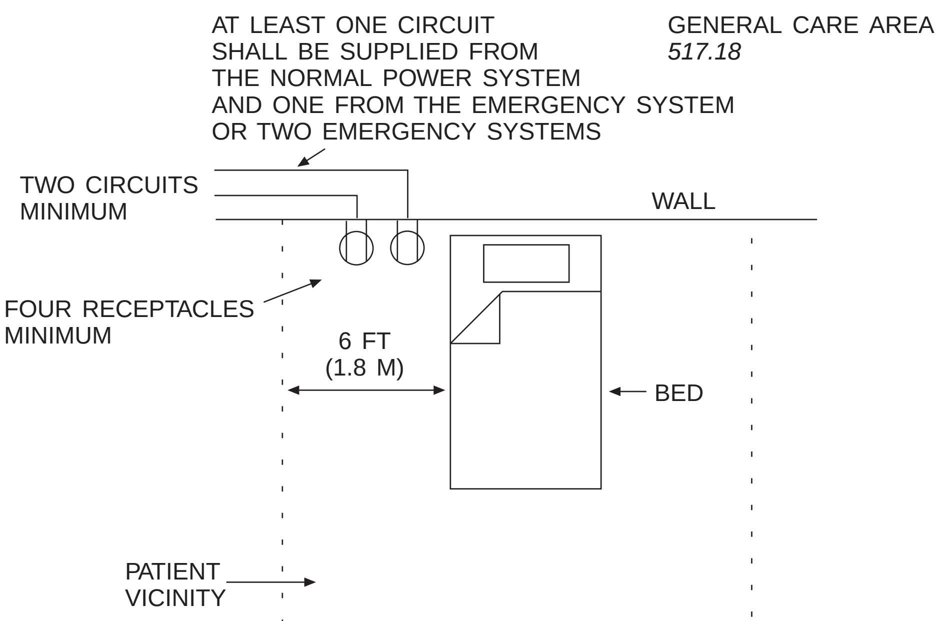


Figure 10.1 Four receptacles and at least two circuits are required to serve a patient bed location of a general care area.

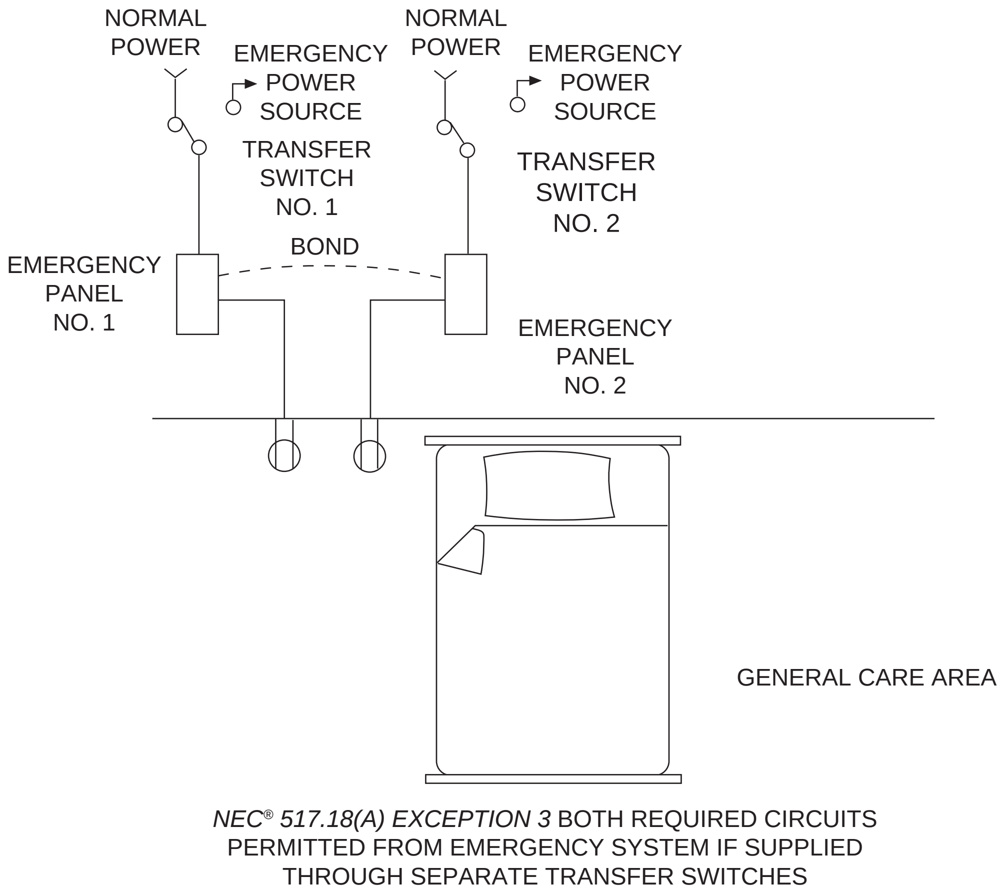


Figure 10.2 The two required bed location circuits in a general care area are permitted to be from the emergency system if the circuits are supplied by separate transfer switches.

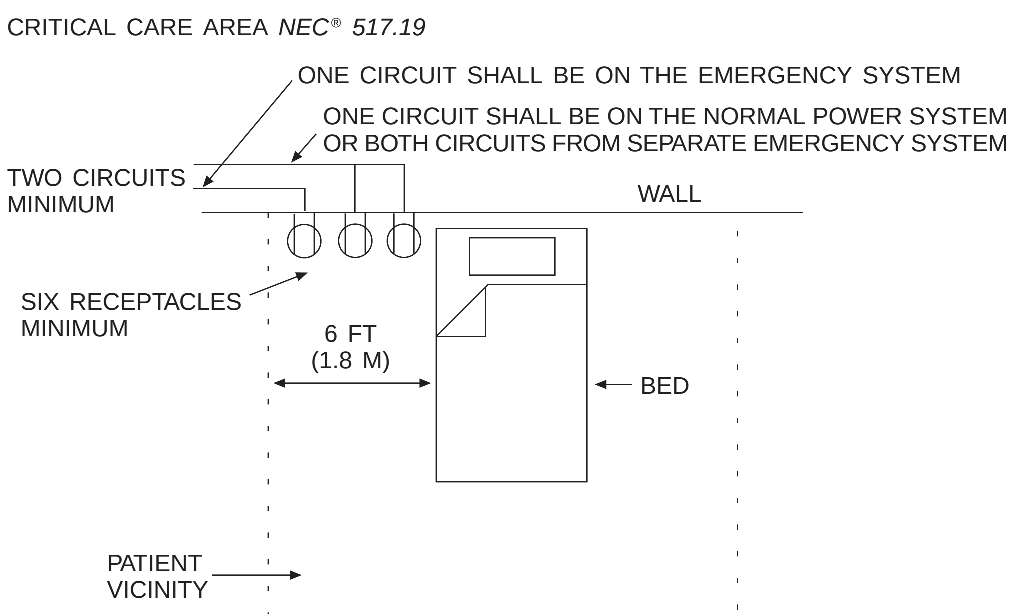


Figure 10.3 Six receptacles are required to serve the patient bed location of a critical care area. These are served by a minimum of two branch circuits, one of which is supplied from the emergency electrical system.

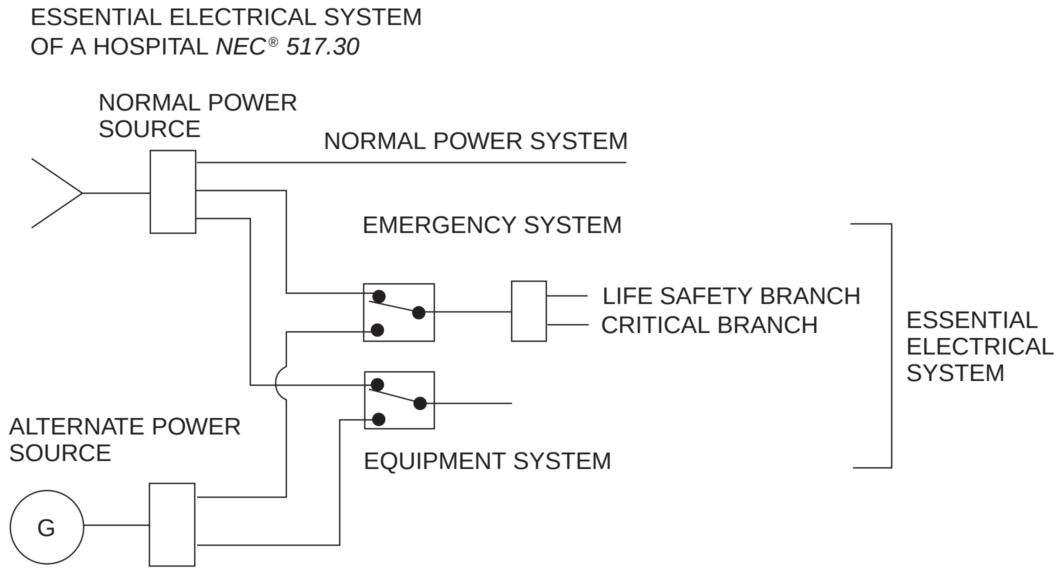


Figure 10.4 The essential electrical system consists of the emergency system and the equipment system. If the essential electrical system demand load is greater than 150 kVA, then each branch is required to be served by a separate transfer switch.

It is permitted to serve both the emergency system and the equipment system from the same transfer switch. If the demand load for the essential electrical system exceeds 150 kVA, then a separate transfer switch is required for the equipment system, the life safety branch, and the critical branch. In addition, an equipment system shall be provided in most types of health care facilities. All three of these systems make up the essential electrical systems. For a hospital, these systems are covered in *517.30* through *517.35*. For nursing homes and limited care facilities, these systems are covered in *517.40* through *517.44*.

Part IV deals with wiring in inhalation anesthetizing locations. Where flammable anesthetics are administered, the area is considered a classified hazardous location. An isolated power system is required where flammable anesthetics are used. Wiring requirements for other than hazardous anesthetizing locations are found in *517.61(C)*.

Part V deals with X-ray installations. Rating of supply conductors, disconnect, and overcurrent protection is covered by this part. Wiring of the control circuit and grounding is also covered. X-ray units have a momentary current rating and a long-time current rating. *NEC® 517.72(A)* requires the disconnecting means to have a current rating not less than 50% of the momentary input rating of the X-ray equipment or 100% of the long-time rating, whichever is greater. *NEC® 517.73(A)(1)* requires the supply conductors to be sized in the same manner as the disconnecting means.

Part VI covers requirements for communications, signaling systems, data systems, fire alarm systems, and systems operating at less than 120 volts. The key issue here is grounding. It is important that a patient not be exposed to hazard through the grounding of electrical equipment.

Isolated power systems are covered in *Part VII*. Isolated power systems are required to supply circuits within areas where flammable anesthetizing agents are used. The requirements on which isolated systems are required are found in *517.61(A)(1)*. The installation of the isolated power system is covered in *517.160*. Circuits serving an anesthetizing location where flammable anesthetics are used are required to be isolated from the electrical distribution system in the building. This can be accomplished by operating the circuits ungrounded. A common means of establishing an ungrounded electrical system is by use of an isolation transformer that has no connection between the primary and secondary windings. *NEC® 517.160(A)(1)* requires all isolated circuits to be controlled by a switch that opens each ungrounded conductor. Each operating room is required to have the circuits supplied by a separate isolation transformer. An induction room that serves an operating room is permitted to have the circuits supplied from the same isolation transformer as the operating room. The isolated circuits are generally 125-volt, single-phase, 2-wire. The conductors are required to be identified by the colors orange and brown. The wires must have colored stripes not white , green, or gray. Solid-colored wires are not permitted. When supplying 125-volt, 15- or 20-ampere receptacles, the orange conductor shall be connected to the silver-colored terminal where a grounded conductor would normally have been terminated. This rule found in *517.160(A)(5)* is illustrated in Figure 10.5.

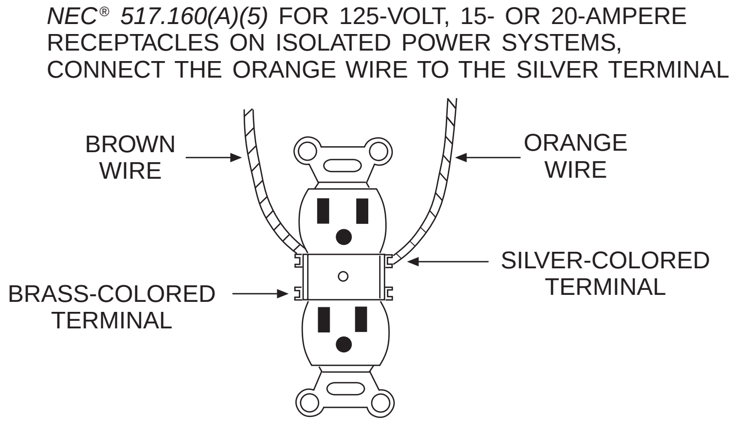


Figure 10.5 The orange conductor with colored stripes of an isolated 125-volt circuit connected to a 15- or 20-ampere receptacle shall be connected to the silver-colored terminal intended for connection of the grounded conductor in a normal power system.

Article 660 covers the installation of X-ray equipment for nonmedical and nondental use. The article provides specifications for minimum circuit rating and wire size, and the disconnect for the equipment. Wiring of the control system and grounding of the equipment are also covered.

Article 680, Part IV covers the wiring to and in the area around therapeutic pools and tubs in health care facilities. Specifications are placed on receptacles and luminaires (lighting fixtures) in the area. Grounding and bonding of equipment is the main emphasis of this part. Bonding and grounding of metal parts within 5 ft (1.5 m) of the inside edge of the hydromassage unit is important for safety. The permitted methods of grounding and bonding are given in *680.62(C)* and *(D)*. Therapeutic tubs and hydromassage tubs are required by *680.62(A)* to be ground-fault circuit-interrupter protected. *NEC® 680.62(E)* requires that any receptacle within 5 ft (1.5 m) is also required to be ground-fault circuit-interrupter protected.

WIRING IN HOSPITALS

Several very important issues deal with wiring in health care facilities and hospitals in particular. Reliability of electrical supply is necessary for equipment and lighting needed for human life support. Lighting and exit marking are needed for egress from the building in case of an emergency. Special measures must be taken to ensure that equipment in a patient area is grounded in such a way that differences in voltage will not be present between equipment such that a hazard to the patient will be created.

Definition of Areas Within a Hospital

Patient vicinity: The area within 6 ft (1.8 m) horizontally from the perimeter of the bed, and within $7\frac{1}{2}$ ft (2.3 m) above the floor. Figure 10.1 and Figure 10.3 illustrate the patient vicinity.

Patient bed location: The intended location of the patient bed, or the procedure table of a critical care area.

General care area: An area where the patient is not generally connected to electrical equipment. If so, the connection is basically external to the body, and there is no apparent hazard of electrical current affecting life-supporting organs of the body.

Critical care area: This is an area where a patient may be put in intimate contact with electrical equipment that may produce a real hazard of electrical shock to essential body organs, or where the reliability of the equipment is necessary for life support. See the Code for specific locations that come within this definition.

Wet location: An area that is made intentionally wet for some specific purpose. Wet locations are covered in *517.20*. Refer to *Article 680, Part VI* for installation requirements for therapeutic pools and tubs in health care facilities.

Anesthetizing location: An area intended for administration of flammable or nonflammable inhalation anesthetic agents in the course of examination or treatment.

Essential electrical system: This electrical system is required to have an alternate source of power. The emergency electrical system and the equipment electrical system are part of the essential electrical system. The building electrical system is made up of the normal power system and the essential electrical system.

This system includes lighting circuits and equipment considered necessary for minimal operation and life safety. Power is provided for the life safety branch and the critical branch. See Figure 10.4. There is usually a delay before power is provided to the equipment systems branch.

Life safety branch: This system provides light and power for the emergency systems of *Article 700*, such as lighting for egress, exit signs, and alarm and communications systems. This is covered in *517.32* and is illustrated in Figure 10.4.

Critical branch: This system supplies power in selected areas for illumination and receptacles considered essential for protection of life. For hospitals, specific locations are specified in *517.33*. A patient bed location in a critical care area shall have at least one branch-circuit supplied from the critical branch, as shown in Figure 10.4.

Hospital Receptacle Requirements

Hospital grade receptacles are required to be installed in patient care areas, above the classified portion of an anesthetizing location, and in certain other locations. These devices are usually identified by a visible green dot, as shown in Figure 10.6. Some devices are made of a clear material to allow employees to determine visually if an electrical malfunction occurs. Required hospital grade receptacles for the general care patient area are found in *517.18(B)*, for the critical care area in *517.19(B)(2)*, and for hospital use above hazardous anesthetizing locations in *517.61(B)(5)*.

Receptacles with equipment grounding terminals insulated from the yoke are permitted to be used in hospitals for such devices as electronic equipment in which electrical noise may be a problem. These receptacle outlets with the insulated grounding terminals are required to be distinctively identified from the front. They have an orange triangle visible on the receptacle, as shown in Figure 10.6. Rules on the installation of isolated ground receptacles are found in *250.146(D)*, *406.10(D)*, and *517.16*. They shall also be identified as hospital grade. In the case of an insulated ground receptacle, grounding of the equipment plugged into the receptacle is dependant only on the insulated copper equipment grounding conductor. There is no redundancy for the equipment ground. These receptacles should only be used where there is a definite need for an isolated ground to prevent electrical noise of sensitive equipment.

In the case of a critical care area, there shall be at least one branch-circuit from the emergency system, and that receptacle or receptacles shall be identified. This is necessary to make sure essential equipment is attached to an emergency circuit if normal power is lost. It is also required that the location of the branch-circuit overcurrent device panelboard be indicated so the device can be reset quickly if necessary to maintain operation of life-saving equipment. These requirements are found in *517.19(A)*.

Grounding in Hospitals

Proper installation of the equipment grounding system, particularly in hospitals, is extremely important. The goal, especially in critical care areas, is to prevent any two pieces of metal equipment that may be contacted simultaneously by a person from developing a voltage difference harmful to a patient. Receptacles and fixed equipment in patient care areas shall be grounded with an insulated copper equipment grounding conductor. Several types of grounding points are discussed in the Code and are defined as follows:

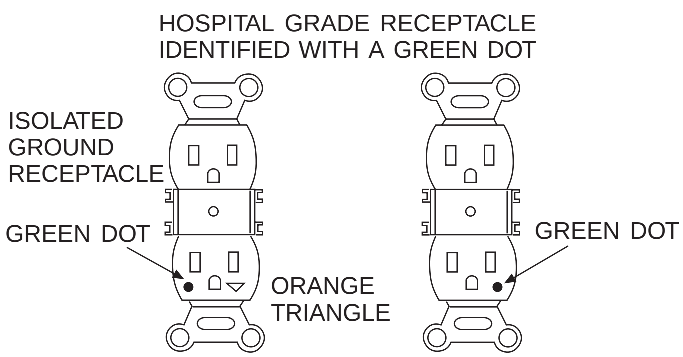


Figure 10.6 A receptacle identified as hospital grade may have the equipment grounding terminal insulated from the yoke of the receptacle and is identified by a green dot and an orange triangle.

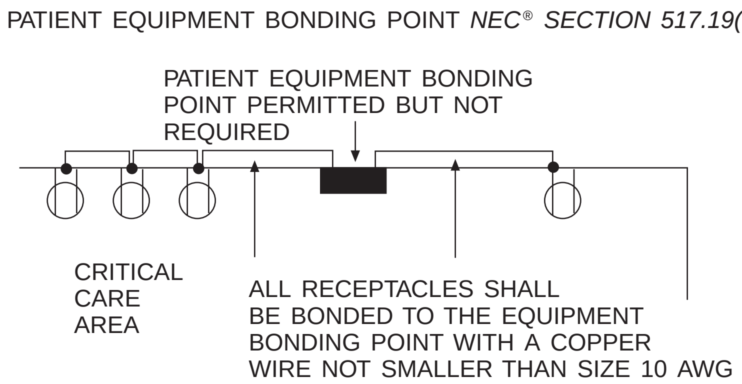


Figure 10.7 If a patient equipment grounding point is provided in a critical care area, the receptacle outlets are required to be bonded to that point.

- Patient equipment grounding point: This is a grounding bus with plug jacks available for the grounding of equipment to be operated in the patient bed location and listed for the purpose. The patient equipment grounding point is not required, as stated in *517.19(C)*. A patient equipment grounding point is illustrated in Figure 10.7.
- Reference grounding point: This is a terminal bus that is a convenient collecting point for equipment grounding conductors and bonding wires. A reference grounding point is required for circuits serving a critical care area. This requirement is found in *517.19(B)(2)*. A reference grounding point is illustrated in Figure 10.8. The reference grounding point is defined in *517.2* as the ground bus in a panelboard serving a patient care area. For an operating room it is the grounding bus of the isolated grounding system. Patient care areas are frequently served from two separate panelboards. This means the grounding bus in each panelboard is a reference grounding point. *NEC® 517.14* requires the grounding bus of any panelboard serving circuits in the same patient vicinity to be bonded together with an insulated copper conductor not smaller than size 10 AWG.

The patient equipment grounding point and the reference grounding point are frequently the same point for critical care areas. When the room is large, these grounding and bonding points may be separated. A patient equipment grounding point is permitted but not required. If installed, the patient equipment grounding point shall be connected directly to the reference grounding point by means of a continuous length of insulated copper conductor. The reference grounding point of the room is bonded to the panelboard grounding bus supplying power to the room. Circuits in the critical care patient area are supplied from a panelboard of the normal power system and a panelboard of the essential electrical system. The equipment grounding buses of each of these panelboards serving the patient care area are required to be bonded together by means of a continuous length of insulated copper conductor, as required by *517.14.* This is illustrated in Figure 10.9.

A patient bed location is permitted to have receptacles supplied from both the emergency and the normal power panelboards. The equipment grounding buses of these panelboards shall be bonded together to make sure a difference in voltage between equipment at the bed location cannot develop to a sufficient level to be harmful to the patient.

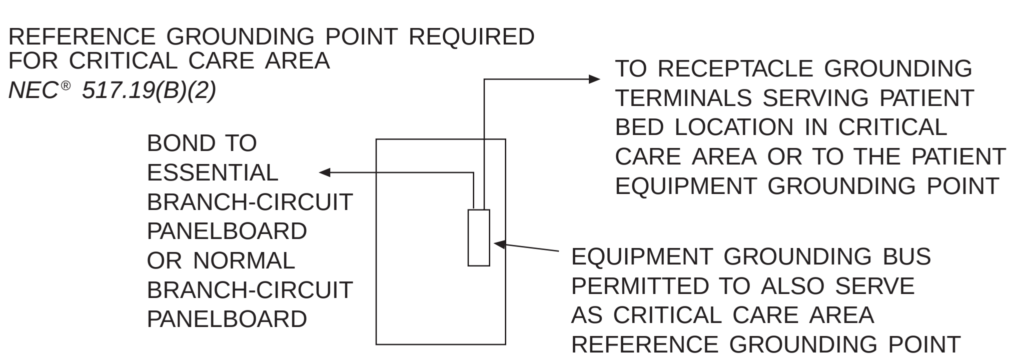


Figure 10.8 A reference grounding point is required to be provided for circuits supplying the patient vicinity of a critical care area.

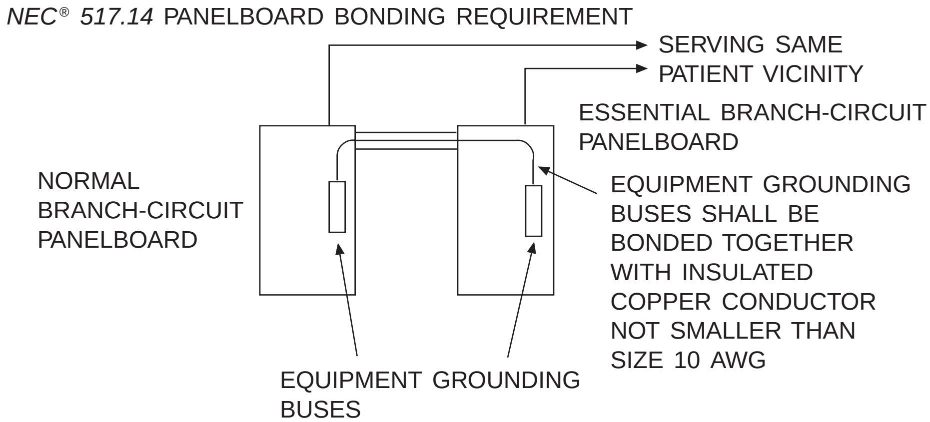


Figure 10.9 The equipment grounding bus of a panelboard serving circuits in a patient vicinity shall be bonded.

Hospital Required Electrical Systems

Essential electrical systems must be connected to the normal power system and the standby power source through a transfer switch. The essential electrical system may consist of a separate critical branch and a life safety branch. If there is a life safety branch, it is not permitted to occupy the same raceway or cable with other wiring. This requirement is found in *517.30(C)(1).* The critical branch and the life safety branch are not permitted to share the same enclosures, raceways, or cables. The emergency wiring system in a hospital shall be in metal raceway. The types of loads permitted to be connected to the life safety branch of a hospital are limited to egress illumination, exit signs, alarm systems, emergency communication systems, and illumination at the generator location. It is important that receptacles supplied by the emergency electrical system be easily recognized. This is illustrated by Figure 10.10. It is required that these receptacles have a distinctive color or be supplied with faceplates that have a distinctive color. Frequently the receptacles supplied by the emergency system are red.

Power circuits within an anesthetizing location classified as a hazardous location shall be isolated from the normal distribution system. The lower 5 ft (1.52 m) of an anesthetizing room where flammable agents are used shall be considered to be a Class I, Division 1 hazardous location, as stated in *517.60(A)(1).*

Ground-Fault Protection

A solidly grounded electrical system operating with conductors more than 150 volts to ground and 1000 amperes or more is required to be provided with equipment ground-fault protection. This subject is discussed in detail in *Unit 4.* This type of protection is intended to detect a ground-fault that is great enough to cause damage or create a hazard, but is too small to be detected quickly by the service overcurrent protective

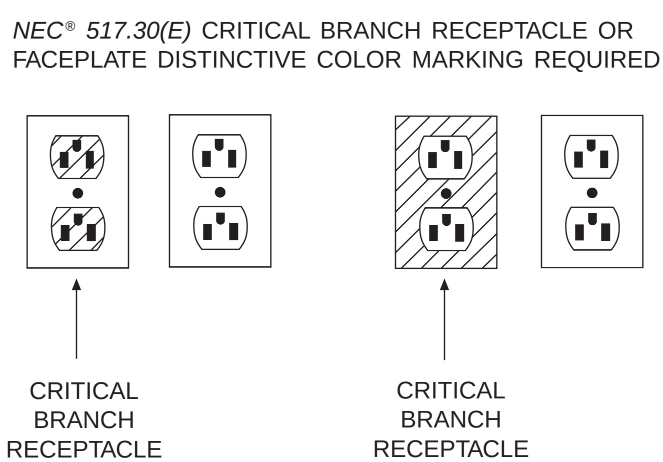


Figure 10.10 Receptacles supplied from the critical branch or the life safety branch of the emergency system are required to be either distinctively marked or have faceplates with a distinctive color.

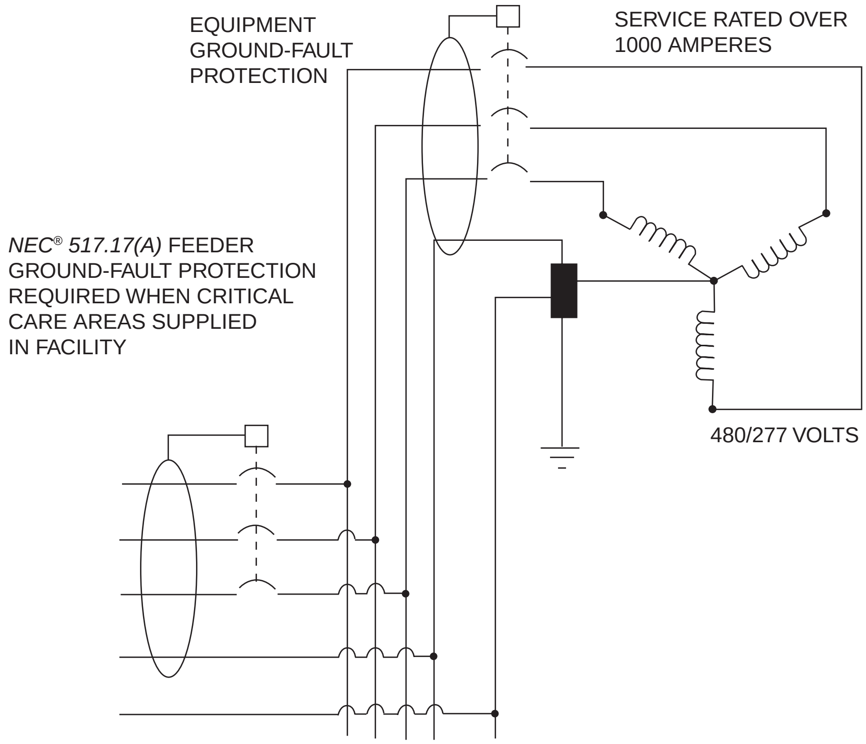


Figure 10.11 The requirement for down-line equipment ground-fault protection on feeders when the service is provided with equipment ground-fault protection only applies in the case where the health care facility supplies power to a critical care area or electrically powered life-support equipment.

device. In the case of a health care facility that supplies power to a critical care area or supplies power for life-support equipment, a hazard is created if a ground fault in some non-essential remote part of the facility should cause an interruption in power by causing the operation of the service ground-fault protection system. This is why in *517.17* equipment ground-fault protection is required on the all feeders supplied directly from the service equipment, except those that are not solidly grounded or the essential electrical system feeders. These ground-fault protective devices must be set to trip out the feeder on a ground-fault at a level that is not likely to trip out the service ground fault protective device. Figure 10.11 is a diagram of the service ground-fault protective device and one feeder ground-fault protective device.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 517 Health Care Facilities

References to other NFPA standards are provided at the end of sections where material in those sections was taken from those standards.

517.2: The definition of ambulatory health care occupancy was revised with the addition of urgent care facility for the treatment of persons who by the nature of their injuries are incapable of self-preservation in an emergency situation.

517.2: Within the definition of patient care area, there is a revision of the definition of wet location. The term now used is wet procedure location to indicate that it is an area where a procedure takes place under wet conditions with the patient present.

517.32(C)(3): It is permitted to connect a mechanical system to the life safety branch of the emergency system, provided that the mechanical system is required to be operated in an emergency to help provide for life safety.

517.32(F): Generator set accessories was added to the list of loads that are permitted to be connected to the life safety branch of the emergency system.

517.34(A)(7): The equipment system of a health care facility is required to be connected to the stand-by power system during an emergency, but delayed operation is permitted for much of the equipment supplied. Added to the list of equipment that is permitted to be supplied after an appropriate time delay is the ventilation system for operating rooms and delivery rooms.

517.40(B): Some nursing homes and limited care facilities provide inpatient care where sustained electric life support equipment is necessary. The rules are the same for the installation of those systems, but the change deals with which parts of the facility are involved. It is made clear that these systems are to be installed only in those portions of the facility where these services are intended to be provided.

517.160(A)(5): An isolated power system installed in an anesthetizing location of a health care facility is required to have the 120-volt circuit wires identified with the colors orange and brown, with the orange wire connected to the silver colored screw (neutral side) of the hospital grade receptacle. Use of a solid color for these wires is no longer permitted. It is now required that the orange and brown wires be ones with a colored stripe that is not white, green, or gray.

WORKSHEET NO. 10—BEGINNING HEALTH CARE FACILITIES

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. For a general care area in a hospital, as illustrated in Figure 10.12, each patient bed location is required to be provided with two branch-circuits:
   A. one of which shall originate from the emergency electrical system.
   B. both of which shall originate from the emergency electrical system.
   C. both of which shall originate from the normal electrical system.
   D. with not less than two receptacles connected to each branch-circuit.
   E. that are permitted to originate from any electrical system desired.

   Code reference ___________________

2. The minimum number of receptacles serving the patient bed location of a critical care area of a hospital is:
   A. not specified.
   B. four.
   C. six.
   D. eight.
   E. six duplex receptacles for a total of twelve.

   Code reference ___________________

3. All emergency system receptacles at the patient bed location of a critical care area of a hospital:
   A. shall be supplied by a minimum of two emergency circuits.
   B. are not permitted to originate from the same panelboard.
   C. are required to be supplied by a 20-ampere branch-circuit.
   D. are required to be identified as to panelboard and circuit number from which they are supplied.
   E. are to be divided so at least one receptacle is on each side of the bed.

   Code reference ___________________

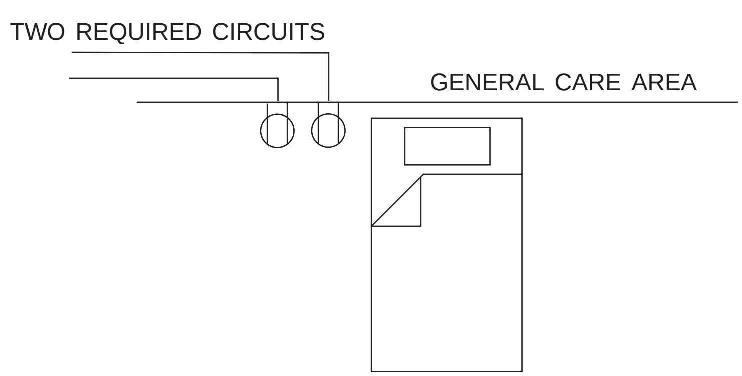


Figure 10.12 Which circuits are required to serve the receptacle outlets at the patient bed location of a general care area of a hospital?

4. Even though circuit wiring is run in metal raceway of a hospital, an insulated copper equipment grounding conductor is required to be run in the raceway and connected to the grounding terminal of:
   A. all equipment, receptacles and lighting fixtures in the hospital.
   B. receptacles installed in basements and other below grade areas.
   C. for every circuit protected with a ground-fault circuit-interrupter.
   D. ceiling luminaires (lighting fixtures) in patient care areas.
   E. all receptacles in patient care areas.

   Code reference ___________________

5. Circuits for patient bed locations of critical care areas of a hospital are supplied from a panelboard on the normal power system and a panelboard from the critical branch of the emergency system. The equipment grounding bus in each panelboard is required to be bonded together, as shown in Figure 10.13, with an insulated copper conductor not smaller than size:
   A. 12 AWG.
   B. 10 AWG.
   C. 8 AWG.
   D. 6 AWG.
   E. 4 AWG.

   Code reference ___________________

6. All receptacle outlets rated 20 amperes or less at 125 volts installed in the patient vicinity of a hospital general care area are required to be:
   A. of the insulated ground type.
   B. listed as hospital grade.
   C. protected by a ground-fault circuit-interrupter.
   D. constructed of clear plastic to allow examination of the internal connections.
   E. listed as commercial grade.

   Code reference ___________________

7. A room of a hospital where patients are anesthetized with flammable anesthetics, as illustrated in Figure 10.14, is classified as a Class I, Division 1 location from the floor up to a height of:
   A. 2 ft (600 mm).
   B. 3 ft (900 mm).
   C. 4 ft (1.22 m).
   D. 5 ft (1.52 m).
   E. the ceiling.

   Code reference ___________________

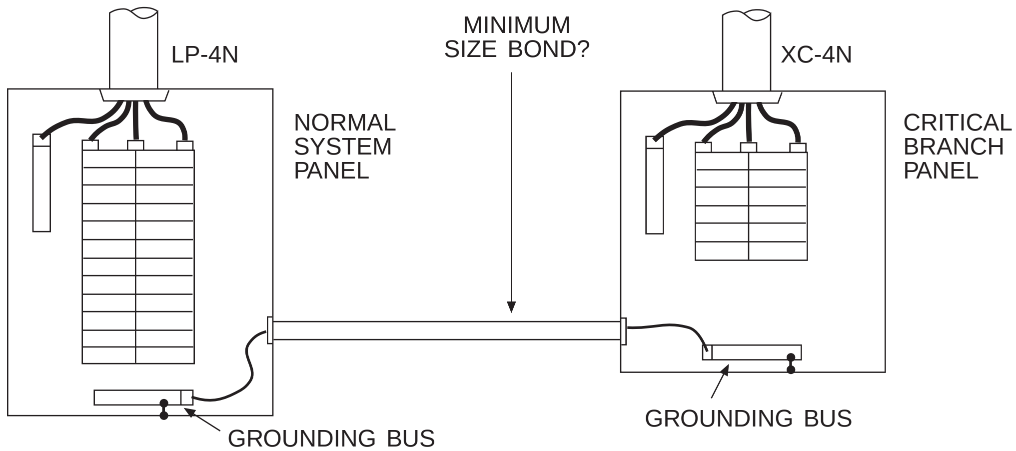


Figure 10.13 Determine the minimum size conductor required to bond the equipment grounding buses of the normal panelboard and the emergency panelboard serving the same patient vicinity.

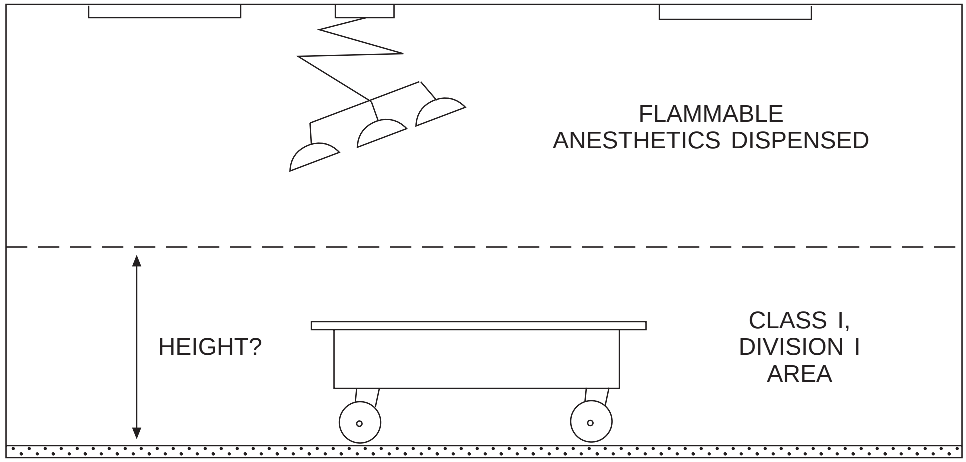


Figure 10.14 In the portion of an operating room from the floor up, what height is considered to be a Class I, Division 1 hazardous location when flammable anesthetics are dispensed in the room?

8. In a hospital, an exit sign circuit is a part of the:
   A. equipment system.
   B. critical branch of the emergency system.
   C. normal power system.
   D. alternate power branch of the normal power system.
   E. life safety branch of the emergency system.

   Code reference ___________________

9. A receptacle rated 15 or 20 amperes, 125 volts installed adjacent to the sink of a bathroom in a general care area patient room of a hospital is:
   A. not required to be ground-fault circuit-interrupter protected.
   B. required to be grounded to the room bonding point.
   C. required to be ground-fault circuit-interrupter protected.
   D. grounded with a size 10 AWG insulated copper equipment grounding wire.
   E. supplied from an isolated power system.

   Code reference ___________________

10. Circuit conductors of the life safety branch in a nursing home are:
   A. required to be kept entirely independent of other wiring and shall not share the same box, raceway, or cabinet with other wiring.
   B. permitted to share the same box, raceway, or cabinet with other wiring in the building.
   C. permitted to share the same box, raceway, or cabinet with circuits of the critical branch, but not other circuits in the building.
   D. permitted to share the same box, raceway, or cabinet with any other circuit of the essential electrical system but not other building circuits.
   E. limited to a maximum rating of 20 amperes.

   Code reference ___________________

11. Receptacles in a hospital supplied from the emergency system are:
   A. required to be kept 18 in. (450 mm) from other receptacles.
   B. required to be distinctively identified to indicate they are supplied by the emergency system.
   C. required to be equipped with pilot lights to indicate when they are energized.
   D. required to be red or their face plates are required to be red.
   E. required to be marked with a label indicating emergency power.

   Code reference ___________________

12. A wiring method that is permitted to be installed in a hospital to supply circuits serving a patient care area is:
    A. Rigid Nonmetallic Conduit, schedule 80.
    B. Electrical Nonmetallic Tubing, which is listed as fire rated.
    C. Type UF Cable.
    D. Type MC Cable where the metal covering is identified as a grounding return path.
    E. any listed cable that has a metal sheath for protection.

Code reference ___________________

13. Receptacles installed within the general patient care area, bathroom, or playroom of a pediatric facility in a hospital are required to be equipped with a listed tamper-resistant device or cover for circuits:
    A. rated 125 volts, 15 amperes.
    B. rated 125 volts and not over 20 amperes.
    C. rated 125 or 250 volts and not over 30 amperes.
    D. rated 125 volts up to 30 amperes.
    E. having any amperage or voltage rating.

Code reference ___________________

14. If an outage of the normal power to a hospital occurs, the circuits supplied from the critical branch are required to have their power restored in not more than:
    A. 10 seconds.
    B. 20 seconds.
    C. 30 seconds.
    D. 60 seconds.
    E. whatever is considered a reasonable time.

Code reference ___________________

15. Receptacles rated 20 amperes at 125 volts in an operating room of a hospital are supplied from an isolated power system (see Figure 10.15). The orange conductor with colored stripes of the isolated power system is to be:
    A. connected to the equipment grounding terminal of the receptacles.
    B. run without splices and looped at each receptacle terminal connection.
    C. connected only to the silver-colored screw terminal of the receptacles.
    D. connected only to the brass-colored screw terminal of the receptacles.
    E. connected to either the silver- or brass-colored terminal of the receptacles

Code reference ___________________

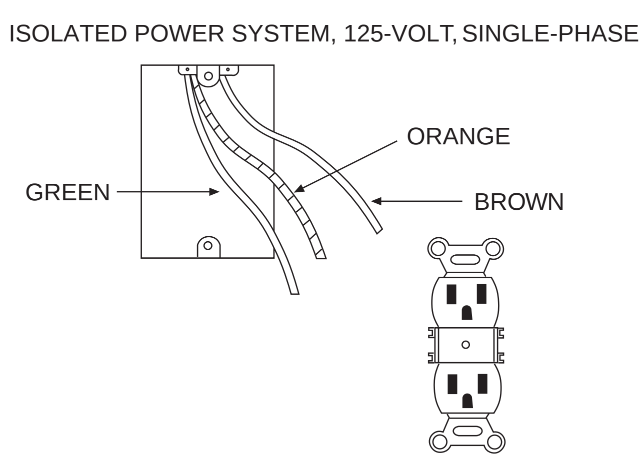


Figure 10.15 Which conductor of an isolated power system in a hospital is required to be connected to the silver-colored terminal of a receptacle?

WORKSHEET NO. 10—ADVANCED HEALTH CARE FACILITIES

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer, or indicates where the answer is found, as well as the Code reference where the answer is found.

1. The equipment grounding bus of a panelboard supplying receptacle circuits at the bed location of the critical care area of a hospital, shown in Figure 10.16, is considered to be:
   A. the patient equipment grounding point.
   B. a room bonding point.
   C. a remote bonding point.
   D. the reference grounding point.
   E. the emergency system grounding point.

   Code reference ___________________

2. For a critical care area in a hospital, each patient bed location is required to be provided with two branch-circuits:
   A. one of which shall originate from the emergency electrical system.
   B. both of which shall originate from the emergency electrical system.
   C. both of which shall originate from the normal electrical system.
   D. with not less than two receptacles connected to each branch-circuit.
   E. that are permitted to originate from any electrical system desired.

   Code reference ___________________

3. The patient bed location of a critical care area of a hospital is supplied by only one circuit from the critical branch of the emergency system. The circuit from the emergency system serving a receptacle at the patient bed location, as shown in Figure 10.17, is:
   A. also permitted to serve receptacles in the same room outside of the patient vicinity.
   B. not permitted to serve receptacles outside of the patient vicinity.
   C. permitted to supply fixed equipment in the room.

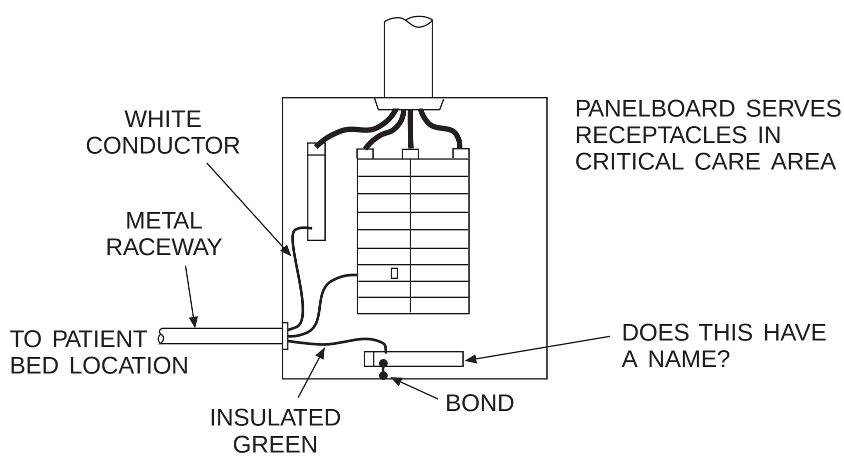


Figure 10.16 What is the name given to the equipment grounding bus of an emergency panel that serves receptacles in the patient bed location of a critical care area of a hospital.

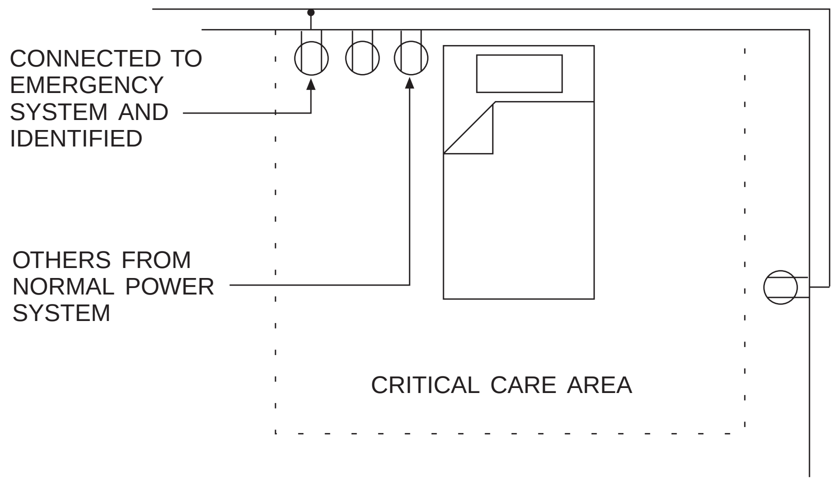


Figure 10.17 There is only one emergency system circuit serving this patient bed location of a critical care area. Is it permitted to supply another receptacle outside of the patient bed location on that same circuit?

D. permitted to supply a receptacle at an adjacent bed location.
E. not permitted to supply a second receptacle at that same patient bed location.

Code reference ___________________

4. The minimum number of receptacles serving the patient bed location of a general care area of a hospital is:
A. not specified.
B. four.
C. six.
D. eight.
E. six duplex receptacles for a total of twelve.

Code reference ___________________

5. An isolated power system in a hospital is required to be supplied power from the:
A. critical branch of the emergency system.
B. equipment system.
C. life safety branch of the emergency system.
D. normal power system but connected to the generator through an optional equipment transfer switch.
E. normal power system.

Code reference ___________________

6. All receptacles installed in wet procedure locations and not served by an isolated power system shall be:
A. supplied by an isolated power system.
B. bonded to a room bonding point with a copper wire not smaller than size 10 AWG.
C. located not less than 5 ft (1.5 m) above the floor.
D. mounted in nonmetallic boxes with nonmetallic face plates.
E. ground-fault circuit-interrupter protected for personnel.

Code reference ___________________

7. A hydromassage bathtub installed in a health care facility is required to have the metal piping, hand rails, metal parts of electrical equipment, and the pump motor bonded together. If bonded with a copper wire, it is required to be:

A. not smaller than size 10 AWG.
B. solid and not smaller than size 10 AWG.
C. solid and not smaller than size 8 AWG either insulated, covered, or bare.
D. solid or stranded and not smaller than size 8 AWG.
E. not smaller than size 6 AWG.

Code reference ___________________

8. Fixed room luminaires (lighting fixtures) are mounted at least 8 ft (2.5 m) above the floor of an anesthetizing location where flammable anesthetics are used and an isolated power system is installed. These luminaires (lighting fixtures) are permitted in this location:
   A. and powered by a normal grounded electrical system if the switch is located outside in another area.
   B. and powered by a normal grounded electrical system if the switch is located above the Class I, Division 1 hazardous location.
   C. if powered only by the isolated power system.
   D. if provided with explosionproof enclosures.
   E. if the fixtures have no exposed metallic parts.

Code reference ___________________

9. The disconnecting means for permanently installed X-ray equipment shall be:
   A. operable from a location readily accessible from the X-ray control.
   B. located within sight of the X-ray machine.
   C. permitted to be a cord cap and attachment plug in the main circuit to the unit.
   D. capable of interrupting 125% of the momentary current of the unit.
   E. located anywhere in the room.

Code reference ___________________

10. The wiring of circuits for exit signs and emergency lighting throughout patient care areas of a hospital are:
   A. permitted to be run in Type MC Cable where the metal sheath is approved as a grounding means.
   B. permitted to have short lengths of Flexible Metal Conduit not exceeding 6 ft (1.8 m).
   C. required to be run as nonflexible metal raceway or as Type MI Cable.
   D. required to be run as Rigid Metal Conduit or Intermediate Metal Conduit.
   E. permitted to be run using Type AC or Type MC Cable with an insulated equipment grounding conductor and metal sheath approved as a grounding means.

Code reference ___________________

11. The power source for the essential electrical system for a hospital is an engine driven generator with a main disconnect and overcurrent device rated more than 1000 amperes, 3-phase, 480Y/277 volts solidly grounded as shown in Figure 10.18. Equipment ground-fault protection is:
   A. required between the generator and the essential electrical system transfer switches.
   B. required on the feeders on the load side of the essential electrical system transfer switches.
   C. permitted on the feeders between the generator and the essential transfer switches.
   D. permitted on the load side of the essential electrical system transfer switches.
   E. not permitted between the generator and the essential electrical system transfer switches or on the load side of the transfer switches.

Code reference ___________________

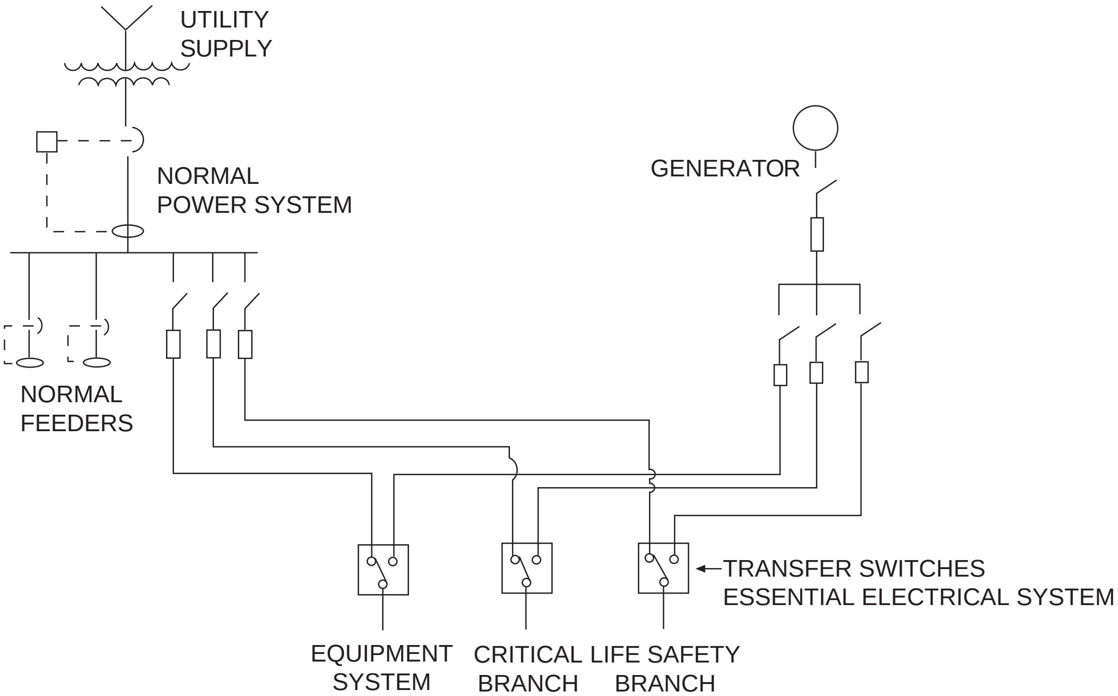


Figure 10.18 Where is equipment ground-fault protection required relative to the essential electrical system of a hospital?

12. A critical care area of a hospital is equipped with a patient grounding point as shown in Figure 10.19. An equipment bonding jumper shall be used to connect the patient equipment grounding point and the grounding terminal of receptacles. The minimum size copper bonding jumper permitted is:
    A. 14 AWG.
    B. 12 AWG.
    C. 10 AWG.
    D. 8 AWG.
    E. not specified and depends upon the rating of the circuit and sized according to *Table 250.122*.

Code reference ___________________

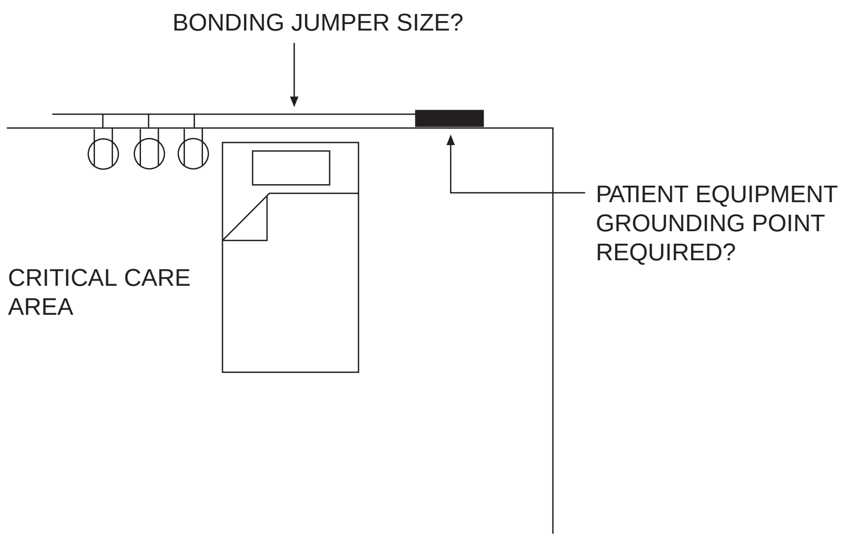


Figure 10.19 Determine the minimum size bonding jumper required from the receptacles to the optional patient equipment grounding point in a critical care area of a hospital.

13. A room in a hospital used for the storage of flammable anesthetics or disinfectants is considered to be a:
    A. Class I, Division 2 location for the entire room, floor to ceiling.
    B. Class I, Division 2 location from the floor up to a height of 18 in. (450 mm).
    C. Class I, Division 1 location from the floor up to a height of 18 in. (450 mm).
    D. Class I, Division 1 location for the entire room, floor to ceiling.
    E. an unclassified area, however, all wiring is to be in Rigid Metal Conduit using boxes with threaded hubs.

    Code reference ___________________

14. A hospital has a demand load on the essential electrical system of more than 150 kVA. A single standby generator supplies the equipment system, the critical branch, and the life safety branch. Upon a loss of normal utility power to the hospital, the equipment system is:
    A. required to be energized in not more than 10 seconds.
    B. permitted to be completely or partially transferred to the generator manually.
    C. required to be started simultaneously along with the emergency system.
    D. permitted to be started simultaneously along with the emergency system.
    E. required to have power restored automatically with an appropriate time lag.

    Code reference ___________________

15. A hospital has an equipment system, a life safety branch, and a critical branch all supplied from one standby generator. The demand load of the essential electrical system is more than 150 kVA. The minimum number of transfer switches required for this installation is:
    A. zero.
    B. one.
    C. two
    D. three.
    E. not specified in the Code.

    Code reference ___________________

UNIT 11

Emergency and Alternate Power Systems

OBJECTIVES

After completion of this unit, the student should be able to:

- determine the minimum size conductor permitted to connect a standby generator to a wiring system.
- explain the purpose of transfer equipment for a standby power system.
- explain ventilation and insulating needs for battery rooms.
- define terms used in the Code to describe solar photovoltaic systems.
- name the types of equipment and circuits that make up the emergency electrical system of a typical commercial building.
- explain how the wiring is to be run for emergency electrical circuits.
- explain the type of electrical equipment and circuits powered by a legally required standby electrical power system.
- describe a typical application where there is an optional standby electric power system.
- define an interconnected electric power production source.
- explain the difference between a supervised and an unsupervised fire alarm system.
- explain how the wires are to be attached to a fire alarm pull station.
- answer typical wiring installation questions from *Articles 445, 480, 690, 692, 695, 700, 701, 702, 705, 708,* and *760.*
- state at least three changes that occurred from the 2005 to the 2008 Code for *Articles 445, 480, 690, 692, 695, 700, 701, 702, 705, 708,* or *760.*

CODE DISCUSSION

Alternate electric power-producing systems are discussed in this unit, as well as the Code articles that cover their installation. These systems may be legally required for some buildings, such as a hospital, or they may be optional. Emergency electrical systems are discussed in this unit. The most simple emergency system consists of exit signs and lighting for building evacuation. Other buildings may have more extensive requirements. The electrical Code covers the installation of these systems, while other codes cover what systems and equipment are required in a particular building. The installation of fire alarm systems is covered in this unit.

Article 445 covers the requirements for generators to be connected to wiring systems. The markings for generators are covered in *445.11*. Even though the full-load rated current is required to be marked on the nameplate, there are many older generators in operation that list only the continuous rating in kilowatts or kilovolt-amperes. The Equations 8.5 and 8.6 in *Unit 8* can be used to determine the full-load current if the continuous rating is in kVA or kW. *NEC® 445.12(A)* requires constant voltage generators, such as the ones used for standby power, to be protected from overcurrent. This is generally done by the manufacturer with either a set of fuses or a circuit breaker as an integral part of the generator. The conductors between the generator and the point where the connection is made to the premises wiring system is required to be not less than 1.15 times the full-load continuous output current of the generator. This conductor is required by *240.4* to be protected according to its ampere rating, therefore, the conductor is generally sized to the rating of the output overcurrent device of the generator. The connection to the premises wiring system is usually made to a transfer switch.

A disconnecting means is required to be installed to disconnect the generator ungrounded conductors from the premises wiring system. The location of the disconnecting means is not specified. A switch or circuit breaker on the generator unit is a convenient means of disconnecting the ungrounded conductors from the generator. A transfer switch can also be used to disconnect the ungrounded conductors from the generator. *NEC® 445.18* does not require a disconnect for the conductors if the generator prime mover can readily be shut off and the generator is not operating in parallel with another electrical supply such as the utility.

Article 480 deals with stationary storage battery installations. The main emphasis of this article is the rigid mounting of the batteries, corrosion prevention, ventilation of the battery room, and guarding of live parts when the batteries are connected for the circuit to operate at 50 volts or more. The rules on guarding are found in *110.27.* It is also necessary to provide working clearances around battery installations according to *110.26.*

Specific requirements for the connection of storage batteries as a part of an electrical system are covered in various articles throughout the Code. Storage batteries can function as a stand-alone standby power system. An inverter can be used to convert the direct current to alternating current in the event of a power outage. Energy conversion efficiencies of more than 85% are common for inverters. The batteries can be kept charged as needed with a small automatically operated generator. Operating in this manner, generators are supplying a nearly constant load, and will operate more efficiently. Batteries are usually installed as a part of a photovoltaic power system. Batteries can also be used with wind generating systems and small hydroelectric turbines. There are no specific rules in the Code for general installation of battery power systems. The best source is *Part VIII* of *Article 690* on solar photovoltaic systems.

Article 690 applies to solar photovoltaic electric power systems including the dc-to-ac inverter, charge controller, sun tracking system, and wiring of components in the system. Several important definitions are covered in *690.2.* It is important to understand the basic photovoltaic terminology in order to apply the rules of *Article 690.* A typical silicon photovoltaic cell is about 4 in. (100 mm) in diameter and has an operating output of about 3 amperes at 0.5 volts dc. These photovoltaic cells are connected in series to obtain the desired output voltage and manufactured into a unit called a solar photovoltaic module. As many modules as needed are assembled into a solar photovoltaic array to achieve the desired output voltage and power. A typical solar photovoltaic power system is shown in Figure 11.1. Modules are usually connected in series to achieve the desired voltage. Each module or series of modules is called a photovoltaic source circuit. These source circuits are connected in parallel until the desired power is achieved. The wires connecting to a group of photovoltaic source circuits is called the photovoltaic output circuit. If an output circuit connects to ten source circuits each producing 3 amperes at 36 volts, the output circuit will be rated 30 amperes at 36 volts.

The rated output voltage of the solar photovoltaic array will be higher than the nominal operating voltage of the photovoltaic system because the array will not be able to maintain maximum output throughout

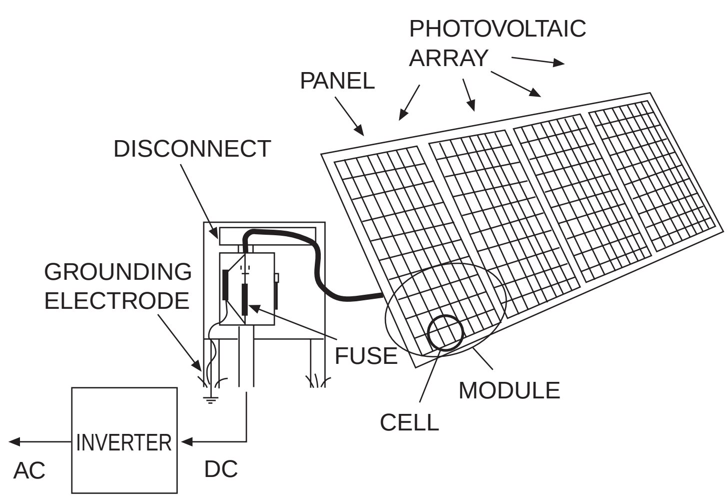


Figure 11.1 Photovoltaic cells are assembled into modules, which are then assembled into panels. A group of panels make up an array.

the day. The output of the array can be sent directly to the load or to a set of storage batteries. Output from the photovoltaic array goes to a charge controller which supplies the desired voltage and current to the batteries and the load. Solar photovoltaic systems are sometimes interconnected with building wiring and the utility simultaneously to form what is known as an interconnected electric power production system, the wiring of which is covered in *Article 705*.

Part II of *Article 690* covers circuit conductor sizing and overcurrent protection. *Part III* specifies the disconnecting means requirements. It is important to remember that if light strikes the photovoltaic array, a voltage is being produced. Also, when a system is interconnected with a utility system or run in parallel with another power production system, backfeeding may be a problem. When a switch is opened, both sides of the switch may still be energized. This is why placement of disconnects is important. Wiring methods are covered in *Part IV* and grounding is covered in *Part V.* A stand-alone solar photovoltaic power system is a separately derived system and grounding should meet the requirements of *250.30.* Connected as a standby power system by means of a transfer switch at the main service of a building or operated as an interconnected power system in parallel with a utility supply, the solar photovoltaic system connects to the service of a building and is not considered a separately derived system. In this case, the same rules for grounding are followed as would be the case for a utility supplied electrical system. This is explained a little more clearly in *Part V* of *Article 692* on fuel cell systems.

Article 692 provides the rules for the installation of fuel cell systems to supply power for premises wiring systems. Definitions important to understanding this article are in *692.2.* Fuel cells produce direct current. The direct current can be utilized for some loads, but for many loads the dc must be converted to ac with an inverter. The inverter may be a part of the fuel cell unit, or it may be connected as an auxiliary unit. *NEC® 692.8(B)* requires the feeder conductor from the fuel cell system to have an ampacity not less than the nameplate rated current or the rating of the overcurrent device on the fuel cell system. The output conductors from the inverter are sized according to the rated output current of the inverter. *NEC® 692.13* requires that a means be provided to disconnect all ungrounded conductors of the fuel cell system from the premises wiring system.

Fuel cells operated as a stand-alone system are considered a separately derived system and are required to be grounded following the rules of *250.30.* If the system is operated in parallel with another power system, such as the utility system, the fuel cell system is required to be grounded to the grounded circuit conductor terminal of the premises wiring system. This is also the case where the fuel cell system is operated as a standby power system and connected to the wiring by means of a transfer switch. The fuel cell system may also contain batteries. *NEC® 692.56* requires a warning to be placed at the main disconnect location calling attention to the energy storage system, but no rules are included for the installation of the batteries. The rules of *Article 480* must be followed for the battery installation but there are no rules for the installation of the complete battery system, including charge controller and inverter. The best place to find this information is in *Part VIII* of *Article 690* on solar photovoltaic power systems.

Article 695 deals with the electrical power, wiring, and controls for fire pumps and associated equipment. This article assembles the electrical installation requirements related to fire-pumping installations together in one location in the Code. Much of the article is taken directly from *NFPA20, Standard for the Installation of Stationary Pumps for Fire Prevention.* The rules applying to fire pumping systems may seem contrary to normal safety rules in the Code, but it is important to note that the purpose of the system is to reduce a fire emergency to allow the building to be evacuated and to assist fire-fighting personnel in dealing with the emergency. Hopefully, the operation of the pumping system will put out the fire or limit the extent of damage. In any case, the electrical system is to be installed for maximum reliability under heavy load conditions. The system is to be installed to minimize its exposure to damage. Overcurrent protection is set high enough to prevent premature shutdown of the pumping system. With a building on fire, and human life in danger, damage or burnout of pumping system motors and associated equipment is of little concern. *NEC® 695.3* directs that the power supply be reliable. In the case where the pumping system is supplied power by a tap to the normal power system, the tap ahead of the service disconnect is not permitted to be made in the service disconnecting means enclosure, *695.3(A)(1).*

The supply conductors for the pumping system are not permitted to be protected from overload, but only protected from short circuits as stated in *695.6(D)* and *240.4(A).* When the system is supplied from a dedicated transformer, overcurrent protection is not permitted to be installed on the secondary of the transformer. The minimum setting of the transformer primary overcurrent protection shall be sufficient to continuously supply the sum of the locked-rotor currents of all motors of the system and the full-load current of the other loads of the system.

A separate service is required for a fire pump installation. The power source is required to be reliable and capable of supplying the locked-rotor current of all pump motors and pressure maintenance pump motors, and the full-load current of any associated equipment. Power source requirements are discussed in *695.3*. A separate service is permitted as shown in Figure 11.2. It is also permitted to tap ahead of the service disconnect. An on-site generator is also permitted to supply the fire pump and associated equipment. Rules for determination of the minimum size of generator are found in *695.3(B)(1)*. Obviously it is important to make sure the fire-pumping system is always ready for operation. Therefore, the system is required to be supervised to ensure that power is supplied to all system components, and a signal will indicate if any part of the system is not ready for operation. Disconnects must be capable of being locked in the “closed” position to make sure they are not inadvertently opened.

Article 700 deals with the installation of emergency electrical systems. The fine print notes to *700.1* provide information that helps understand the type of electrical circuits that may be included as part of an emergency electrical system. Emergency systems are required in buildings where there is public assembly, schools, hotels, theaters, sports arenas, and health care facilities. Typical equipment included as a part of the emergency system is illumination for safe exiting of the building, exit signs, fire detection and alarm systems, elevators, fire pumps, ventilation and other building utilities necessary for life safety. *NEC® 700.12* requires load transfer to a backup power source to occur in not more than 10 seconds.

The wiring of these systems is covered in *Part II*. Emergency circuits are required to be kept independent of other circuits used for light and power. If the building is wired with raceway, then the emergency circuits are required to be run in dedicated raceways that contain only emergency circuits. The sources of power for these systems are covered in *Part III*. Emergency illumination is the most common type of emergency system installed. The requirements for the circuits, equipment, and control of equipment are covered in *Parts IV* and *V*.

For some buildings requiring only safe evacuation of the building, unit equipment is satisfactory for safe exiting from the facilities using illuminated exit signs and adequate area lighting. The illumination units are not permitted to depend upon only one lamp for illumination in any particular area. Each area will require two single-lamp units or one two-lamp unit. Power for the illumination units is required to be from the same

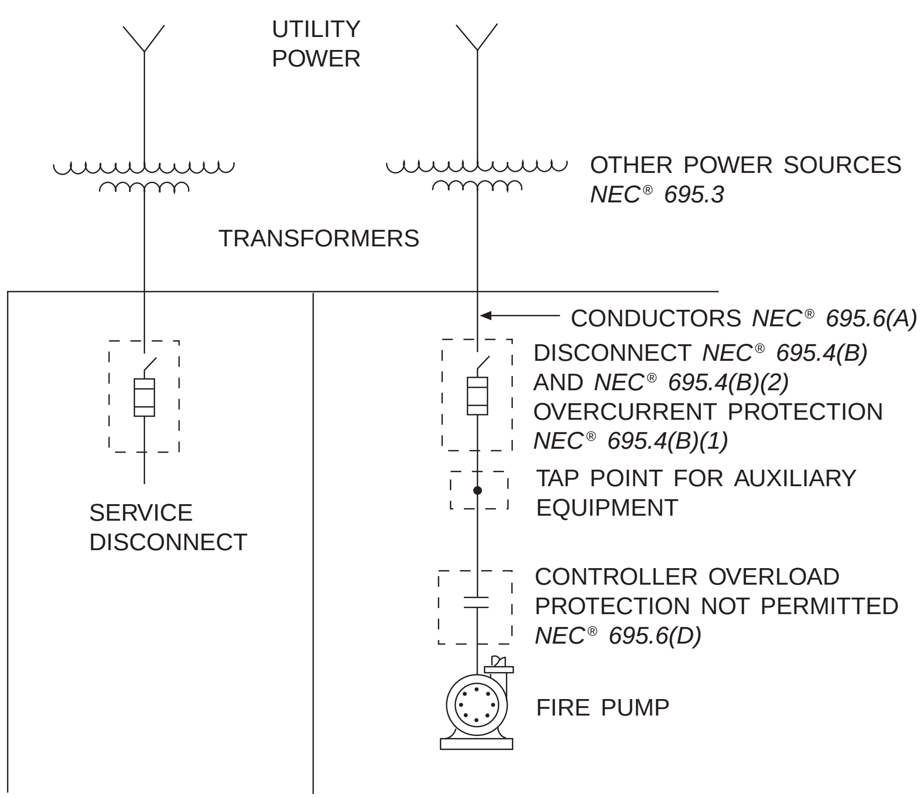


Figure 11.2 A fire pump system is required to have a separate service capable of reliably supplying the locked-rotor current of the fire pump and pressure maintenance pump and the full-load current of the other associated equipment. The conductors and equipment are to be protected from short circuits and ground faults only.

circuit that supplies the normal lighting in the area. The emergency light units are required to be connected to the circuit ahead of any local switches. These rules are found in *700.12(F)*. High intensity discharge lighting will generally not relight when power is restored and this needs to be considered when installing emergency lighting. The emergency lighting units will turn off when power is restored, but the HID lamps will not necessarily relight immediately. One way to solve this problem is to include fluorescent or incandescent lights as a part of the lighting in the area.

NEC® 700.12 specifies the power sources that are acceptable for emergency circuits. One source is battery-powered illumination units. More extensive systems may require more power. One alternative is a battery system that must be able to supply the load for not less than 1.5 hours. Deep cycle batteries are required and vented lead-acid batteries requiring periodic filling with water are required to have a transparent case to indicate electrolyte level. Another power source is an on-site generator which must have a fuel supply for the engine to last not less than two hours. The generator must be automatic starting with automatic load transfer. It is not permitted for the engine to operate on a utility natural gas supply. If the generator is not capable of starting and powering the load within 10 seconds, another temporary power system is required to fill the gap in time until the generator is capable of supplying the emergency load. An uninterruptible power supply is also permitted to supply emergency loads. A separate service in some situations may be permitted as an emergency power supply but only if approved by the local jurisdiction.

Article 701 on legally required standby systems do not include emergency systems. These are systems that are required to be installed because a system in a building may create a condition that becomes life threatening if normal power fails. Or it may be a system that would hamper rescue or fire fighting. It can include lighting, ventilation and smoke removal, and communications systems. *NEC® 701.11* requires the standby power system to be up and running within 60 seconds of a normal system power failure. The power source is permitted to be a generator, storage batteries, uninterruptible power supply, separate service if approved by the authority having jurisdiction, or a connection ahead of the service disconnect if acceptable to the authority having jurisdiction. *NEC® 701.10* permits the wiring of circuits for a legally required standby power system to occupy the same raceways, cables, boxes, and cabinets with normal wiring in the building. For illumination, unit equipment the same as specified for emergency systems is permitted to be used. *NEC® 701.7* requires transfer equipment to be automatic and it shall be arranged in such a way that there will not be an interconnection between the normal power supply and the legally required standby power source.

Article 702 applies to optional standby power systems intended to supply loads for industrial, commercial, farm, and residential buildings and facilities. The type of power source is not specified. It could be a generator, storage batteries, or any type of alternate power system such as solar photovoltaics or fuel cells. Portable generators and tractor driven generators are permitted for this type of installation. An example of a portable tractor driven generator is shown in Figure 11.3. *NEC® 702.9* permits the wiring of circuits for an

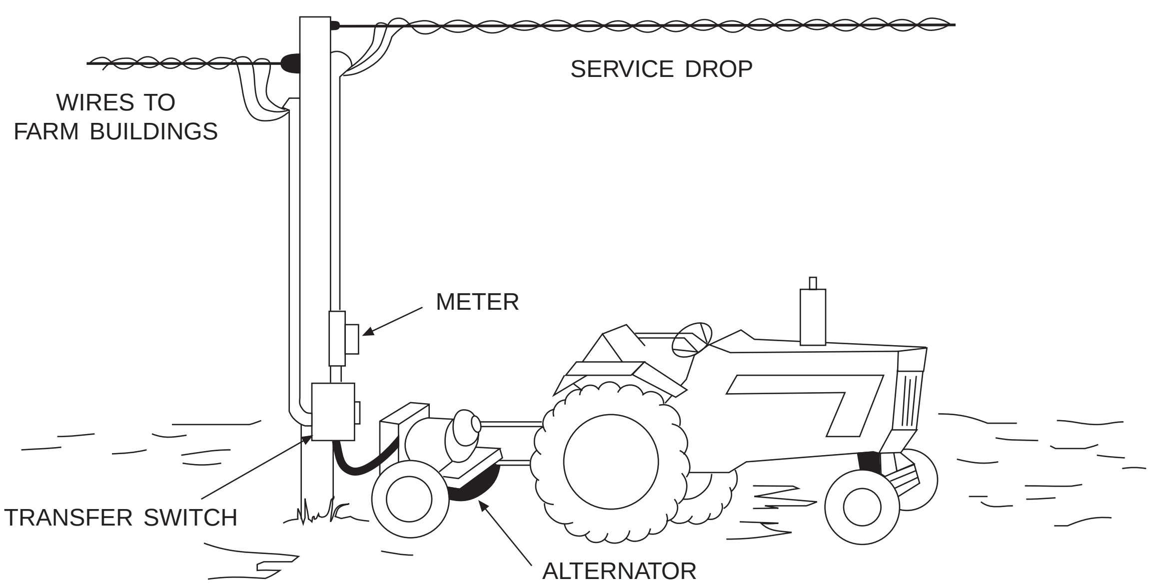


Figure 11.3 A portable generator that has a permanent means of attachment to a premises wiring system, such as this tractor powered portable generator at a farm distribution pole, is considered to be an optional standby power system.

optional standby power system to occupy the same raceways, cables, boxes, and cabinets with normal wiring in the building. *NEC® 702.6* allows manual transfer equipment but it shall be arranged in such a way that there will not be an interconnection between the normal power supply and the optional standby power source.

Article 705 specifies the method of interconnecting an alternate power system to operate in parallel with another power system such as a utility power supply. These systems are only permitted to be connected in parallel with a utility power system through a contractual agreement with the specific electric utility. Some states have a net power agreement law where the utility must purchase power from the customer. *NEC® 705.12* generally requires the connection of the alternate power source to be at the service disconnecting means. The connection is permitted to be on the supply side of the service disconnect or it is permitted to be on the load side. *NEC® 705.14* requires the customer power production system to be compatible with the utility power supply. In particular, the customer power source frequency and voltage must be the same as the utility power supply and the waveshapes must be compatible. The customer power source making connection with the utility supply is usually a generator, the output from an inverter, or the output from a transformer. The connection must be controlled so that the customer power supply is synchronized with the utility supply when the connection is completed so the two wave forms are in phase with each other.

NEC® 705.21 requires a means be accessible to disconnect all ungrounded conductors of the customer power source. *NEC® 705.40* requires that the power production source be automatically disconnected from the utility supply in case of a failure of the utility supply. This can be in the form of a load transfer switch that will connect the customer source to the customer load while disconnecting the source from the utility supply.

Article 708 provides rules for the wiring of portions of premises wiring systems that are ruled by a governmental jurisdiction as critical operations power systems (COPS). These would be portions of wiring systems that must provide power for operations that are necessary for emergency workers, or it may provide power for a portion of a building where human lives may be at risk if power is lost for an extended period of time. These power systems are to be installed in such a manner that they have a chance to survive a major storm or flood or some other widespread disaster where an entire area loses electrical power for an extended period of time. The critical operations power system will not only consist of well-protected wiring, but also one or more power sources. Many of the rules in this *Article* are directed at the installing electrician, but many are also directed at the persons or organization that has jurisdiction over the facility.

Article 760 provides rules for the installation and testing of fire alarm systems. It is important to understand that the purpose of such a system is to provide warning for the evacuation of a building and area. Emergency systems will provide directions and lighting for the evacuation of the premises. It is important to keep in mind that reliability of the system is of major importance. Wiring of the alarm initiation circuits and the warning circuits must be supervised so that any failure in the system will be noted so that immediate repairs can be undertaken. Making sure that all portions of the systems are properly supervised calls for some wiring rules that are not necessary in other types of wiring in the facility. Another important point is that the wiring of fire alarm systems is to be kept separated with other wiring of the building so that failures in other circuits will not compromise the integrity of the fire alarm circuits. This subject is discussed in more detail later in this *Unit.*

EMERGENCY ELECTRICAL SYSTEMS

Emergency electrical systems must be installed to ensure the highest practical level of reliability. The wiring for these systems is required to be run completely independent from normal power and lighting circuits. These systems frequently are supplied power from a separate service or from a tap to the normal service plus a backup power source such as a generator. When a backup power source is installed, the transfer of load from normal power to the alternate power source must be automatic and occur in not more than 10 seconds. This transfer of load from one power source to another is accomplished using a transfer switch such as the one illustrated in Figure 11.4. *NEC® 700.6* requires this transfer of emergency load from normal to standby power to be done in such a way that there is never an interconnection between the standby power source and the normal power source. A legally required standby power source is intended to supply loads other than emergency systems that must be operated to protect personnel from injury or to aid fire fighters or rescue personnel. The load is permitted to be transferred to the standby source in not more than 60 seconds. In the case of an optional standby power system, the load transfer is permitted to be manual and there is no specified time in which the load transfer must occur.

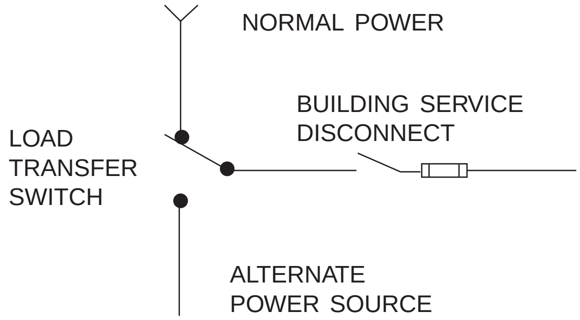


Figure 11.4 A load transfer switch is required when connecting a standby power source to a premises wiring system, and it prevents interconnection of the standby power source to the normal power source.

The primary function of the emergency electrical system, covered in *Article 700,* is to provide automatic illumination for safe exiting of a building and panic control during an emergency. This would require illumination in places where people assemble in the event that power to the normal illumination is interrupted. Illumination is required to safely exit the building, including power for the marking of exits from the building.

The emergency electrical system also may include fire alarm systems, power for fire pumps, ventilation where necessary to provide life safety, or other functions necessary to prevent other life-threatening hazards.

A self-contained, battery-operated exit sign may consist of a standard universal exit sign that is internally equipped with a battery, charger, and a means of automatically transferring to battery power on loss of normal operating power. Exit signs of this type, which are listed by an independent testing laboratory, are readily available with operational time ratings in excess of 4 hours. The following criteria are used in determining whether self-contained, battery-operated exit signs are acceptable in lieu of conventionally wired exit signs. Self-contained, battery-operated signs are permitted to be installed provided the following conditions are met:

- The power supply for the exit signs and illumination units shall be from the same branch-circuit as that serving the normal lighting in the area, and shall be connected ahead of any local switches, *700.12(F).*
- The operational time rating of the units shall not be less than that required by the rules applicable to the facility in which they are installed.

Fire Alarm Systems

A fire alarm system, covered in *Article 760,* is an assemblage of components, acceptable to the authority having jurisdiction, that will indicate a fire emergency requiring immediate action. The system shall alert all occupants of a building in which it is installed when a fire emergency is present.

The authority having jurisdiction is the governmental, legally employed agency that can require the installation of a fire alarm system with specified features, characteristics, functions, and capabilities. The authority having jurisdiction may be a person, firm, or corporation with financial or other interest in the protected property and whose authority lies in contractual arrangements between the affected parties. The electrical inspection authority has jurisdiction over installation methods, materials, and some operational characteristics of all systems.

Fire alarm systems required to be installed by governmental agencies are designed and installed to save lives by alerting occupants to a fire emergency. Life safety systems may provide some property protection. These systems are often termed local protective signaling systems. Fire alarm systems installed to protect or limit property loss are not required by governmental agencies. These optional systems are installed to protect high-value properties or to reduce insurance premiums.

Fire alarm systems required for life safety shall be the supervised type. This requirement is not in the *NEC®*, but is required by other codes. A supervised circuit will indicate a ground fault or an open circuit with a distinctive audible signal at the control panel location and remote locations as required. Class A supervised circuits will continue to operate with a single open-circuit conductor. Class B supervised circuits will not operate with an open circuit. A Class A fire-alarm initiating circuit is shown in Figure 11.5. Supervision is provided by the design of the control panel and correct installation of the field wiring. Circuits required to be supervised are:

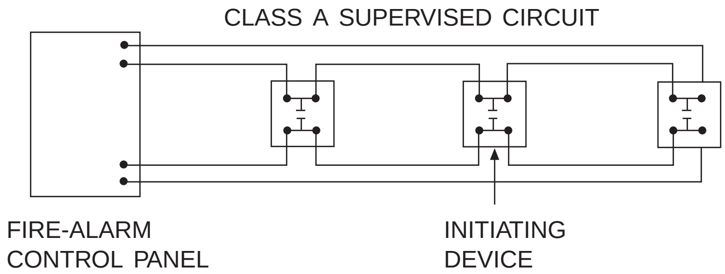


Figure 11.5 A Class A supervised fire-alarm initiating circuit completes a loop on each side of the initiating device and will allow the system to remain functional even with one open circuit.

- The main operating power
- The initiating circuits
- The sounding device circuits

The initiation circuit senses the fire emergency condition and permits initiation current to flow in the circuit. Initiating devices are of several common types: pull stations, products of combustion detectors, heat detectors, and water flow switches. Rules not a part of the electrical Code are provided for the proper location of these initiating devices.

The signaling circuit alerts building occupants to the fire emergency. Sounding devices installed on the signaling circuit are of several common types. Typical sounding devices are horns, buzzers, bells, chimes, electronic signals, and sirens. The type of sounding device used in a building must have a distinctive sound not used for any other purpose in the building. Sounding devices must be audible in all areas of the protected facility. Visual signals are now being provided for hearing-impaired persons by some building codes for barrier-free design. Visual signals, when installed, are required to be on a supervised circuit.

One type of initiating device is a heat detector. Several types of heat detectors are used for fire alarm systems. One type operates at a predetermined fixed temperature. Another operates at a predetermined rate of rise in temperature. Both types may be combined in one unit.

There are several types of products of combustion detectors. The photoelectric type is designed to detect visible particles in smoke by obscuring the light or by light scattering. Another is the ionization type, which is designed to detect invisible products of combustion by using the electrical conducting nature of air in the presence of low-level radioactivity. The conductivity of air is changed by the presence of combustion products or other gas or vapor.

Duct detectors are installed to prevent toxic vapors from being moved from one part of the building to another. There are basically two types of duct detectors. The heat type is used to detect abnormal temperatures in air-handling systems. They are permitted in systems under 15,000 cubic feet per minute (425 m^3/min) air capacity by some codes. Some are similar to the fixed temperature detectors described earlier. This type is no longer acceptable for new construction by some state and local codes. Smoke-type duct detectors are adaptations of photoelectric or ionization-type detectors. They are installed to sample the air in a duct system to detect abnormal smoke in air-handling systems. All air-handling systems are not required to have automatic detectors. Refer to state and local codes for specific requirements.

Flame detectors are a type activated by visible light, light invisible to human eye, or flame flicker. These units are for special occupancies or hazards and are not required by codes, but they may be provided for an additional level of protection.

Wiring Fire Alarm Systems

It is important to understand how supervised electrical circuits operate to understand how the wiring is to be installed. The wiring for the initiation circuit or the sounding circuit shall be installed such that the system will function when an initiation action has been taken. If the initiation circuit is not properly installed, it is possible for an initiation station to develop an open circuit at a later time without activating the trouble indicator. Specific requirements for wiring the fire alarm system are found in *Article 760*. This discussion is intended to show the proper wiring of the fire-alarm circuits to make sure they will function properly.

The Class A initiating circuit requires four wires. A resistor is not required at the last initiating station. The current-limiting resistor is built into the alarm control unit. One wire on each side of the circuit can open, which sounds the trouble signal, and the initiating circuit will still function. Figure 11.5 shows a Class A initiating circuit properly installed.

The Class B initiating circuit has only two wires. An end-of-line resistor is installed to complete the supervisory circuit. A trickle current flows through the wires at all times. A short circuit, a ground fault, or an open wire will prevent proper operation, and a trouble signal will sound. A control unit with four terminals may be connected for a 2-wire Class B circuit. Figure 11.6 shows a properly wired Class B initiating circuit. An end-of-line resistor is used for a Class B supervised circuit.

The sounding circuit is also required to be supervised. One method is the series circuit, in which a trickle current passes through each sounding device connected in series. The fire-alarm control panel is adjusted for the number and type of sounding devices used. Figure 11.7 shows a series-type sounding circuit.

A polarized sounding circuit is shown in Figure 11.8, and an end-of-line resistor is used. This system is supervised with a current flowing along one wire, then through the end-of-line resistor, and back to the alarm control panel on the other wire. Proper polarity must be observed for connecting to the sounding devices.

Wire splices and terminations are a source of problems in any wiring system. It is not uncommon to have a splice or termination fail and cause an open circuit. For this reason, it is not permitted to make a connection to an initiation station that depends on one splice or termination. If an open circuit should occur, it is possible for the supervisory circuit to function, but an initiation station may be inoperative. If a connection to an initiation station is made with two separate terminations or with a loop termination, an open circuit to an initiation station will most likely open the supervisory circuit. Proper connections to an initiating station are shown in Figure 11.9.

In the process of wiring in an initiating circuit, it may be necessary to make a tee tap. This procedure is a frequent source of error. If this is not done properly, the tee tap circuit will not be supervised. It is

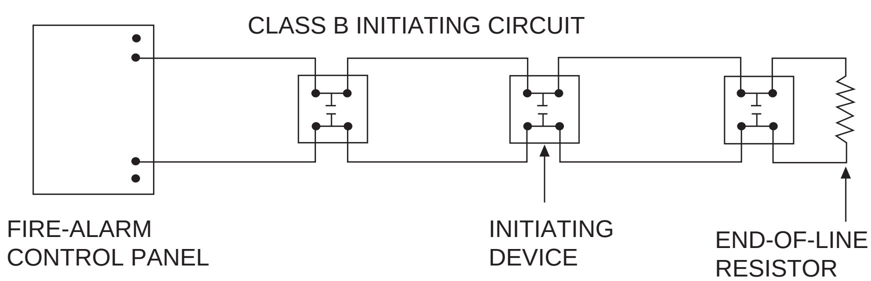


Figure 11.6 A Class B supervised fire-alarm initiating circuit has only one conductor for each side of the initiating devices and must have an end-of-the-line resistor to complete the supervisory circuit.

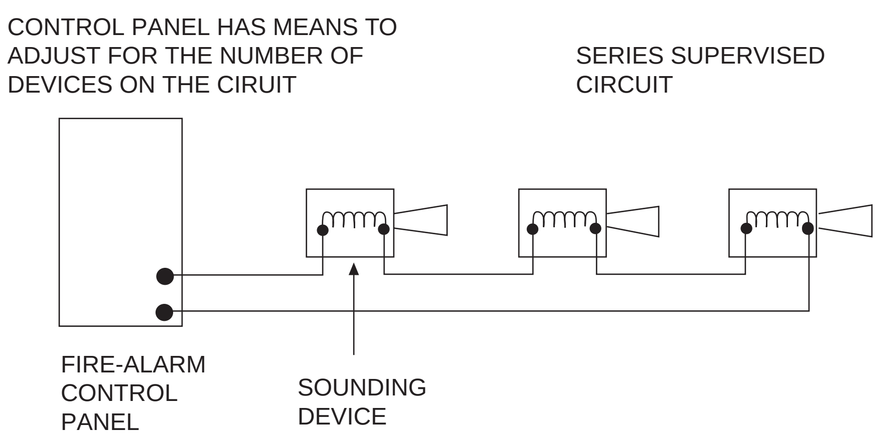


Figure 11.7 A series-type supervised fire-alarm sounding circuit passes a supervisory current through each sounding device.

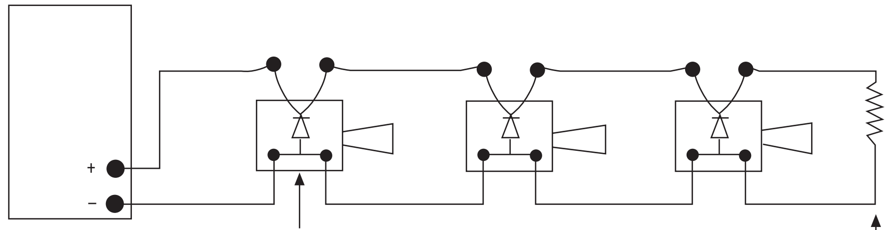


Figure 11.8 A parallel or polarized fire-alarm sounding circuit has two terminal connections to each side of the sounding device, and an end-of-the-line resistor is needed to complete the supervisory circuit.

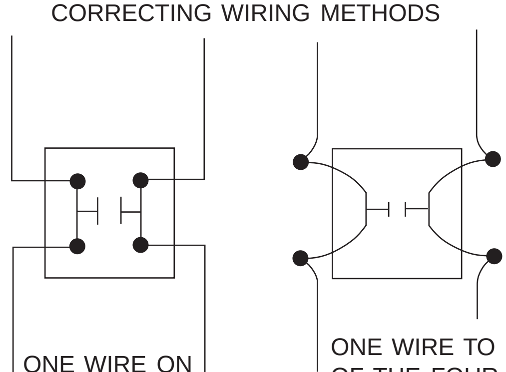


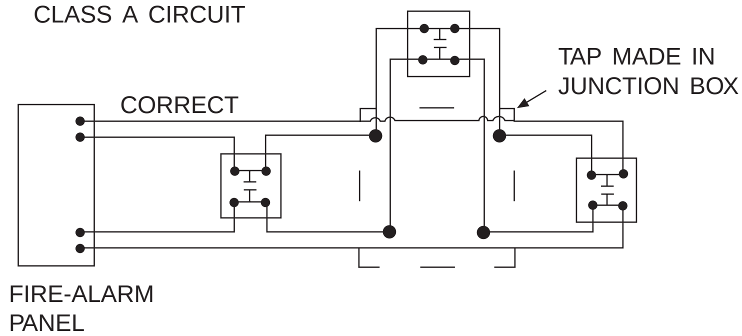
Figure 11.9 Only one conductor is attached to a terminal of a fire-alarm device so that an open conductor will always stop the supervisory current flow and provide a trouble signal.

possible for an open circuit to occur, rendering one or more initiating devices not operable without sounding a trouble signal. The proper method of making a tee tap for a Class A initiating circuit and a Class B initiating circuit is shown in Figure 11.10. Note that the initiating stations are all connected in a series circuit.

Computerized fire alarm systems are frequently used on large buildings. A remote terminal unit is placed in an area or on a floor. Each remote terminal unit has an initiating circuit and a sounding circuit. The central computer interrogates each remote terminal unit for a status check. If an alarm is initiated, the sounding signal is given in a predetermined strategy. For large buildings, evacuation of the areas of greater danger is initiated first. The rules for supervision and wiring discussed earlier must be followed for the initiating and sounding circuits of each remote terminal unit.

Fire Pumps

Power for a fire pump installation is required to be independent of the normal power system for a building. *NEC® 695.4(A)* permits the power source to connect directly to a listed fire pump controller, or a listed combination fire pump controller and transfer switch. *NEC® 695.4(B)* permits a disconnecting means with overcurrent protection to be installed ahead of the fire pump controller. Figure 11.11 shows a diagram of a fire pump installation with and without a transformer. A fire pump must be ready at all times. Therefore, there is a requirement that the disconnecting means must either be capable of being locked in the closed position or must be supervised to indicate if the switch is open. The disconnect is not sized the same as would be the



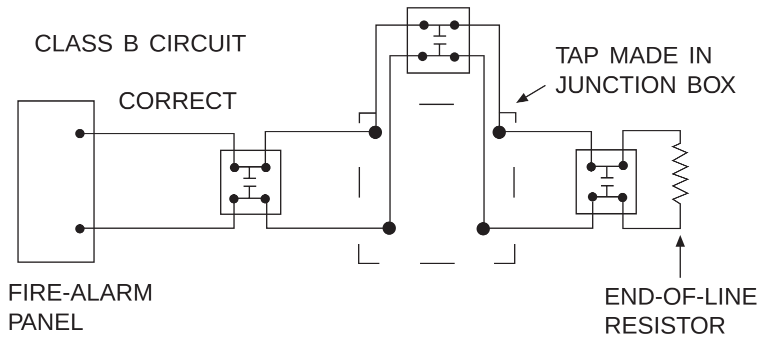


Figure 11.10 Tapping a fire alarm circuit at a later time to install additional devices must be done in such a way that the supervisory current is forced to travel through every terminal in the circuit. A proper tap of a Class A and Class B initiating circuit is shown.

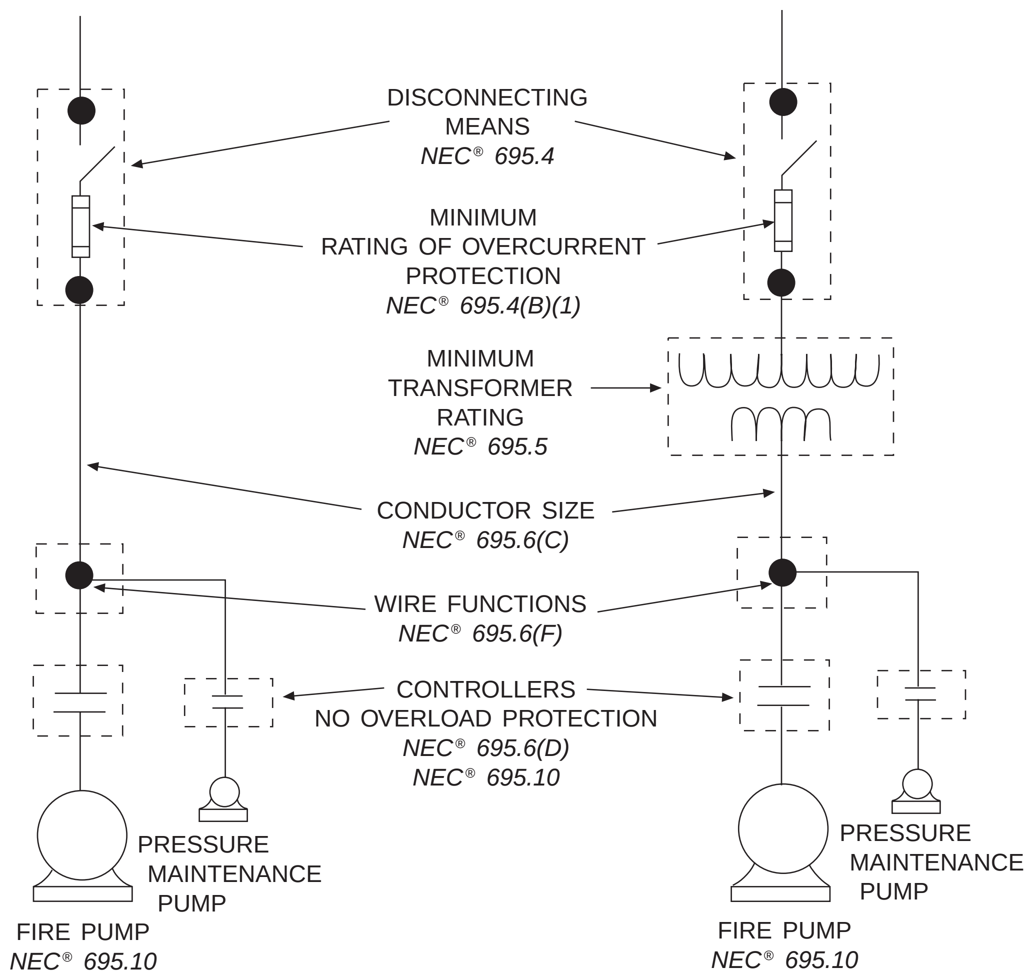


Figure 11.11 A disconnecting means with overcurrent protection is permitted to be installed on the supply side of a listed fire pump controller. The left diagram is supplied from a utility transformer and the right diagram is supplied with a customer owned transformer.

case for a typical motor circuit. The overcurrent device is not permitted to have a rating less than the locked rotor current of the fire pump and the pressure maintenance pump. The next higher standard rating overcurrent device is selected from *240.6(A).* The rating of the overcurrent device will dictate the minimum rating of switch.

NEC® 695.6(C)(2) specifies the minimum rating of conductor required for the service to the fire pump installation and the individual circuit conductors to each component of the system. In Figure 11.11, there is a main service conductor supplying both motors, and a tap to the fire pump and another tap to the pressure maintenance pump (sometimes called a jockey pump). Overcurrent protection is not permitted on these individual taps. *NEC® 695.6(D)* permits the tap conductors to be sized according to the rules in the article with no restriction as to length of tap or size of conductor as would normally be the case if the rules in *240.21* applied. The conductor minimum ampacity is to be not less than 1.25 times the full-load current of the motor. If the conductor runs are long from the power supply to the fire pump controller, there is a maximum voltage drop permitted by *695.7.* When starting, the voltage at the controller terminals is not permitted to drop more than 15% below the nominal circuit voltage which, for a 480-volt motor, would be 408 volts (480 V × 0.85 = 408 V). The voltage drop is not permitted to be more than 5% of motor rated voltage when the motor is operating at 1.15 times the motor rated full-load current. For a 3-phase motor rated at 460 volts, the voltage is not permitted to drop below 437 volts. These voltage-drop criteria can be calculated based upon locked-rotor current and motor full-load current using equations 6.6 and 6.7 in *Unit 6* to determine the minimum permitted conductor size.

If a transformer is installed in the fire pump circuit, it is required to have a minimum rating of not less than 1.25 times the full-load current of the motors plus 100% of the rating of auxiliary equipment. The minimum kVA rating of the transformer needed to supply a fire pump load can be determined using Equation 11.1 for single-phase loads and Equation 11.2 for 3-phase loads. The next larger kVA rating of transformer would be chosen after making the calculation. Overcurrent protection for the transformer is installed only on the primary side of the transformer. The overcurrent device rating is not permitted to be more than the values given in either *Table 450.3(A)* or *Table 450.3(B).* But the overcurrent device protecting the transformer is not permitted to be less than the locked-rotor current of the motors supplied after an adjustment in current is made for the primary to secondary voltage difference. This adjustment can be made using Equation 11.3. If this criteria cannot be met, then it will be necessary to increase the transformer rating in order to meet both the overcurrent protection rules of *450.3* and *695.4(B)(1).*

Single-Phase:

$$\textbf{Fire Pump Transformer kVA} = \frac{\textbf{Voltage} \times \textbf{Current} \times \textbf{1.25}}{\textbf{1000}} \qquad \textbf{Eq. 11.1}$$

Three-Phase:

$$\textbf{Fire Pump Transformer kVA} = \frac{\textbf{1.73} \times \textbf{Voltage} \times \textbf{Current} \times \textbf{1.25}}{\textbf{1000}} \qquad \textbf{Eq. 11.2}$$

$$\textbf{Minimum Fuse Rating} = \textbf{Motor Locked-Rotor Current} \times \frac{\textbf{Secondary Voltage}}{\textbf{Primary Voltage}} \qquad \textbf{Eq. 11.3}$$

The following examples will help to understand the various rules for sizing conductors, disconnecting means, and overcurrent protection for a fire pump installation.

Example 11.1 A fire pump installation in a building consists of a 75-horsepower, 3-phase, 460-volt, design B motor and a pressure maintenance pump rated 1.5 horsepower, 3-phase, 460 volts, design B. There is a fusible disconnect installed ahead of the controller as shown in Figure 11.12. Determine the minimum size copper conductors with 75°C insulation and terminations permitted to supply these two motors assuming the voltage-drop limitations will be satisfied.

Answer: *NEC® 695.6(C)(2)* requires the conductors to be not less than 1.25 times the combined full-load current of the two motors. Look up the motor full-load currents in *Table 430.250.* Size the conductors using *Table 310.16*. The 75-horsepower motor has a full-load current of 96 amperes, and the 1.5-horsepower motor has a full-load current of 3.0. The minimum conductor ampacity is 124 amperes (99 A × 1.25 = 124 A). The minimum conductor size permitted is 1 AWG copper.

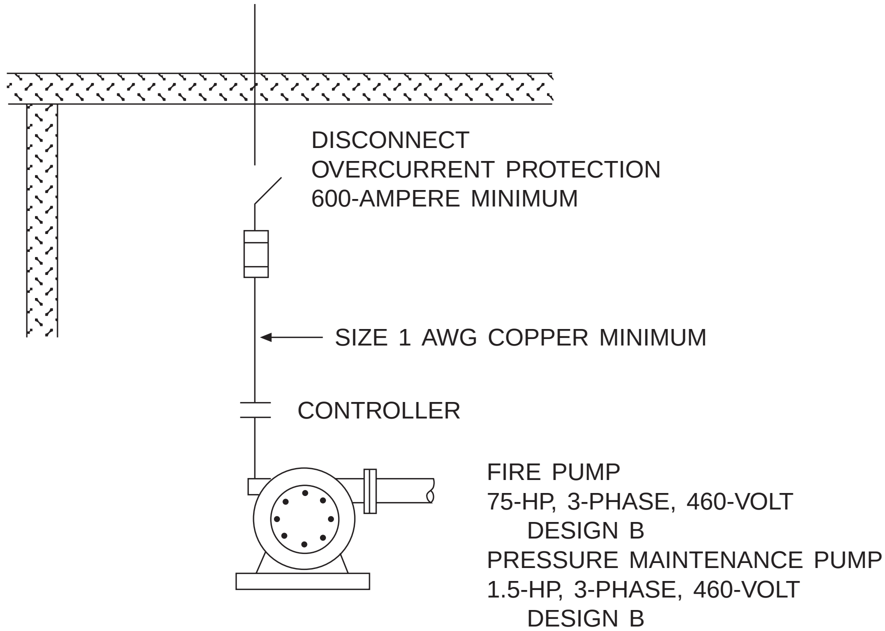


Figure 11.12 The minimum conductor size for a fire pump installation is required to be not less than 1.25 times the full-load current of the fire pump and pressure maintenance pump motors plus the full-load current of other associated loads.

Example 11.2 With the same fire pump installation as Example 11.1, determine the minimum size fuses permitted to be installed in the disconnect.

Answer: *NEC® 695.4(B)* requires the rating of the overcurrent device in the disconnect to be not less than the sum of the locked currents of the two motors. Look up the locked rotor currents in *Table 430.251(B)* and find 543 amperes for the 75-horsepower motor and 20 amperes for the 1.5-horsepower motor. The combined locked rotor current is 563 amperes. The next higher standard overcurrent device rating listed in *240.6(A)* is 600 amperes.

Example 11.3 Assume the fire pump installation of Example 11.1 is supplied through a customer owned transformer as shown in the right-hand diagram of Figure 11.11. Determine the minimum rating of transformer required for the fire pump installation.

Answer: *NEC® 695.5(A)* requires the transformer to have a kVA rating not less than 1.25 times the full-load volt-amperes of the motor. This is determined using Equation 11.2. Look up the full-load current in *Table 430.250* and multiply by the voltage and by 1.25 and 1.73 to get 102.8 kVA (99 A $\times$ 480 V $\times$ 1.73 $\times$ 1.25 = 102,762 VA).

ALTERNATE ELECTRICAL POWER SYSTEMS

Alternate electric power systems can be used for a variety of applications. These systems can be used as a stand-alone system to provide the total power needs when the building is located in a remote area where extension of utility lines to the building is impractical. Alternate power systems can be used as standby power. In this case, the power system is connected to the normal power system with a transfer switch and operated only when utility power is not available. Another approach is to operate the alternate power system interactively in parallel with the utility power system. This must be done in such a way that the two power systems will be synchronized. Excess power leaves the property and is sold to the utility. The connection is made only by utility approval. The economics of this arrangement vary from state to state. Following is a discussion of the most popular alternate power sources and the major components of alternate power systems.

Solar Photovoltaic Systems

The photovoltaic process was first discovered in 1839. It was in 1954 when Bell Laboratories developed the first practical solar cell to produce dc power. Solid state electronic devices are made of semiconducting materials such as silicon crystals containing an impurity that gives them an apparent charge, either positive or negative. These crystals are called n-type semiconductors and p-type semiconductors. A solar cell consists of an n-type semiconductor in contact with a p-type semiconductor. When light penetrates these semiconducting materials, they absorb much of the energy of the photons of light, which dislodges electrons from their positions within the atomic crystal structure. Electrons from the p-type semiconductor cross the boundary (called a junction) and enter the n-type semiconductor. An electrical field between these two materials prevents the electrons from returning across the junction. If an electrical conductor is attached to each of the semiconductors, the electrons can return from the n-type semiconductor to the p-type semiconductor through an external electrical circuit. A cross-sectional view of a solar cell is shown in Figure 11.13.

A typical solar cell has an area of about 100 square centimeters (15.5 in.^{2}). The power output of a solar cell depends upon the intensity of light received. At noon in areas where the sun is very high and the sky is clear, the output of a solar cell is about 3 amperes or more at 0.5 volts which gives 1.5 watts. Later in the day, the power output will decrease as the sunlight must travel through the thick atmosphere. Located in space above the earth's atmosphere, solar cells produce about 35% more energy than at noon on earth. Solar cells are expensive to produce. Research continues to produce them at lower cost with as high an efficiency as possible. Single-crystal solar cells (mono-crystalline) have the highest practical efficiency which is about 20%. Polycrystalline solar cells (multicrystalline silicon) are less expensive to produce but have a lower efficiency. Amorphous silicon cells consist of a thin film deposited on a base material and are relatively inexpensive to produce, but their efficiency is lower than for single-crystal solar cells.

Solar cells are arranged into modules consisting typically of 36 solar cells connected in series to give a practical operating output of approximately 18 volts dc and a maximum operating current level of about 3 amperes. These are frequently called the maximum power point voltage and current (V_{mpp} and I_{mpp}). The open-circuit voltage of the module is the output voltage with no current being drawn. The open-circuit voltage (V_{OC}) will be higher than the operating output voltage. Wire insulation and all electrical components must be rated higher than the open-circuit voltage of the system. Another important characteristic of a photovoltaic module is the short-circuit current (I_{SC}). This is the maximum current that can be supplied by the photovoltaic module when the output terminals are shorted together. Ambient temperature affects the output of a solar cell. The lower the ambient temperature, the higher the rated open-circuit voltage of the solar cell. Required markings on a photovoltaic module are listed in *690.51* and include these values plus maximum power and maximum permitted system voltage.

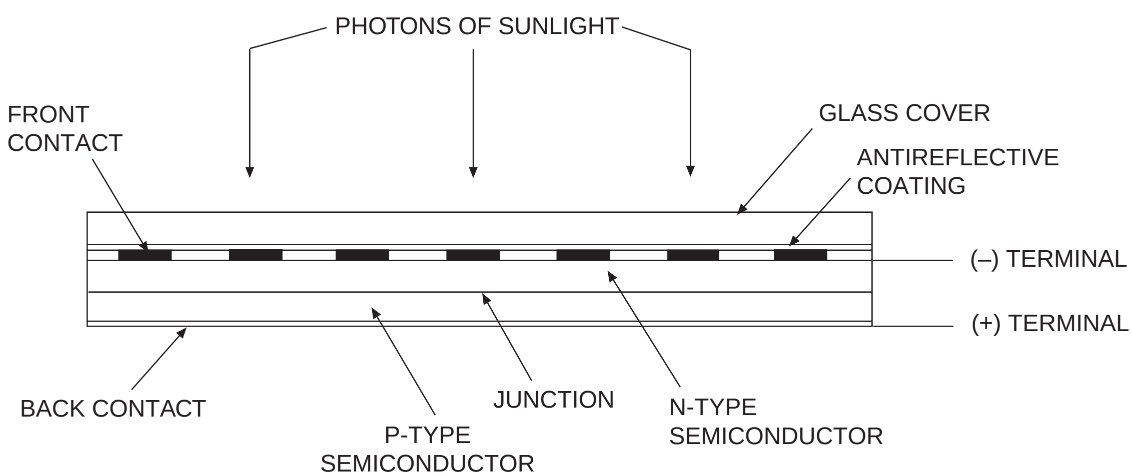


Figure 11.13 A solar photovoltaic cell consists of a p-type semiconductor on the bottom and an n-type semiconductor on top. When sunlight falls on the cell, electrons move across the junction from the bottom layer to the top layer producing about 3 amperes or more of direct current at 0.5 volts.

Photovoltaic modules are connected together in series to obtain the desired operating voltage. Typical systems operate at 12, 24, and 48 volts. Modules can be connected together in series to obtain a higher system voltage. The maximum permitted system voltage marked on the module must not be exceeded. One module will supply 12 volts, two modules in series will supply 24 volts, and four modules in series will supply 48 volts. Panels are connected in parallel to increase the current and power output from an array. When connected in series, the voltage and power of the individual modules will add. The maximum operating current will remain a constant value. When connected in parallel, the power and current of modules or sets of modules will add. The operating output voltage will remain a constant value. A stand-alone photovoltaic system to provide only dc power will have a photovoltaic array, a charge controller, and a set of batteries. With the addition of an inverter both ac and dc loads can be supplied. A system of this type is shown in Figure 11.14.

The operating voltage of the photovoltaic array must be higher than the nominal operating voltage of the system. Maximum output will not be maintained at all times and the photovoltaic panels must produce a voltage high enough to charge the batteries. Output voltage to the batteries and the loads will be regulated by the charge controller. The charge controller monitors the status of the batteries and the load and controls the rate of charging. By supplying the batteries and loads with a series of dc pulses, the charge controller can maintain the average output voltage at the desired level. When the battery charge is high, the pulses are far apart and when the battery charge is low, the pulses are close together.

Article 690 deals with the installation of the total photovoltaic system. The photovoltaic system may be installed to provide only dc power as a stand-alone power source or fed into an inverter to produce ac 60-hertz power. To maintain a constant power supply throughout the day, this system must include batteries. Rules for

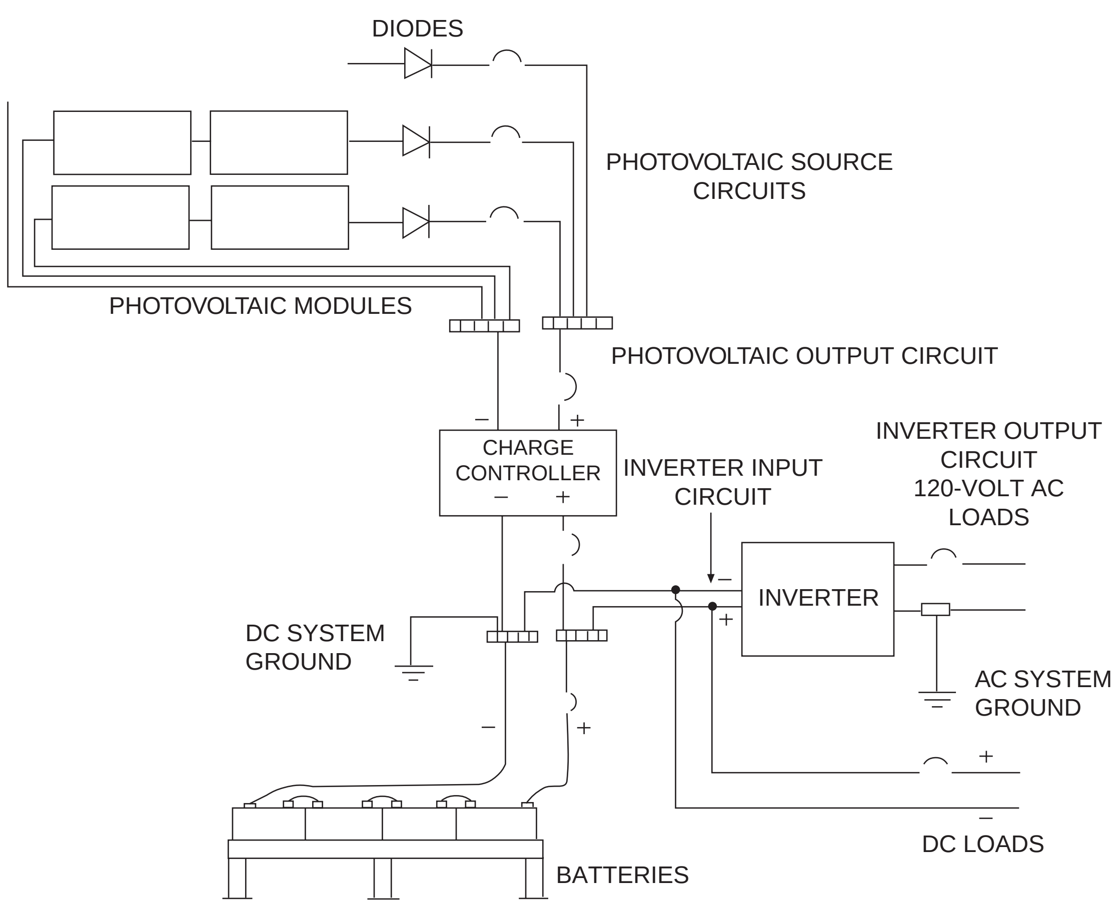


Figure 11.14 A solar photovoltaic power system that produces alternating current for use in a premises wiring system usually has a charge controller, batteries, and inverter along with the solar array. Disconnects are required to isolate each component of the system and overcurrent devices are required to protect all conductors and equipment.

the installation of batteries are found in *Article 480*. A typical example will help to understand how the total system ratings are determined and how different sections of the Code apply.

Example 11.4 The individual modules of a mono-crystalline photovoltaic system to be installed for a dwelling is rated with an open-circuit voltage (V_{OC}) of 20.9 volts, a maximum short-circuit current (I_{SC}) of 4.2 amperes, operating voltage of 17.0 volts, maximum operating current of 3.82 amperes, and maximum power (P_{max}) of 65 watts. Each module is 18.5 by 40.5 in. (47 by 103 cm). The system will operate at a nominal 24 volts dc with two modules connected in series for each module set. The array will consist of 12-module sets connected in parallel. The installation is similar to Figure 11.14. The lowest expected winter temperature is 20°F (–7°C). For each module set, determine the following: open-circuit voltage, short-circuit current, operating voltage, maximum operating current, and maximum power output.

Answer: The short-circuit current (I_{SC}) will remain at 4.2 amperes. The maximum output current will remain at 3.82 amperes. There are two modules in series. Therefore, the open-circuit voltage (V_{OC}) will be 41.8 volts (20.9 V + 20.9 V = 41.8 V). The operating voltage will be 34.0 volts (17.0 V + 17.0 V = 34.0 V). The maximum power (P_{max}) will be 130 watts (65 W + 65 W = 130 W).

All wiring and equipment of the photovoltaic system are required to have a rating not less than the maximum open-circuit voltage of the system. *NEC® 690.7* describes the method of determining the open-circuit voltage of the system. The open-circuit voltage of the module sets must be corrected for the lowest expected ambient temperature. For Example 11.4, the open-circuit voltage of each module set is 41.8 volts and the correction factor from *Table 690.7* is 1.13 to give a maximum photovoltaic system voltage of 47.2 volts (41.8 V × 1.13 = 47.2 V). These values are used to size the conductors, overcurrent protection, and ratings of disconnects.

NEC® 690.15 requires that disconnecting means be provided so that all components can be isolated from all sources of power. In the case of a photovoltaic power source, a voltage will be present any time the sun is shining on the solar cells. Switches and circuit breakers installed in the dc circuits must be dc rated. *NEC® 690.8(B)* specifies that conductors shall have an ampacity not less than 1.25 times the computed maximum circuit current determined in *690.8(A).* Photovoltaic systems are assembled in different ways, and care must be taken to identify the current that can flow on the various sections of the circuit.

Example 11.5 The photovoltaic array described in Example 11.4 supplies 60 hertz ac power at 120 volts, with a 2500-watt continuously rated true sine wave inverter. The inverter has a surge rating of 7500 watts. The continuous output current is 20.8 amperes. The nominal input is 24 volts and 123 amperes dc. The input voltage range is 14.9 to 30.7 volts dc with an input current at minimum voltage of 197 amperes dc. The efficiency of the inverter is 85%. There are 24 deep cycle, 6-volt lead-acid batteries with a rating of 350 ampere-hours. The batteries can deliver up to 75 amperes for three hours continuously on a charge of 17.5 amperes for 20 hours. Four batteries are connected in series to get 24 volts and six sets are connected in parallel. The ambient temperature of the wiring on the solar array could reach 130°F (54°C). Determine the minimum size copper conductors with 75°C rated terminations permitted for the following: (1) the photovoltaic source circuits to the solar modules and (2) the photovoltaic output circuit to the charge controller.

Answer: First determine the photovoltaic source circuit current, *690.8(A)(1).* There are two modules connected in series for each source circuit with a maximum short-circuit current of 4.2 amperes. The source circuit current is the short-circuit current multiplied by 1.25 to get 5.25 amperes. *NEC® 690.8(B)(1)* requires the source circuit conductors to have an ampacity not less than 1.25 times the value calculated by *690.8(A)(1),* which is 6.6 amperes (5.25 A × 1.25 = 6.6 A). Because the ambient temperature of the conductors is above 30°C, a temperature correction is required according to *690.31(C).* The correction factor from *Table 690.31(C)* is 0.67. Divide the 6.6 amperes by 0.67 to get 9.9 amperes. From *Table 310.16,* the minimum conductor size permitted is 14 AWG. However, a smaller size may be permitted.

The photovoltaic output circuit current is the sum of the source circuit maximum currents, *690.8(A)(2).* The source circuit current was determined to be 5.25 amperes. This solar array consists of six source circuits connected in parallel for an output current of 31.5 amperes. *NEC® 690.8(B)(1)* requires the conductor to have an ampacity not less than 1.25 times the output circuit current, which is

39.3 amperes. If the conductors are exposed to an ambient temperature greater than 30°C (86°F), then an adjustment must be made using the appropriate factor from *Table 690.31(C)*. Assuming no adjustment is needed, the minimum photovoltaic output circuit conductor size is 8 AWG copper. Single conductor cables listed as sunlight and moisture resistant are permitted to be installed for individual module interconnections, *690.31(D)*, in sizes 18 AWG copper and larger.

The maximum current output from the charge controller will not be greater than the maximum photovoltaic output circuit supplying the charge controller from the solar array. Therefore, the output dc conductors from the charge controller will be the same as the dc input conductors. Batteries will release current slowly for a long period of time or at a high ampere rate for a limited period of time. An overcurrent device near the batteries is important to minimize the length of unprotected circuit. The battery output conductors will depend upon the rating of the overcurrent device protecting the battery circuit. The rating of that overcurrent device will depend upon the maximum expected dc load to be drawn from the batteries. If the batteries supply an inverter, the maximum current will be the maximum draw of the inverter at the inverter minimum input voltage and producing the maximum continuous ac output current, *690.8(A)(4)*. If dc loads are supplied directly from the batteries, the sum of the ratings of the dc output circuit overcurrent devices is added to get the total dc load.

Example 11.6 Consider the photovoltaic system described in Examples 11.4 and 11.5 where all of the dc output of the system supplies the 2500-watt inverter that is 85% efficient and has a 2-wire 120-volt ac circuit that draws 20.8 amperes. The dc input to the inverter is nominal 24 volts with a minimum of 14.9 volts and a maximum of 30.7 volts. The maximum input current at minimum input voltage is 197 amperes. Determine the minimum size copper conductors between the batteries and the inverter and determine the minimum size 120-volt ac conductors from the inverter to the premises wiring system transfer switch.

Answer: The input dc current at minimum voltage is 197 amperes. *NEC® 690.8(B)(1)* requires the conductor ampacity to be not less than the value determined in *690.8(A)(4)*. The overcurrent device will be 250 amperes (200 A × 1.25 = 250 A). The minimum conductor size will be 4/0 AWG copper between the battery and the inverter applying the rule of *240.4(B)*. If the dc input current at minimum voltage is not given, it can be calculated by dividing the continuous output rating of the inverter by the minimum input voltage and the efficiency.

$$\text{dc inverter input current} = \frac{2500\text{ W}}{14.9\text{ V} \times 0.85} = 197\text{ A}$$

The inverter ac output conductor minimum size is determined by multiplying the nameplate output rating by 1.25 as stated in *690.8(B)(1)* to get 26 amperes. The minimum conductor size is 10 AWG copper.

Fuel Cell Systems

A fuel cell is an electrochemical device that converts hydrogen and oxygen into electricity, water, and heat. It is like a battery except, rather than requiring periodic recharging, it runs continuously as long as it gets a constant supply of hydrogen gas and oxygen. The process was discovered in 1839 and remained a curiosity until NASA developed it as an energy source for space travel. Fuel cells were not practical until recently because they were expensive to build. In order for the process to work, hydrogen molecules had to be broken down into its basic components of electrons and protons. That can be accomplished by exposing the hydrogen molecules to a material called a catalyst. The catalyst that can break down hydrogen contains the metal platinum, which is very expensive. Advances in chemistry and engineering in recent years have reduced the amount of platinum needed in the catalyst. Advantages of fuel cells is they have no moving parts, they run at high efficiency, they produce virtually no noise, and if operated on pure hydrogen, they run pollution free. All of the major automobile manufacturers are testing fuel cell powered electric vehicles. Fuel cells are also being tested as electric power sources for dwellings. As a result, the Code makes provisions in *Article 692* for fuel cell connection to premises wiring systems.

A simplified view of a fuel cell is shown in Figure 11.15. Fuel cells manufactured today are actually very thin, and they are assembled together in long stacks similar to slices of bread. The fuel cell has two

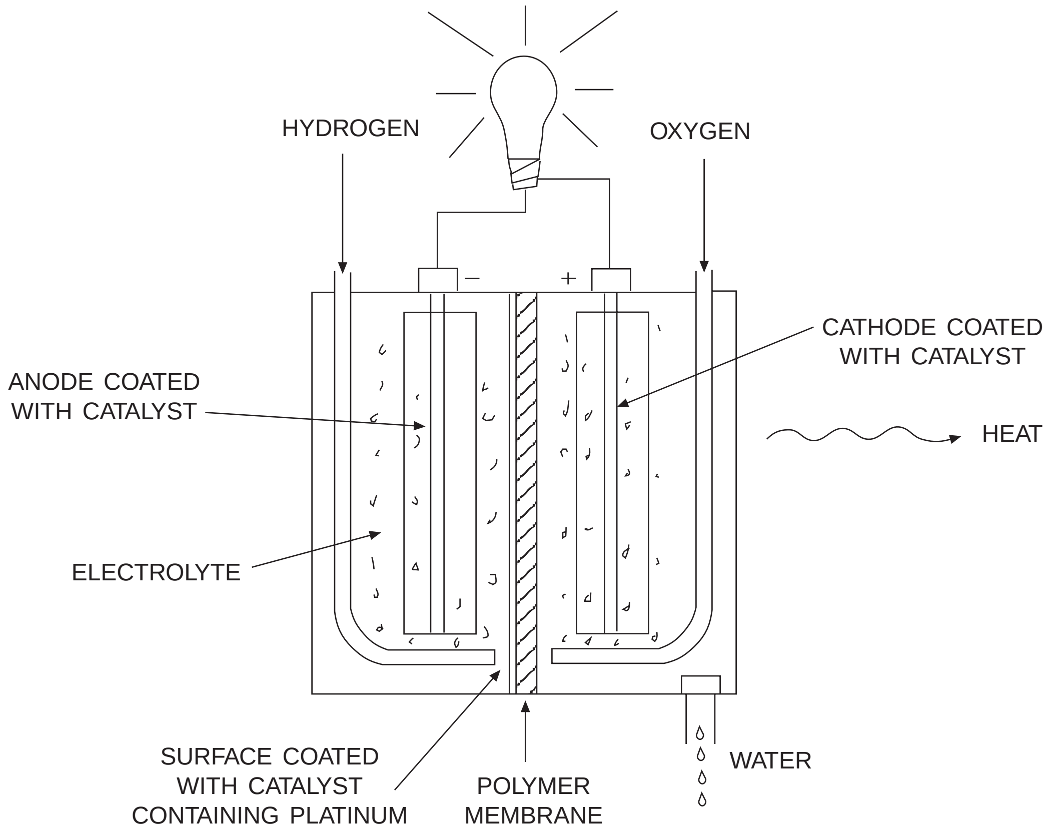


Figure 11.15 A fuel cell has two chambers containing an electrolyte and separated by a membrane. Hydrogen gas is injected into one chamber and oxygen into the other. A catalyst separates the hydrogen molecules into protons and electrons. The protons move through the membrane to the other side and combine with oxygen to form water and heat. The electrons must travel through an external circuit as direct current to get to the other chamber.

chambers separated by a membrane that is porous to protons. There is an electrode in each chamber partially coated with a catalyst. Hydrogen molecules are fed into one chamber, and the catalyst breaks down the molecules into protons and electrons. The protons pass through the membrane to the other side. The electrons are trapped in the chamber and build up a negative charge. The protons arriving in the second chamber create a positive charge. A little less than one volt will develop between the electrodes in each chamber. If a circuit is completed between the two electrodes, electrons can flow from the first to the second chamber. Oxygen is pumped into the second chamber which combines with the electrons and protons to form water. Heat is also produced during this chemical formation of water. Fuel cells produce direct current and many cells are assembled into stacks and connected in series to obtain the desired output voltage.

There are a number of different types of fuel cells available or being tested. Two types are being used as stationary units to produce power for premises wiring or interconnection to electric utility grids. One is the phosphoric acid fuel cell and the other is the proton-exchange membrane fuel cell. The latter type is being tested as a power source for electric vehicles.

Air contains plenty of oxygen to operate a fuel cell but hydrogen in the form of a gas is needed. Hydrogen gas will most likely be readily available in the future, but for now, it is not easy for the consumer to obtain. Petroleum fuels and alcohols are good sources of hydrogen. Fuel cells are available that run on natural gas, propane, ethanol, methanol, gasoline, and other fuels. Before the fuel cell can get the hydrogen it needs from these fuels, the fuel must first be reformed to free the hydrogen to become a gas. A device called a **reformer** must be installed between the fuel tank and the fuel cell. A reformer is not needed if pure hydrogen is used as the fuel. The reformer takes oxygen out of the air to combine with the carbon in the fuel to free the hydrogen. The waste product from the reformer is mostly carbon dioxide and a little carbon monoxide.

The direct current from the fuel cells can be used to power loads or it can be passed through an inverter to convert it to alternating current. A typical fuel cell power system produces a constant supply of electricity day and night and is illustrated in Figure 11.16. In order to handle temporary peak loads, the fuel cell power

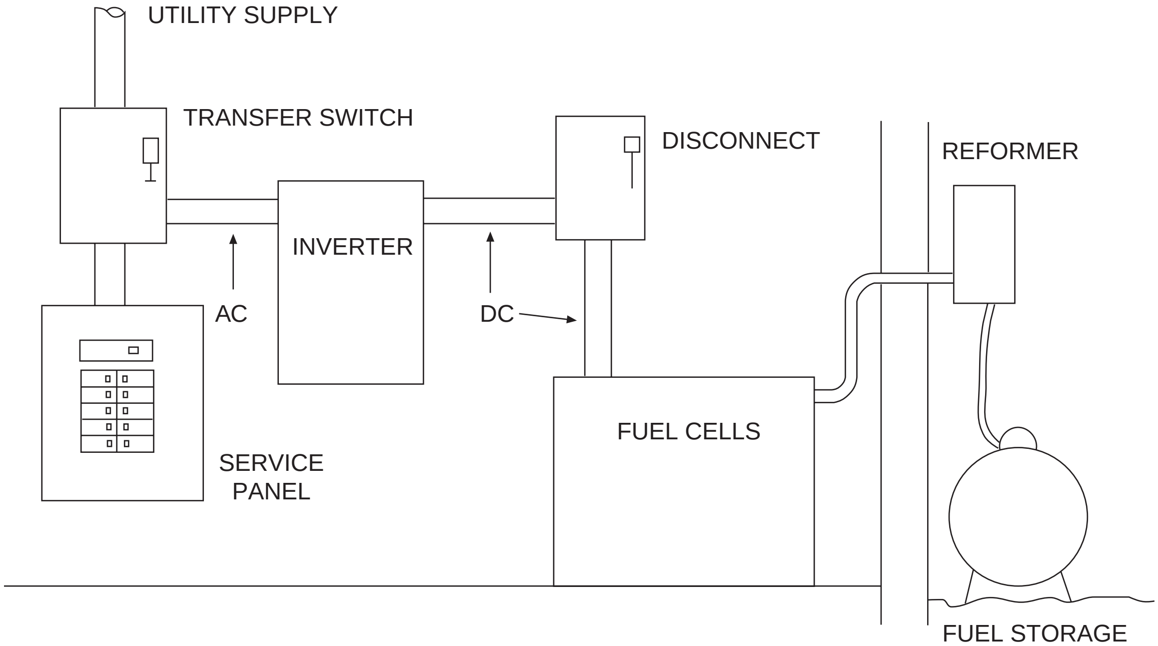


Figure 11.16 A fuel cell system operating as a standby power source uses an inverter to change the direct current to alternating current. The connection to the premises wiring system can be by means of a transfer switch. Fuels such as natural gas, ethanol, propane, and gasoline can be used as an energy source but a reformer is needed to free the hydrogen so it can be utilized by the fuel cell.

system can be combined with batteries to extend its capacity. The fuel cell power system can be interconnected to operate in parallel with the utility power grid. This may not be economical in many areas of the country. A fuel cell power system can act as a stand-alone system to power a building with no connection to the utility power grid. This may be especially desirable in remote areas where utility electrical lines are not available. It would be necessary to transport fuel to the location such as propane. Another alternative is to use the fuel cell power system as a standby power unit and connect it to a standard service through a transfer switch. Fuel cells produce heat as well as electricity. The heat can be reclaimed for water heating and space heating.

Storage Batteries

A stationary installation of storage batteries to provide electrical energy for premises lighting, power, and heating may be a separate system or it may be a part of a number of alternate power systems. Decisions relative to guarding of live parts in *110.27* or grounding of the direct current system in *250.162* depends upon the system voltage. *NEC® 480.2* under nominal battery voltage specifies that voltage is taken as a nominal value by cell. For a lead-acid battery it is 2 volts per cell and for an alkali battery it is 1.2 volts per cell. A 6-volt lead-acid battery has three cells and a 12-volt lead-acid battery has six cells.

Other important concerns are ventilation of the battery room, *480.8(A)*, working space around battery racks, *480.8(C)*, and containment of electrolyte leakage, *480.8(D)*. Ventilated lead-acid batteries release hydrogen when charging. If adequate ventilation is not provided, an explosive mixture can accumulate. The actual rules for determining working space about battery installations is found in *110.26*. *Table 110.26(A)* does not specify whether the voltages are ac or dc. Therefore, they apply to both ac and dc voltages. Minimum working space in front of equipment is given in *Table 110.26(A)* as 3 ft (900 mm). *NEC® 110.26(A)(1)(b)* permits a smaller working distance by special permission for systems operating at not more than 60 volts dc. Typical battery systems for alternate power production operate at 12, 24, and 48 volts.

Batteries used for home power should be of the deep cycle type. These are different from automotive batteries. Deep cycle batteries are built to be repeatedly heavily discharged. They give up their power at a slower rate than an automotive battery but they can take hundreds of deep discharging and recharging cycles. Their energy capacity is given in ampere-hours. Assume a deep cycle battery is rated 105 ampere-hours. Theoretically, the battery can give up its energy at a rate of 105 amperes for one hour or at a rate of one ampere for 105 hours. These batteries are generally rated for an even discharge over 20 hours. This would mean that a 105 ampere-hour battery is rated to deliver a steady current of 5.25 amperes for 20 hours. If more current is needed, multiple batteries can be connected in parallel. For example, if four 105 ampere-hour batteries are connected in parallel, they will be designed to deliver 21 amperes. The batteries will deliver current at a much faster rate, but batteries will deliver the maximum energy to a load if discharged slowly.

Golf cart batteries are generally used for home power applications. They deliver 6 volts and have a rating between 220 and 300 ampere-hours. They are unsealed and must be housed in a well ventilated area. Since most home applications are at 12 or 24 volts, they are required to be connected in series to obtain the required voltage and in parallel to obtain the desired current delivering capacity. Industrial stationary batteries deliver 2 volts and have ratings up to 3000 ampere-hours. They are generally too bulky and hard to handle for home applications.

Inverters

An inverter is an electronic device that converts direct current to alternating current. Alternate power sources such as batteries, photovoltaics, fuel cells, and some wind machines produce direct current. This direct current can be used for many applications but in the home there are appliances that require alternating current. Most inverters are made to accept 12, 24, or 48 volts dc. Inverters made for the U.S. market generally have a 2-wire output of 120-volt, 60-hertz ac. Some manufacturers list their inverters to be connected in parallel to the dc supply with their outputs connected in series to produce 120/240-volt, 3-wire ac. The Code recognizes that most inverters will have a 2-wire, 120-volt ac output. *NEC® 692.10(C)* permits a 120/240-volt, 3-wire panel to be supplied by a stand-alone 2-wire 120-volt power source provided there are no 240-volt loads operated or there are no multiwire branch-circuits.

The output of an inverter may be a true sine wave or it may be a modified sine wave. A true sine wave is more difficult to produce and the equipment is more expensive. The output from a true sine wave inverter and a modified sine wave inverter is shown in Figure 11.17. The modified sine wave inverter may result in interference with some electronic equipment.

Generators

Generators are available that produce alternating current and direct current. An ac generator is used for the purpose of supplying power to a premises wiring system. Rules applying to generators are found in *Article 445. NEC® 445.12(A)* requires that generators be provided with overload protection. No specific rules are provided as to how this is accomplished. It is, therefore, the responsibility of the manufacturer to provide generator overload protection. If overcurrent protection is not present and the generator is not marked as inherently protected, then overload protection is required to be installed at the generator end of the conductors supplying the premises

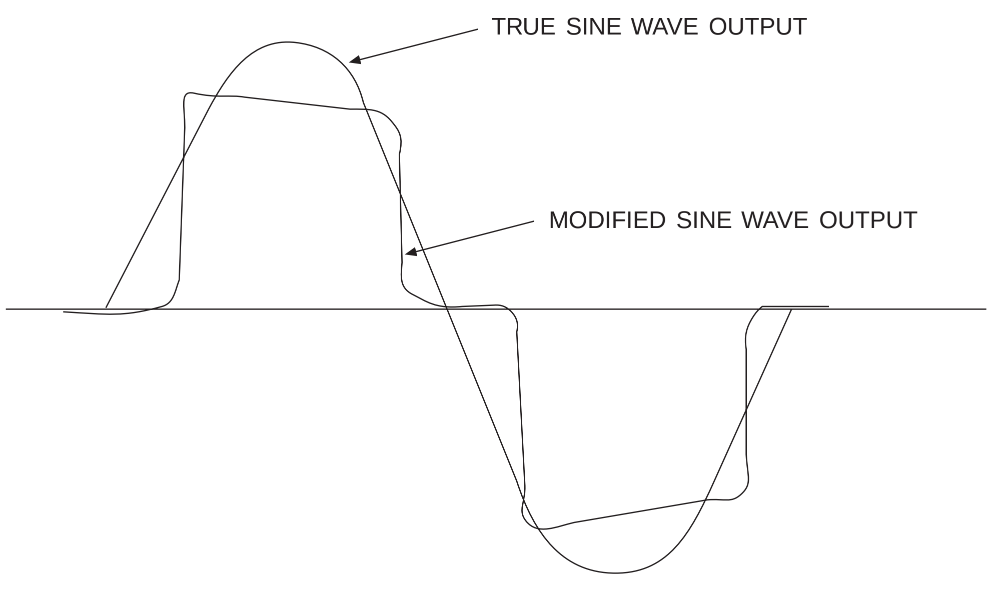


Figure 11.17 The alternating current waveform from an inverter is usually either a true sine wave or a modified sine wave.

wiring system. All the electrician can do is base the overcurrent protection on the full-load current rating of the generator.

The nameplate is required to provide the generator rated full-load output current. If that value is not given, the full-load current can be estimated from the continuous kW rating and the output voltage. Equations 11.4 and 11.5 can be used to estimate the full-load current of an ac generator if only the continuous kW rating and voltage are given.

$$\textbf{Approximate Full-Load Current}_{\textbf{1-Phase}} = \frac{\textbf{kW} \times \textbf{1000}}{\textbf{Voltage}} \qquad \textbf{Eq. 11.4}$$

$$\textbf{Approximate Full-Load Current}_{\textbf{3-Phase}} = \frac{\textbf{kW} \times \textbf{1000}}{\textbf{1.73} \times \textbf{Voltage}} \qquad \textbf{Eq. 11.5}$$

NEC® 445.18 requires that a disconnecting means be installed at the generator on the load side of all overcurrent and control devices. Generally, this disconnecting means is an integral part of the generator. *NEC® 445.13* applies to the conductors from the generator terminals to the premises wiring system. The conductors between the generator and the point of connection to the premises wiring system are not permitted to have an ampacity less than 1.15 times the generator rated continuous current. The conductors must have an allowable ampacity not less than the rating of the overcurrent protection at the generator. For a permanent installation, the conductors are usually run in raceway and sized according to *Table 310.16,* as shown in Figure 11.18. For a portable generator installation where multiconductor flexible cord is used, the conductors are sized using *Table 400.5(A)*. Large portable generator installations use single-conductor cables with pin and sleeve connectors for each conductor. These cables when used as individual conductors separated in air are sized using *Table 400.5(B)*.

Connecting Alternate Power Sources

Connecting an alternate power source to a premises wiring system can be done in several ways depending upon the purpose of the installation. The most simple installation is where an alternate power source is the only electrical supply to a building. In this case, the building is wired as normal unless the power supply is 2-wire, 120-volt, 60-hertz ac. In this case, 240-volt circuits and multiwire branch-circuit with a common neutral are not permitted. A stand-alone power source such as a photovoltaic system or a fuel cell system is connected directly to the main disconnect or service panel for the building. A building panel supplied from a 2-wire, 120-volt, 60-hertz inverter is shown in Figure 11.19. This type of connection is permitted by *690.10(C)* and *692.10(C)*.

Alternate power sources may be installed to act as backup systems to the normal utility power supply. A means must be installed to transfer the load or circuits from the utility supply to the alternate power source.

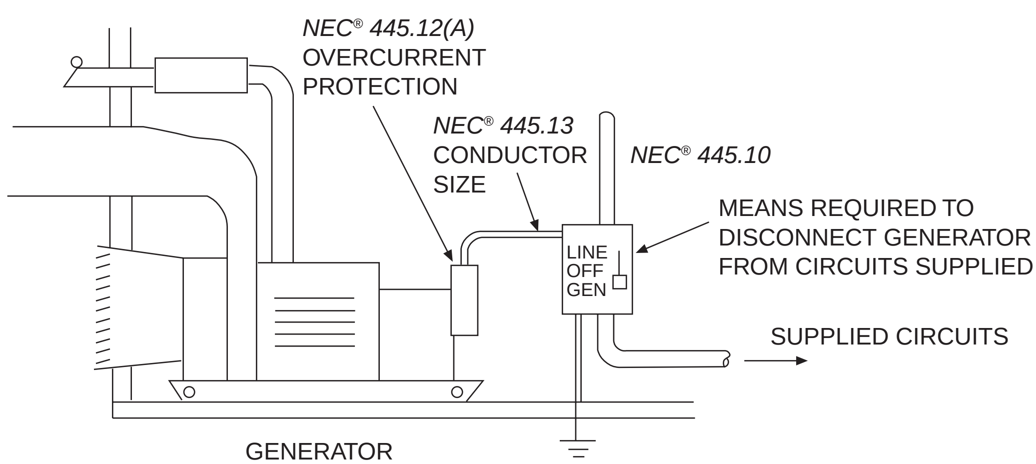


Figure 11.18 The output conductors from a standby generator are required to be sized based upon the rating of the overcurrent device on the generator, or if not provided at the generator, not less than 1.15 times the continuous full-load output of the generator.

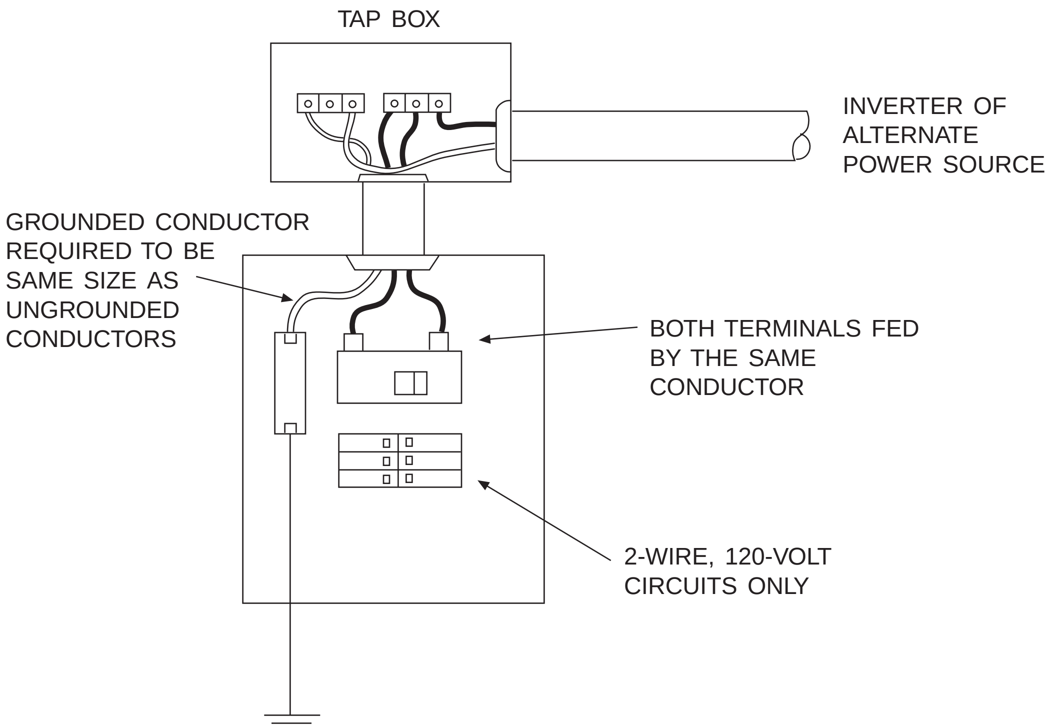


Figure 11.19 A 120-volt, 2-wire inverter output is permitted to supply power to a 3-wire panelboard provided there are no 240-volt loads or multiwire branch-circuits. For this stand-alone system, the connections are made in a tap box with both sides of the main circuit breaker supplied by the same undergrounded conductor from the inverter.

This must be done with some type of transfer equipment in such a way that it prevents inadvertent interconnection of normal and alternate power sources. This is essential to ensure the safety of personnel at the premises and working on utility lines. Figure 11.16 shows a single-phase double-pole, double-throw transfer switch installed ahead of the main service panel so that all circuits can be supplied from the alternate power source. A transfer switch installed at this location will act as the service disconnecting means and must be rated as suitable for use as service equipment. The requirement for the installation of transfer equipment that is legally required is found in *701.7(A)*. The rule for the installation of optional standby power equipment is found in *702.6*. An optional standby power system is defined in *702.1*. An optional standby power system is one that is permanently installed including the generator and prime mover and also a portable generator connected to a premises wiring system through permanently installed transfer equipment such as shown in Figure 11.3.

For the connection of portable generators for temporary installations where the connection is to a premises wiring system normally supplied by utility power, the rules for connection of the alternate power source are found in *702.6(C)*. The connection is required to be made in such a manner that an inadvertent connection between utility power and alternate power cannot occur. The load transfer to the standby generator is permitted by *702.6* where a transfer switch is connected to each circuit that is to be switched to the alternate power source as illustrated in Figure 11.20. A fuel cell electrical power system may be used as a back-up system for utility power in which case the method of interconnection to the premises wiring system is covered in *692.59.*

Grounding dc Power Sources

Direct current electrical system grounding is covered in *Article 250, Part VIII*. Generally dc systems are operated as 2-wire systems, although there are applications for a dc 3-wire electrical system. Standard convention for direct current systems is to ground the negative terminal or conductor. The ungrounded conductor is positive. Red terminals are ungrounded or positive, and black or white terminals are grounded or negative. *NEC® 250.162(A)* requires that 2-wire dc systems operating at more than 50 volts, but not more than 300 volts and serving a premises wiring system, are required to have one conductor grounded. Any 3-wire direct current system serving premises wiring is required to have one conductor grounded. *NEC® 250.160* makes reference to other sections of *Article 250* not specifically intended for ac power systems, and therefore, *250.52* will apply when selecting a grounding electrode for a dc power source.

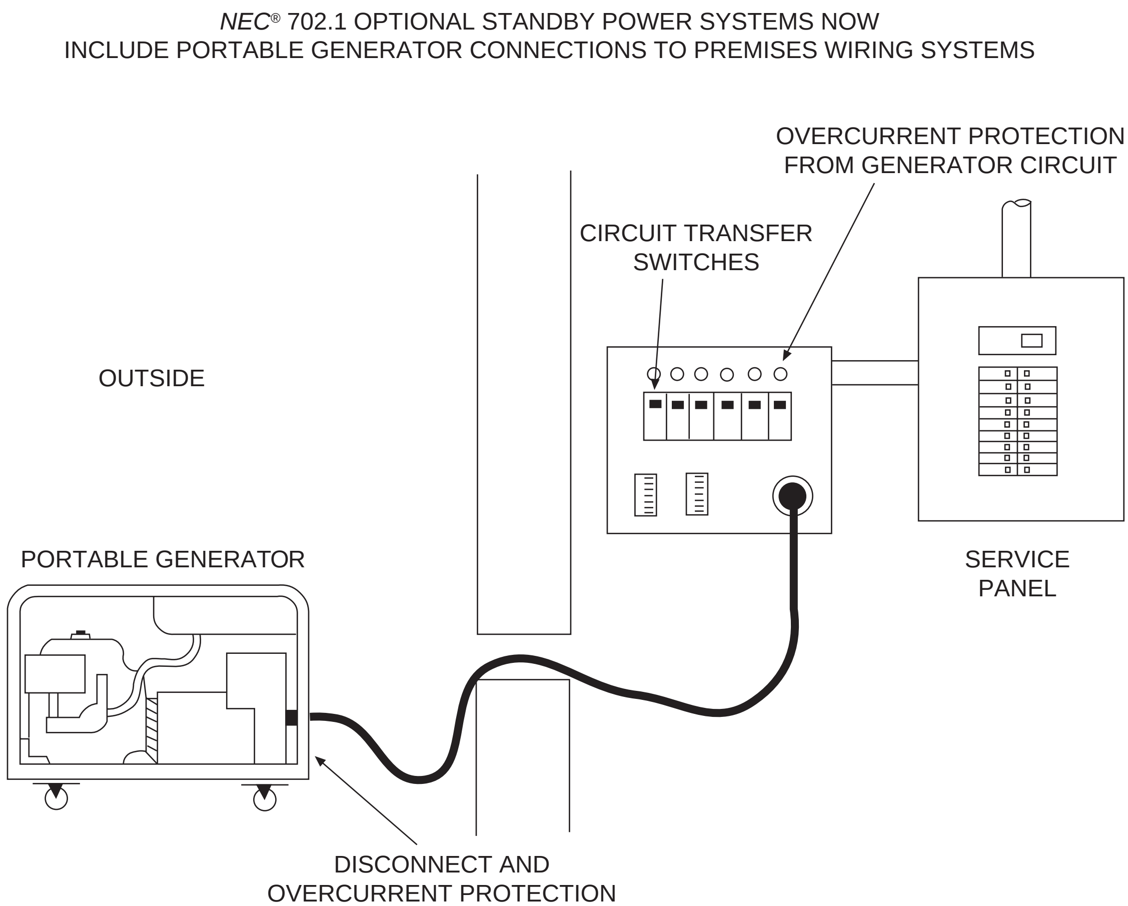


Figure 11.20 A portable generator connected to a premises wiring system is permitted to be connected through a load transfer device either on the supply side or the load side of the service disconnecting means.

The rules for sizing the grounding electrode conductor are found in *250.166.* The minimum size copper grounding electrode conductor in any case is 8 AWG. The minimum size grounding electrode conductor is not permitted to be smaller than the ungrounded conductor. If the grounding electrode is a rod, plate, or pipe, the grounding electrode conductor is not required to be larger than size 6 AWG. If a concrete-encased electrode is used, the maximum size required is 4 AWG. If a grounding ring is used, the minimum size conductor for the grounding ring is 2 AWG and the grounding electrode conductor is required to be of the same size. This grounding electrode conductor is required to be connected to the negative conductor either at the dc source or at the first overcurrent device or disconnecting means supplied by the source. Optional grounding of dc power systems intended to supply premises wiring is common.

NEC® 250.168 requires a bonding jumper to connect the grounded-circuit conductor, the grounding electrode conductor, and the equipment grounding conductor. This conductor is required to be of the same size as the grounding electrode conductor sized in accordance with *250.166.*

Even if a dc electrical system produced by a stand-alone power source is not required to have one conductor grounded to the earth, it is required to provide a grounding electrode and connect it to the metallic enclosures of the electrical systems with a equipment grounding electrode conductor. The rules for sizing the grounding electrode conductor are the same as described in *250.166.*

Direct Current Rating

Direct current as discussed in *Unit 1* is a steady flow of current in one direction. The voltage maintains a constant level and the current never stops flowing. With an ac circuit, the voltage reverses polarity two times each cycle and reaches a zero value two times each cycle. The current builds to a maximum and decreases to zero and stops. Then the current reverses direction. The current actually stops flowing two times each cycle. It is easier to open a circuit when the current stops flowing two times each cycle as opposed to continuously flowing in one direction at a constant level. For this reason, devices intended to break current flow in a dc circuit must be rated for dc operation.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 445 Generators

445.18: A generator is required to be equipped with a disconnecting means that will separate the generator and all control and protective devices from the premises circuits supplied. This is a requirement if the generator is not capable of being easily shut down or in cases where the generator operates in parallel with another generator or some other source of electrical power. If it is a stand-alone generator with no other sources of power, then this rule does not apply. What is new with this section is that when the generator does operate in parallel with another power source, the required disconnecting means must be capable of being locked in the open position.

445:19: This is a new section that permits a single feeder from a single generator or multiple generators operating in parallel to supply multiple disconnects in a manner similar to a service supplying up to six disconnecting means. The feeder is permitted to supply a single switchboard with multiple overcurrent devices or individual enclosures with overcurrent protection. This new arrangement is illustrated in Figure 11.21.

Article 480 Storage Batteries

480.5: A disconnecting means now is required to be installed for all ungrounded conductors from a battery system delivering power at over 30 volts. The disconnecting means is required to be readily accessible and within sight of the battery system. This same issue is now covered in *240.21(H)*, except in that section it states that the overcurrent protection is to be installed as close to the battery terminals as practical.

Article 690 Solar Photovoltaic Systems

690.4(D): There is a longer list of equipment that may be used with a photovoltaic power system that is required to be specifically identified and listed for such use.

690.5: Ground-fault protection required by the previous edition of the Code only applied to roof-mounted dc arrays on dwellings. Now this rule applies to all photovoltaic arrays, but there are two exceptions. The first exception applies in the case of ground-located or pole-mounted arrays with not more than two source circuits. If all wires are run not on buildings, then ground fault protection is not required. The other exception applies to systems not mounted on dwellings and equipment grounding conductors are

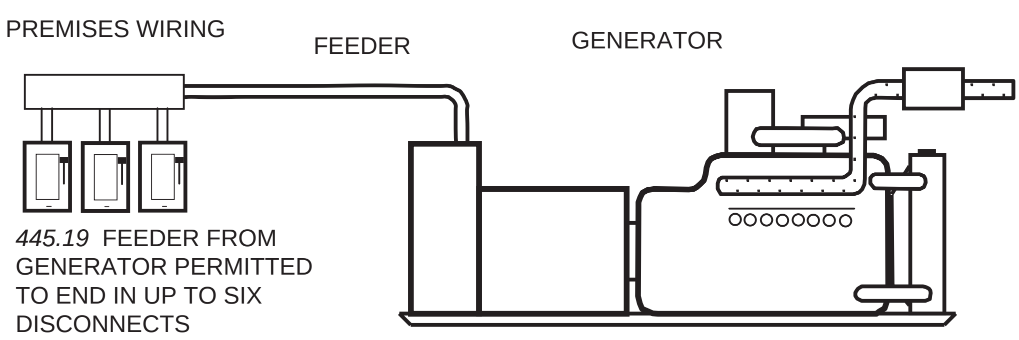


Figure 11.21 A feeder from a generator to a premises wiring system is permitted to terminate in up to six disconnecting means grouped in one location or in a single enclosure.

sized according to *690.45*. That section requires the equipment grounding conductor to have two times the ampere rating of the circuit conductors. Photovoltaic systems under short circuit and fault conditions do not produce the high-fault currents typically experienced in an ac system, and thus overcurrent devices on these dc systems usually do not open quickly. Adequate sizing of the equipment grounding conductor is necessary for protection of equipment and fire prevention during a ground-fault.

690.10(A): There is an additional requirement that for a stand-alone photovoltaic system, the output of the inverter is required to be adequate to supply the largest single load it is intended to supply.

690.10(D): A stand-alone photovoltaic system is permitted to directly supply a load that is only powered when there is adequate light. This new section makes it clear that an energy storage system such as batteries is not required for a stand-alone system.

690.31(A): Where a photovoltaic source or output circuit operates at more than 30 volts and is installed where readily accessible, the circuit conductors shall be run in raceway.

690.31(F): When fine stranded cables are used, listed connectors shall be used to terminate the cables.

690.33(C): Connectors for cables operating at over 30 volts and readily accessible shall be of a type that requires a tool for opening.

690.33(E)(2): The previous edition of the Code required that connectors be of a type that are safe to disconnect under load. That is not always practical. Now there is a rule that if the connector is not safe to disconnect under load, it shall be of a type that requires a tool to open and be marked with a warning not to open under load.

690.42 Exception: This section permits a connection to a grounding electrode to be made at any single point on the system. This new exception permits the grounding electrode to be connected through a listed ground-fault detection device that opens the connection to the grounding electrode if a ground fault occurs.

690.43: When photovoltaic system grounding conductors are installed away from an array, they shall be run with the other circuit conductors.

690.45(A): The rules for sizing an equipment grounding conductor have changed. If there is an overcurrent device in the circuit, the equipment grounding conductor is required to be sized based upon that overcurrent device rating using *Table 250.122*. If there is no overcurrent device, the equipment grounding conductor is to be sized using *Table 250.122* with the short-circuit current rating of the equipment as an assumed overcurrent device.

690.45(B): For other than dwellings and equipment for which ground-fault protection is not provided, the equipment grounding conductor shall have a rating of not less than two times the ampere rating of the circuit conductors. The required grounding of a photovoltaic power system is illustrated in Figure 11.22.

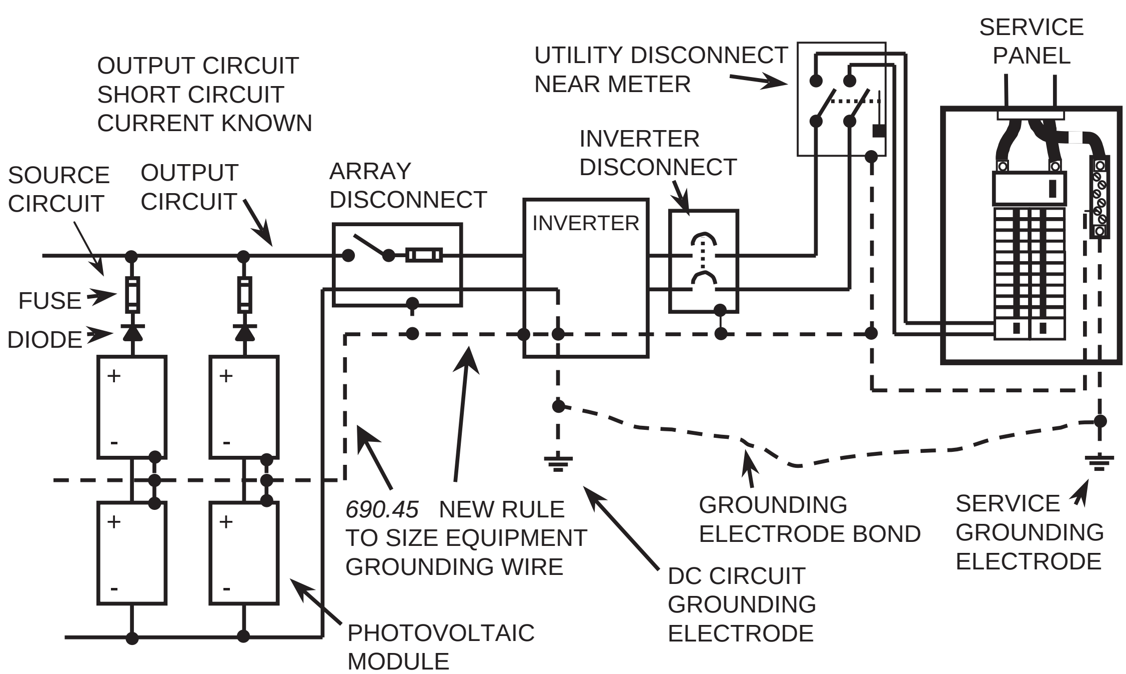


Figure 11.22 There are new rules to determine the size of the equipment grounding conductor to equipment on the dc circuit of a photovoltaic power system for a non-dwelling installation when ground-fault equipment is not provided.

690.46: This is a new section specifying the minimum size of equipment grounding conductor for a photovoltaic array where there are multiple source circuits to modules. The equipment grounding conductor for a group of modules is permitted to be a single conductor sized in accordance with the largest rated circuit of the group as permitted in *250.120(C).*

690.47(C): New rules are provided for sizing and installing the grounding electrode conductors for the ac and dc portions of the photovoltaic system.

690.47(D): This is a new section that requires a grounding electrode to be installed for the frames of a photovoltaic array that is ground mounted, pole mounted, or roof mounted. If a metal array structure in contact with the earth or a metal pole supporting an array is considered to be effectively grounded as required by *250.52,* then an additional grounding electrode is not required. A roof-mounted array is permitted to be grounded to the metal structure of the building if that metal building structure meets the requirements of *250.52* as an effective grounding electrode. Photovoltaic systems where the array and load served are a single unit are not required to be grounded to the earth. If the array is located within 6 ft (1.8 m) of the premises wiring system grounding electrode, an additional grounding electrode is not required.

690.57: All sources of power are required to be capable of being disconnected. A marked off position of a disconnecting means is to indicate that power has been disconnected. If an inverter is switched off but allows ac power to pass to loads, it is to so indicate and not indicate off. A switch marked off must disconnect power in both directions.

690.64: This section specifies the connection of a photovoltaic power system to operate interactively with a utility network. The rules of connection are basically the same as provided in *705.12,* which is explained later.

Article 692 **Fuel Cell Systems**

692.41: Fuel cell power systems that have both ac and dc system grounding requirements are permitted to have a common grounding electrode for both systems. These systems are required to be bonded together, and the grounding electrode conductor is required to be the larger of the ac grounding according to *250.66* or the dc grounding according to *250.166.*

692.65: This section specifies the connection of a fuel cell power system to operate interactively with a utility network. The rules of connection are basically the same as provided in *705.12,* which is explained later.

Article 695 **Fire Pumps**

695.4(A): When a fire pump receives a source of power supply from a generator, a separate disconnect shall be provided for the fire pump, and that disconnect shall be in an enclosure separate from disconnects for other loads supplied by the generator.

695.6(B)(2): The supply conductors to a fire pump installation that are routed through a portion of a building to supply a fire pump installation are now permitted to be supplied by a conductor assembly that is listed for a minimum 2-hour fire-withstand rating.

695.6(D): Circuit conductors supplying power to a fire pump installation are not permitted to be provided with overload protection. Only short-circuit protection is provided. There was some confusion with regard to protection of a transformer that may be a part of the power supply circuit. A sentence was added pointing out that there is a separate section, *695.5(C)(2),* that specifies the overcurrent protection for the primary of a transformer supplying a fire pump installation.

Article 700 **Emergency Systems**

700.6(C): Automatic transfer switches for systems of under 600 volts are now required to be listed for emergency use.

700.9(D)(3): Control wires installed between the load transfer equipment and the emergency generator shall be run independent of other wiring. Wiring to the emergency loads was required to be run independent of other wiring, but this rule did not include emergency-system control wiring.

700.12(B)(6): The disconnect located within sight of an outside generator set supplying emergency loads is now required to be rated as suitable for use as service equipment.

700.23: A dimmer listed for use in emergency systems is permitted to control lighting that will automatically switch to minimum emergency lighting upon failure of normal power. All circuits supplied by the dimmer are required to be wired as though they are emergency circuits, even though they are not used during an emergency.

Article 701 Legally Required Stand-by Systems

701.7(C): An automatic transfer switch rated 600 volts or less and used with a legally required stand-by load shall be listed for use with a legally required standby system.

701.11(B)(5): The disconnect located within sight of an outside generator set supplying power to legally required stand-by loads is now required to be rated as suitable for use as service equipment.

701.18: This section requires coordination of overcurrent devices such that the overcurrent devices closest to a load will open on an overload or fault condition before the overcurrent device from which it is supplied. This is not always easy to accomplish. A new exception was added in the case of a transformer supplying a legally required stand-by load and in the case where two overcurrent devices are in series and are of the same rating. In either case, this new exception exempts these situations from the coordination requirement since coordination is impractical to achieve.

Article 702 Optional Standby Systems

702.5(B)(2)(b): An optional stand-by power system is required to be capable of supplying the full intended load. The addition is a condition that if a load management system is installed along with automatic transfer equipment the stand-by power system need only be capable of supplying the maximum load selected by the load management system.

702.11: The disconnect located within sight of an outside generator set supplying optional stand-by loads is now required to be rated as suitable for use as service equipment.

Article 705 Interconnected Electric Power Production Systems

This *Article* deals with the interconnection of one or more on-site electric power production sources with a utility electric power network. The basic principle is that the loads supplied by the premises wiring will utilize power from the on-site sources supplemented by the utility network if sufficient power is not available on site. When the on-site power sources are producing more electrical energy than is needed on site, the excess power will be placed on the utility network, and the customer will be paid by the utility for the power delivered. On-site sources often produce dc power rather than the 60 Hz ac power of the utility network. An inverter is required to convert the dc power to ac 60 Hz power. An additional transformer may be required to match the voltages. Whether the on-site electric power source is from an inverter or directly from an ac generator, the on-site 60 Hz produced ac power must be synchronized with the utility 60 Hz ac supply. Because some equipment is connected to the live utility network and also to an on-site source, the equipment is live from both sides. This creates special safety and sizing problems that must be addressed. Systems of this type are becoming much more prevalent across the country and new issues have arisen that are now addressed with this *Article.* Most of the past rules remain in this *Article,* but there are substantial additions.

705.12(A): An electric power production source is permitted to be connected on the supply side of the service disconnecting means. In the previous edition of the Code, this was permitted, but it was only stated in *230.82(6).*

705.12(D): The previous edition of the Code required the power production system connection to be located at the service disconnecting means. This new section permits one or more power sources to be connected at any distribution point on the premises wiring system. Paragraph (1) requires a disconnect for each source. Paragraph (3) requires all sources be connected to the premises wiring on the load side of any equipment ground-fault equipment. Paragraph (4) requires the disconnect location of multiple sources to be posted at all disconnect locations. Paragraph (5) requires circuit breakers used as disconnecting means to be listed for back feeding and a fine print note to be provided to explain how to make that determination. In paragraph (6), it states that the method of securing main circuit breakers in a panelboard *(408.36(D))* is not required for power source disconnecting means. These changes are illustrated in Figure 11.23.

705.12(D)(2): This is a new section that specifies the ampere rating of a panelboard that is connected to one or more sources of power in addition to the utility network source of power. The sum of the ratings of all power source overcurrent devices is not permitted to exceed 120% of the panelboard busbar rating,

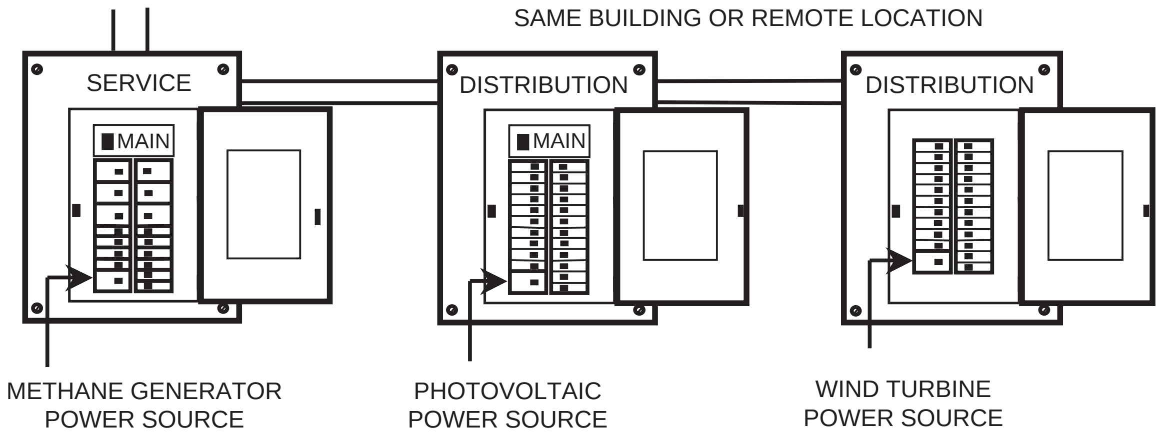


Figure 11.23 Power sources that operate interactively with a utility network are permitted to be connected at any point on the premises wiring, not just at the main service disconnect location.

as illustrated in Figure 11.24. This would mean that if a panelboard has a 200-ampere rating, the main circuit breaker rating plus the rating of the circuit breaker from the utility-interactive inverter would not be permitted to exceed 240 amperes.

705.12(D)(7): This section specifies the location of the circuit breaker for a utility-interactive inverter within a panelboard. If the sum of the main circuit breaker rating and the interactive power source circuit breaker rating does not exceed the rating of the panelboard, then the interactive circuit breaker is permitted to be placed at any location within the panelboard. If their combined ratings does exceed the rating of the panelboard (see *705.12(D)(2)*), then the interactive power source circuit breaker is to be installed at the opposite end of the busbars from the utility source circuit breaker. If one is at the top of the panelboard, then the other must be located at the bottom of the panelboard. A warning label must also be provided at the panelboard stating that the interactive power source circuit breaker is not permitted to be relocated.

705.22(5) & (6): Disconnecting means provided for a power production source or components of the system provided with disconnecting means shall be of such a type that all ungrounded conductors open simultaneously and that the disconnecting means is capable of being locked in the open position, regardless of whether the disconnect is within sight of the equipment.

705.40: If there is a loss of utility-supplied power to a premises wiring system with a utility-interactive inverter, now the inverter is not required to be disconnected if the system is designed to disconnect the utility supply and transfer loads to the inverter.

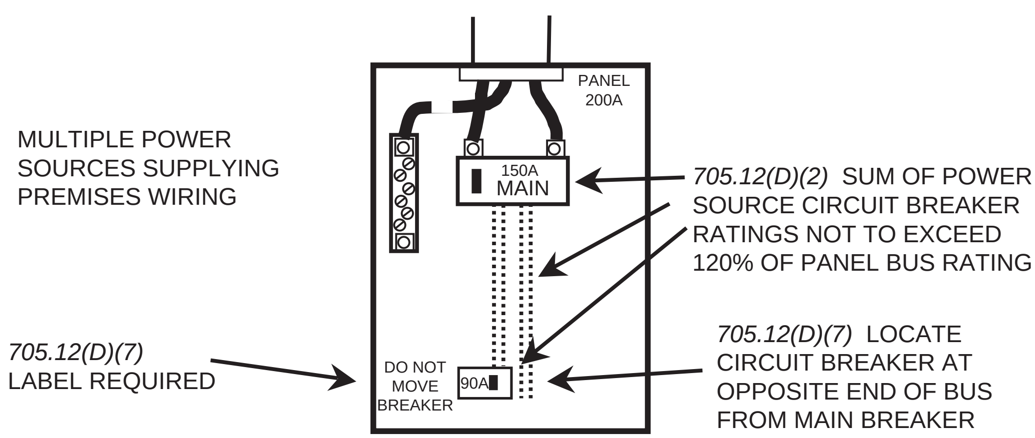


Figure 11.24 An electrical panel that has more than one source of power operating in parallel is not permitted to have the sum of the circuit breaker ratings exceed 120% of the panelboard bus ampere rating.

705.60(A): This is a new section that defines the maximum input and output current of a utility-interactive inverter. These currents are the maximum input and output current ratings of the inverter.

705.60(B): The input and output conductor minimum size is required to be not less than 125% of the inverter rated input and output currents respectively. This section also specifies the minimum rating of the overcurrent devices protecting the inverter input and output conductors. The overcurrent device is not permitted to be less than 125% of the inverter input and output current rating. It is permitted to apply *240.6(A)* and to round this overcurrent device up to the next standard size if the calculated value does not match a standard rating.

705.65(A): The maximum rating of overcurrent device protecting the inverter input and output conductors is to be determined according to *Article 240*. Presumably, this means *240.4*, which requires the conductors to be protected in accordance with their ampere rating.

705.65(B): A transformer is sometimes installed between the inverter and the point of connection to the premises wiring system. This section requires overcurrent protection on both sides of the transformer since it is energized from both sides. The transformer overcurrent rules of *450.3* are to apply. The overcurrent devices are to be sized based upon the transformer being energized from the inverter (primary); then the overcurrent devices are to be sized based upon the transformer being energized from the utility supply end (primary).

705.65(D): Overcurrent devices used in dc circuits of a photovoltaic power system shall be rated for dc operation.

705.95: Inverter output is frequently 120 volts and when connected to one ungrounded conductor and the neutral of a 120/240 volt, 3-wire single-phase premises wiring system, or to a 208/120 volt, 4-wire 3-phase premises wiring system, the power supplied from the inverter reduces the effectiveness of the typical load balancing that is inherent as a part of these electrical systems because the current returns to the inverter rather than the supply transformer. This rule requires that the inverter rated output current be added to the maximum load connected to any one ungrounded conductor when sizing neutral conductors. This is shown in Figure 11.25.

Article 708 Critical Operations Power Systems

This is a new *Article* providing rules for wiring facilities or portions of facilities considered to be critical operations power systems (COPS) by municipal, state, or federal codes. Many of the rules in this *Article* are directed at the electrical contractor performing the installation or the electrical inspector. Many of the rules are directed to the owner of the facility or the management of the facility. The following is a brief review of rules dealing with the electrical supply, equipment, and the wiring of the equipment. The intent is to ensure the continued operation of critical functions during a widespread disaster that results in a lengthy interruption of electrical power. The facility is to be capable of maintaining critical operations for an extended period of time.

708.5(B): Access to circuits and equipment associated with critical operations shall be limited to qualified personnel.

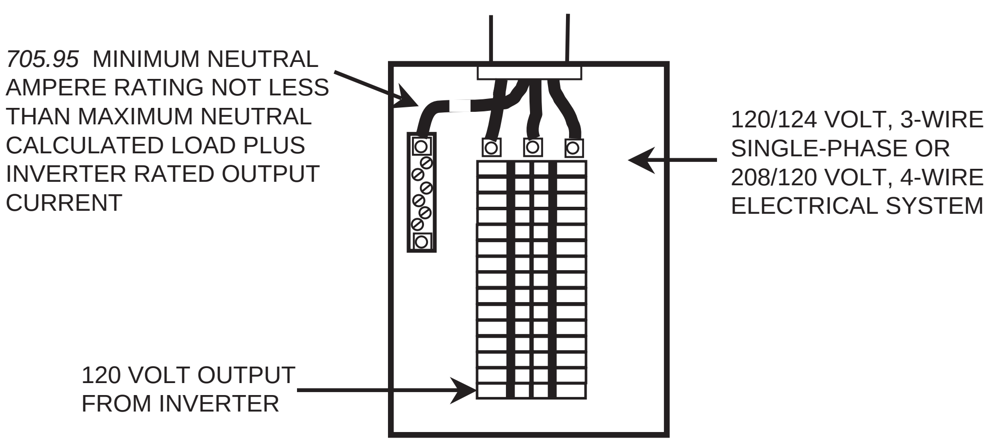


Figure 11.25 When a 120-volt, 2-wire supply from an inverter feeds into a 120/240 volt, 3-wire, single-phase system, or a 208/120 volt, 4-wire, 3-phase system, the neutral conductor is to have an ampere rating not less than the maximum unbalanced load plus the output rating of the inverter.

708.10(A)(1): All boxes, enclosures, and equipment are required to be marked as a part of the critical power system.

708.10(A)(2): Cover plates or receptacles supplied by a critical power circuit shall have a distinctive color or other marking.

708.10(B): Wiring for critical operations circuits is not permitted to share the same raceway, cable, box, or cabinet with circuits that are not a part of the critical power system.

708.10(C)(1): The acceptable wiring systems are provided in this section. Circuits are to be run in Rigid Metal Conduit, Intermediate Metal Conduit, or Type MI cable. Other types of raceway as listed are permitted if encased in not less than 2 in. (50 mm) of concrete. Materials permitted for making flexible connections are also stated.

708.10(C)(2): Feeders supplying critical operations circuits are required to be installed in such a way that they have a minimum 1-hour fire rating. Acceptable methods are discussed in this section.

708.11(A): Distribution equipment is required to be installed in the same area as the circuits supplied.

708.11(B): Feeder distribution equipment is required to be installed in spaces with a 2-hour fire resistance rating and located above the 100-year flood plain.

708.14: Wiring supplying HVAC equipment, fire alarms, security, emergency communications, and signaling systems is required to be installed using the same methods as power wiring. In this section is a list of specific requirements depending upon the type of circuit.

708.20(A): This section deals with the source of power for the critical operations circuits. Power is to be restored to circuits in an appropriate time interval.

708.20(B): If installed inside, the power source is required to be installed in a space fully protected by an automatic fire suppression system or a space with a 1-hour fire rating.

708.20(C): All power sources are required to be grounded as a separately derived system *(250.30);* however, there is an exception depending upon how the equipment is installed.

708.20(D): Surge protection is required to be installed, but there is no specific rule as to exactly which equipment is required to be provided with surge protection.

708.20(E): Automotive-type batteries are not permitted.

708.20(F)(1): An engine-driven generator is to be automatically starting upon loss of normal power; however, there is required delay in starting of at least 15 minutes to avoid nuisance starting and load transfer upon short-time interruptions of normal power.

708.22(A): The power source is required to be capable of supplying all of the critical operations loads simultaneously. An alternate power source (portable is permitted) is required to be available to supply critical operations loads if the main power source is taken out of service for maintenance or repair. This alternate power source is permitted to supply legally required stand-by circuits *(Article 701),* and optional standby circuits *(Article 702).*

708.22(C): The alternate power source is required to be capable of supplying the full critical operations load for a period of up to 72 hours.

708.24: Specifications for load transfer equipment are contained in this section. This transfer switch is only permitted to supply loads that are designated as critical operations loads.

708.30: Branch circuits from the critical operations power system are only permitted to supply critical operations equipment.

708.52(B): This rule applies to equipment ground-fault protection for the service and feeders as required by *230.95* and *215.10.* Similar to health care facilities, if equipment ground-fault protection is required at the main disconnecting means for the critical operations power system, then equipment ground-fault protection is required to be installed at the disconnects for the feeders supplied by this main disconnecting means. This is to prevent a ground-fault downstream from a feeder overcurrent device from taking out the entire critical-operations power system. Proper coordination of devices must, therefore, be provided.

708.54: Overcurrent devices for the entire critical operations power system are required to be coordinated such that a down-line overcurrent device will operate before any overcurrent device that supplies it will operate.

Article 760 Fire Alarm Systems

There was considerable renumbering of the sections in this *Article*. The sections remain basically the same, but section *760.7* was changed to *760.21,* and all of the sections following were given new numbers. Those sections remain in the same order as in the previous edition of the Code.

760.3(G): This is a new paragraph that prohibits fire alarm cables to be run in raceways or cable trays that contain water, gas, drain, or air.

760.24: Cable ties are now recognized as a permitted means of supporting fire alarm cable to the structure.

760.41(B): This section deals with the power source for a non–power-limited fire alarm circuit. There is a new requirement that an individual circuit supply the fire alarm power source.

760.121(B): This section deals with the power source for a power-limited fire alarm circuit. There is a new requirement that an individual circuit supply the fire alarm power source.

760.176: There is a new requirement that non–power-limited fire alarm cable installed in a wet location is required to be listed for use in a wet location or have a moisture-impervious metal sheath.

760.179: There is a new requirement that power-limited fire alarm cable installed in a wet location is required to be listed for use in a wet location or have a moisture-impervious metal sheath.

WORKSHEET NO. 11—BEGINNING EMERGENCY AND ALTERNATE POWER SYSTEMS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A 5.5-kW portable generator supplies 120/240-volt single-phase power to a generator panel in a building that is installed on the load side of the service disconnecting means. The panel contains single-pole double-throw switches installed on selected circuits from the main panel. The output of the generator has an overcurrent protector in each ungrounded conductor that does not serve as a disconnecting means at the generator. The generator is accessible and the engine can easily be shut off. A single disconnecting means is (see Figure 11.24):
   A. required to be installed either in the building or at the generator to disconnect all ungrounded conductors.
   B. required to be installed at the generator and also in the building.
   C. required to be installed only at the generator.
   D. required to be installed only at the termination of the conductors within the building.
   E. not required to be installed because the engine can readily be shut down.

   Code reference ___________________

2. A standby power system for sensitive equipment in a commercial building is supplied by a power system using single-cell stationary lead-acid batteries. The installation is shown in Figure 11.26. The nominal output voltage of 24 single-cell lead-acid batteries connected in series is:
   A. 24 volts.
   B. 28.8 volts.
   C. 48 volts.
   D. 72 volts.
   E. 144 volts.

   Code reference ___________________

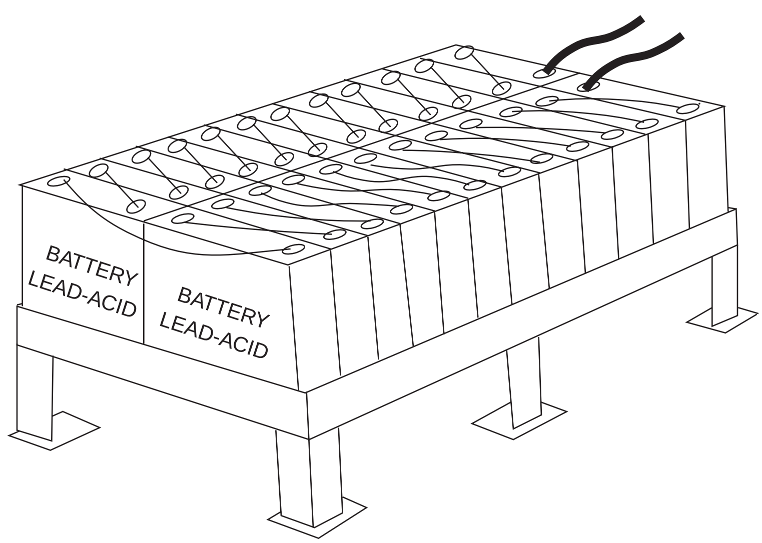


Figure 11.26 Twenty-four lead-acid, liquid electrolyte, single-cell batteries are connected in series as a part of an alternate power system.

3. Storage batteries are installed at a dwelling as a part of a solar photovoltaic power system. The cells of the storage batteries are not permitted to be connected in such a way that the system operates at:
   A. more than 24 volts.
   B. 50 volts or more.
   C. 67 volts or more.
   D. more than 120 volts.
   E. more than 150 volts.

   Code reference ____________________

4. A stand-alone photovoltaic system is shown in Figure 11.27. The photovoltaic source circuit in Figure 11.27 is labeled with the letter:
   A. A
   B. B
   C. C
   D. D
   E. E

   Code reference ____________________

5. The nameplate of a fuel cell electrical power unit, among other information, is required to include:
   A. maximum short-circuit current.
   B. minimum output feeder conductor size.
   C. maximum intermittent current rating.
   D. minimum safe operating voltage.
   E. continuous output current rating.

   Code reference ____________________

6. A fuel cell system is located outside and the feeder conductors run underground to the building and terminate at the distribution panel in the building. A disconnecting means for the feeder between the fuel cell unit and the building:
   A. shall be located at the fuel cell unit.
   B. shall be a fusible switch located on the outside of the building at the point of entry of the fuel cell feeder conductors.

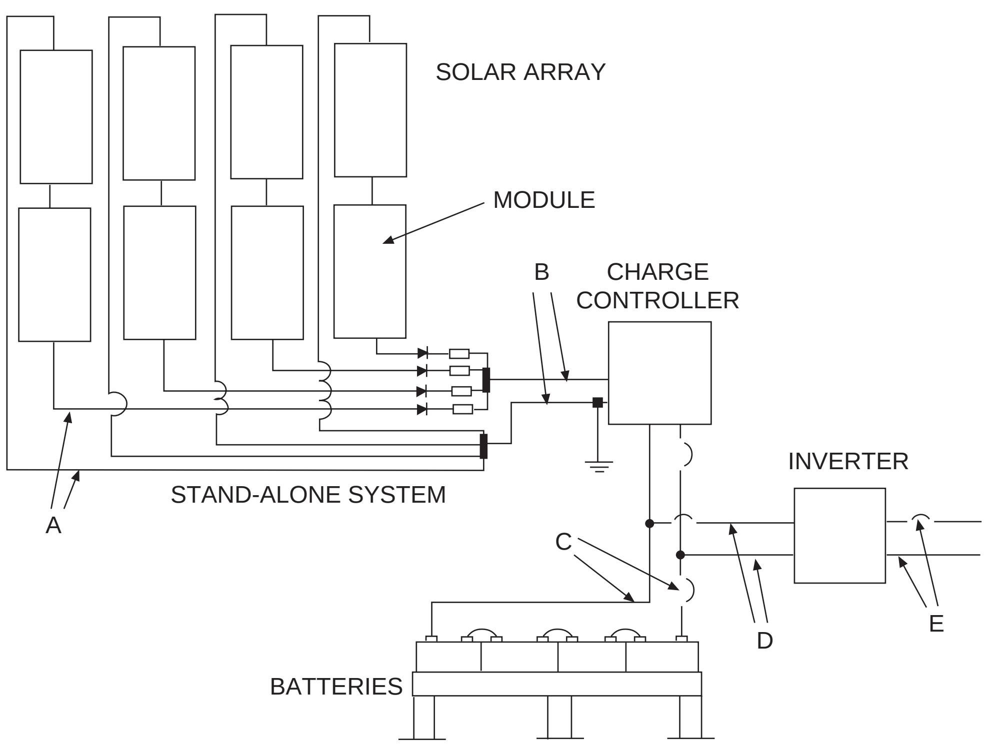


Figure 11.27 A photovoltaic power system consists of the solar array, a charge controller, a set of batteries, and an inverter, along with circuit breakers and fuses to provide safety and protection.

C. is permitted to be the main in the service panel.
D. is required to have integral overcurrent protection rated at not more than 1.15 times the continuous output current rating of the fuel cell unit.
E. shall open both conductors if the output is a 2-wire at 120 volts.

Code reference ___________________

7. The fire pump installation shown in Figure 11.28 receives the source of power directly from a utility transformer. There is no central station monitoring, local signaling, or sealing program with weekly inspections to supervise the disconnect to make sure it is maintained in the closed position. Supervision of the disconnect is:
A. not required when less than 1000 persons occupy the building.
B. not required if the fire pump installation is located in a dedicated 1-hour fire-rated room.
C. permitted to be a lock that prevents the switch to be turned off without use of a key.
D. required to be in the form of an audible intermittent sounding horn.
E. only required for certain facilities such as hospitals and assembly halls that are occupied by more than 1000 persons.

Code reference ___________________

8. A fire pump installation consists of only one motor that is rated 60-horsepower, 3-phase, 460-volt, design B as shown in Figure 11.28. Conductors are copper with 75°C rated terminations. The minimum size copper Type THWN conductor permitted to be run from the controller to the fire pump motor is:
A. 8 AWG. C. 4 AWG. E. 2 AWG.
B. 6 AWG. D. 3 AWG.

Code reference ___________________

9. The circuit conductors from an emergency panelboard to exit signs in a building are:
A. required to be run only in Type MI, MC, or AC Cable, or metallic raceway.
B. required to be run in Rigid Metal Conduit.
C. permitted to be run in the same raceway with normal power conductors provided all conductors have 600-volt insulation.
D. required to be run in separate raceways even when two separate emergency circuits originate from the same panelboard.
E. not permitted to be run in the same raceway with other power or lighting circuit conductors.

Code reference ___________________

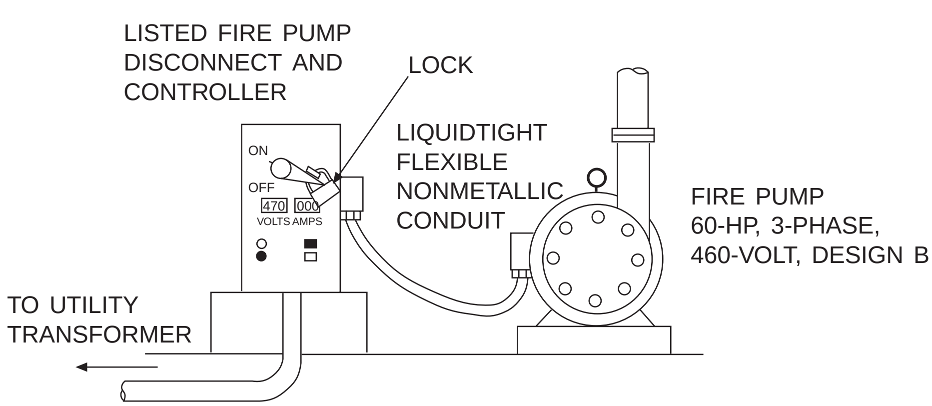


Figure 11.28 The fire pump system is powered with a single 60-horsepower, 3-phase, 460-volt design B motor with no other loads.

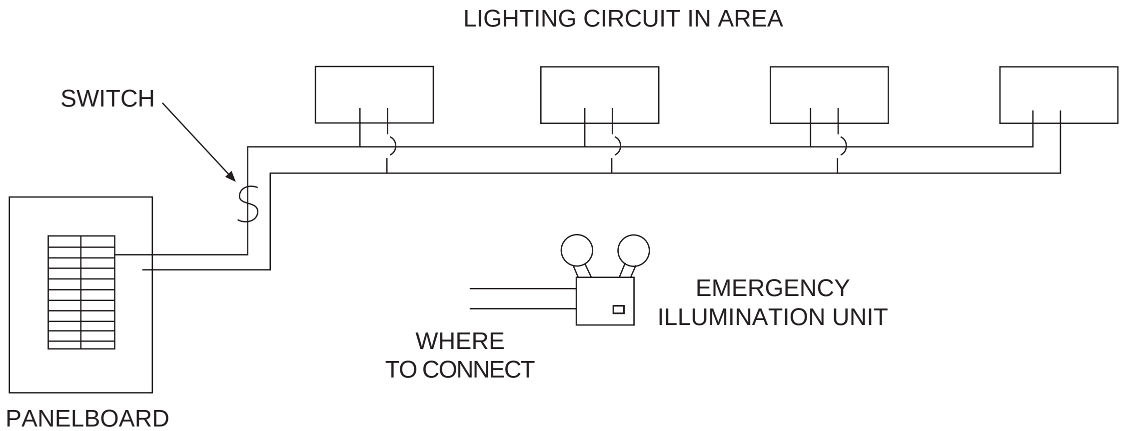


Figure 11.29 How is the emergency illumination unit required to be connected in an area where emergency illumination is required?

10. An area requiring emergency illumination is provided with self-contained battery-powered automatically controlled lighting units with a build-in battery charger as shown in Figure 11.29. The illumination units are required to be connected to:
    A. a branch-circuit serving the lighting in the area covered by the emergency lighting unit and connected on the supply side of any switching.
    B. a dedicated circuit from the first normal power panelboard serving the building.
    C. any circuit serving the building.
    D. a dedicated circuit from the emergency panelboard serving the building.
    E. a branch-circuit serving the lighting in the area covered by the emergency lighting unit and connected on the load side of any switching.

Code reference ___________________

11. A legally required standby power system is one that automatically supplies power to:
    A. emergency electrical systems.
    B. other than emergency electrical systems.
    C. batteries of unit emergency equipment such as area lighting and exit signs.
    D. exit signs and required building evacuation lighting units.
    E. loads in not more than 10 seconds.

Code reference ___________________

12. The wiring supplied by an optional standby power system is:
    A. required to be kept completely separate from circuits of the general wiring of the building.
    B. required to be energized in not more than 60 seconds of a power outage.
    C. required to be run in raceway.
    D. permitted to occupy the same cabinets, boxes, cables, and raceways with general building wiring.
    E. required to be run through the building concealed within spaces that have a minimum 15-minute fire rating.

Code reference ___________________

13. An alternate power production system is to be connected to operate in parallel with the utility supply as an interconnected electric power production source. The alternate power production system connection to the building electrical system is:
    A. required to be on the supply side of the service disconnecting means.
    B. required to be on the load side of the service disconnecting means.
    C. required to be at the service disconnecting means but permitted to be connected either on the supply side or on the load side of the disconnect.
    D. permitted to be made at any location within the building.
    E. required to be at the utility transformer location.

Code reference ___________________

14. Fire alarm cables that are abandoned and not tagged for future use:
    A. are required to be removed in their entirety to prevent spread of fire.
    B. shall have the accessible portion of the cables removed.
    C. are required to be removed only over suspended grid-type ceilings.
    D. are required to be removed only if the cables are not rated for installation in plenums.
    E. are permitted to remain in place even if in accessible areas.

Code reference ___________________

15. A receptacle in the unfinished portion of the basement of a dwelling that is installed to provide power to a non-power-limited fire alarm system is:
    A. required to be ground-fault circuit-interrupter protected.
    B. required to be protected by an arc-fault circuit interrupter.
    C. required to be controlled by a switch.
    D. not permitted to be ground-fault circuit-interrupter protected.
    E. not permitted and the installation is required to be supplied by a circuit near an exit door on the first level.

Code reference ___________________

WORKSHEET NO. 11—ADVANCED EMERGENCY AND ALTERNATE POWER SYSTEMS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. An engine-driven standby generator set is located outside and is permanently installed to supply a building. The output of the generator is 3-phase, 208Y/120-volt, 4-wire and the generator is rated 60 kW with a 200-ampere circuit breaker protecting the output of the generator. The minimum size copper conductors with 75°C insulation from the generator to the distribution panelboard inside the building is:
   A. 1/0 AWG.
   B. 2/0 AWG.
   C. 3/0 AWG.
   D. 4/0 AWG.
   E. 250 kcmil.

   Code reference ___________________

2. A standby power system for sensitive electrical equipment in a commercial building is supplied by single-cell stationary vented lead-acid batteries. Twenty-four of the batteries are installed in a rack that is 36 in. (0.91 m) wide and 72 in. (1.83 m) long. Each individual battery contains 2.2 gallons (8.3 L) of liquid electrolyte (see Figure 11.26). An electrolyte catchment below the batteries is:
   A. not required.
   B. required to be capable of retaining 2.2 gallons.
   C. required to be capable of retaining 13.2 gallons.
   D. required to be capable of retaining 52.8 gallons.
   E. required to be capable of retaining 66.0 gallons.

   Code reference ___________________

3. A solar photovoltaic array, as shown in Figure 11.30, consists of eight modules connected in parallel. The common connecting point with overcurrent protection and blocking diodes is located on the backside of the array. The photovoltaic output circuit runs from the back of the array to a disconnect switch with overcurrent protection then underground to an adjacent building which houses the charge controller, batteries, and inverter. The nameplate rating of the 36 cell modules is: open-circuit

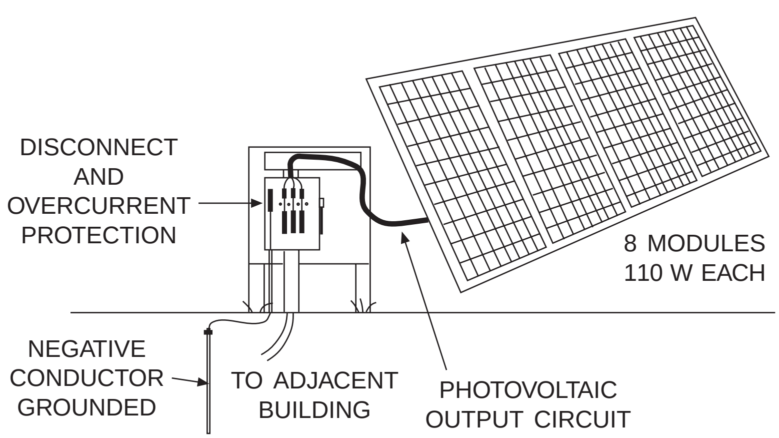


Figure 11.30 Eight solar modules are connected in parallel with one set of conductors between the solar panel and the disconnect and from the disconnect to an adjacent building.

voltage = 21.0 volts; short-circuit current = 7.22 amperes; operating voltage = 17.0 volts; operating current 6.74 amperes; and maximum power = 110 watts. The photovoltaic output circuit is run as copper conductors in underground raceway to the adjacent building and the conductors have 75°C insulation and terminations. The minimum size conductors is:

A. 10 AWG.
B. 8 AWG.
C. 6 AWG.
D. 4 AWG.
E. 3 AWG.

Code reference ___________________

4. A solar photovoltaic power system similar to the system shown in Figure 11.30 has parallel modules connected at a collecting point on the back of the array. The photovoltaic output circuit runs from the array to the disconnect then to an adjacent building housing the remaining components of the system. The photovoltaic output circuit conductors are size 4 AWG copper with 75°C insulation and terminations. The photovoltaic output dc circuit is grounded to a driven 8 ft (2.5 m) rod at the disconnect adjacent to the array. The minimum size grounding electrode conductor permitted for this solar photovoltaic power system is:

A. 8 AWG.
B. 6 AWG.
C. 4 AWG.
D. 3 AWG.
E. 2 AWG.

Code reference ___________________

5. A stand-alone fuel cell system is connected to a building wiring system through a transfer switch and serves as backup power for essential circuits. The installation is shown in Figure 11.31. The output from the inverter is 120 volts, 2-wire. This arrangement is permitted only if:

A. there are no 240-volt, or multiwire branch-circuits supplied by the fuel cell system.
B. the transfer switch is located ahead of the main disconnect for the service.

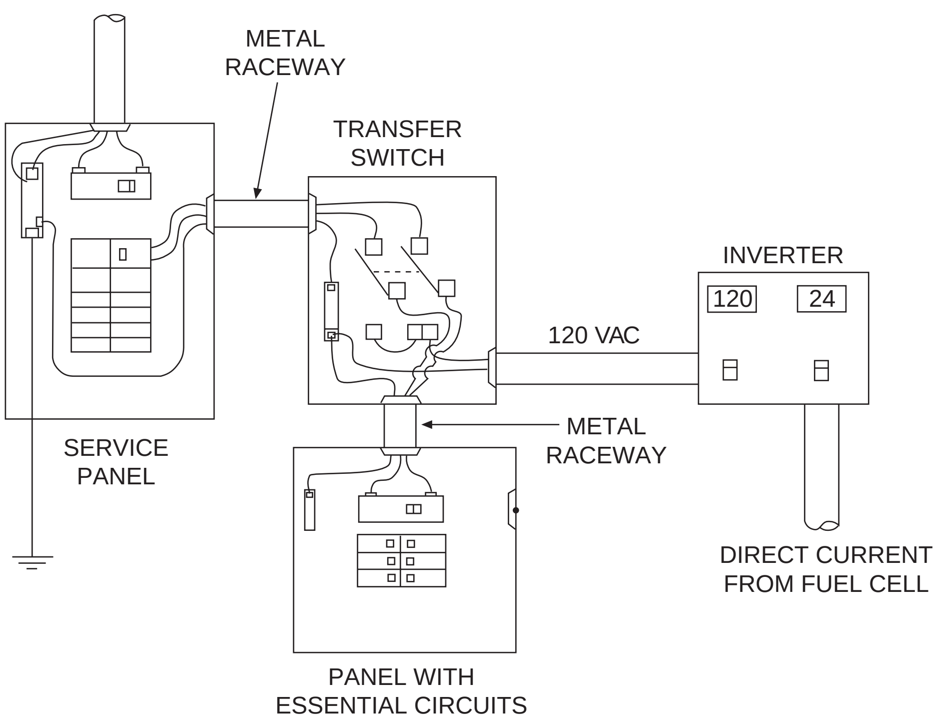


Figure 11.31 A transfer switch is installed on the load side of the service panel to a building with the essential circuits in a separate panelboard. The transfer switch is connected in such a way that the 120-volt, 2-wire output from the fuel cell system supplies both ungrounded busses in the essential circuit panel.

C. the inverter output is run through a transformer to produce a 120/240-volt, 3-wire electrical system.
D. the fuel cell system output is changed over to 120/240-volt, 3-wire.
E. the output of the inverter is not less than the sum of the overcurrent devices supplied.

Code reference ___________________

6. A fuel cell system is complete with inverter and transformer and has a nameplate output of 58 amperes continuous full-load alternating current at 120/240 volts, 3-wire. The output of the fuel cell unit is protected with a 2-pole, 60-ampere circuit breaker. The feeder conductors from the fuel cell to the premises wiring system are copper with 75°C insulation and terminations. The minimum size conductors permitted for the feeder is:
A. 10 AWG.
B. 8 AWG.
C. 6 AWG.
D. 4 AWG.
E. 3 AWG.

Code reference ___________________

7. A 50-horsepower, 460-volt, 3-phase, design B fire pump motor in a building is supplied with copper conductors size 4 AWG with 75°C insulation and terminations. The fire pump circuit is protected with a fusible disconnect as shown in Figure 11.32. The minimum size fuses permitted for the circuit is:
A. 90 amperes.
B. 100 amperes.
C. 300 amperes.
D. 350 amperes.
E. 400 amperes.

Code reference ___________________

8. The flexible conductor connection between the listed fire pump controller and the fire pump, as shown in Figure 11.32, is:
A. required to be Flexible Metallic Tubing.
B. required to be Liquidtight Flexible Nonmetallic Conduit.
C. permitted to be Type MC Cable.
D. permitted to be Liquidtight Flexible Nonmetallic Conduit, Type B.
E. permitted to be Electrical Nonmetallic Tubing.

Code reference ___________________

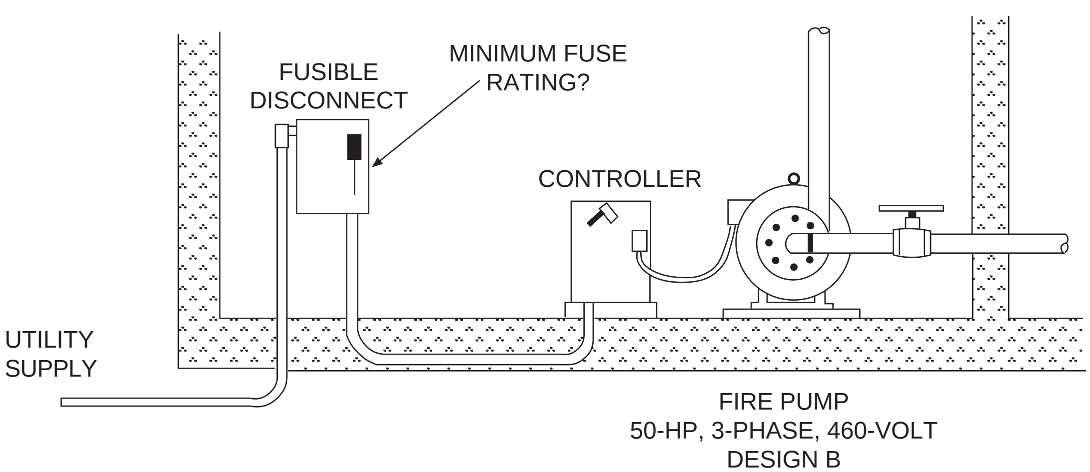


Figure 11.32 A fire pump is rated 50-horsepower, 3-phase, 460-volt, design B and is the only load supplied by the system.

9. The authority having jurisdiction may rule in some situations that the electrical supply for an emergency panel is permitted to be:
   A. a circuit in the first panelboard of the normal power system.
   B. a tap to the normal service conductors entering the building provided the tap is made ahead of the main service disconnect.
   C. a tap to the normal service made at the main lugs of the disconnect.
   D. a separate and independent service to the building supplying only the emergency panelboard.
   E. any circuit from the normal power system in the building.

Code reference ___________________

10. An area requiring emergency illumination that has high-intensity discharge lighting such as high-pressure sodium, metal halide, or mercury vapor as the normal lighting, in the case of a power interruption, is required to:
   A. have emergency illumination that will remain operating until the normal illumination units are operating or provide other means of illumination until the luminaires (lighting fixtures) restrike.
   B. operate only until the power to the circuit has been restored.
   C. have several incandescent or fluorescent luminaires (lighting fixtures) that operate continuously controlled only by a locked-on circuit breaker.
   D. also have incandescent or fluorescent luminaires (lighting fixtures) on the same circuits with the high intensity discharge lights.
   E. provide extra exit doors to the area.

Code reference ___________________

11. Circuit wiring supplied by the legally required standby power system is:
   A. required to be kept completely independent of other circuits in the building.
   B. only permitted to be run in Type AC , MC, or MI Cable or run as single conductors in metal raceway.
   C. required to receive power after an outage with a time period not to exceed 10 seconds.
   D. permitted to occupy the same raceways, cables, boxes, and cabinets with other general wiring.
   E. permitted to utilize manual transfer equipment if the building has qualified maintenance personnel on duty at all times.

Code reference ___________________

12. A portable engine-generator set that is connected to a premises wiring system by means of a transfer switch is:
   A. permitted to serve on a legally required standby power system.
   B. only required to meet the rules of a temporary electrical system.
   C. a violation and not permitted to supply power to a premises wiring system.
   D. not permitted to be used to supply emergency circuits if rated less than 10 kW.
   E. considered to be an optional standby power system.

Code reference ___________________

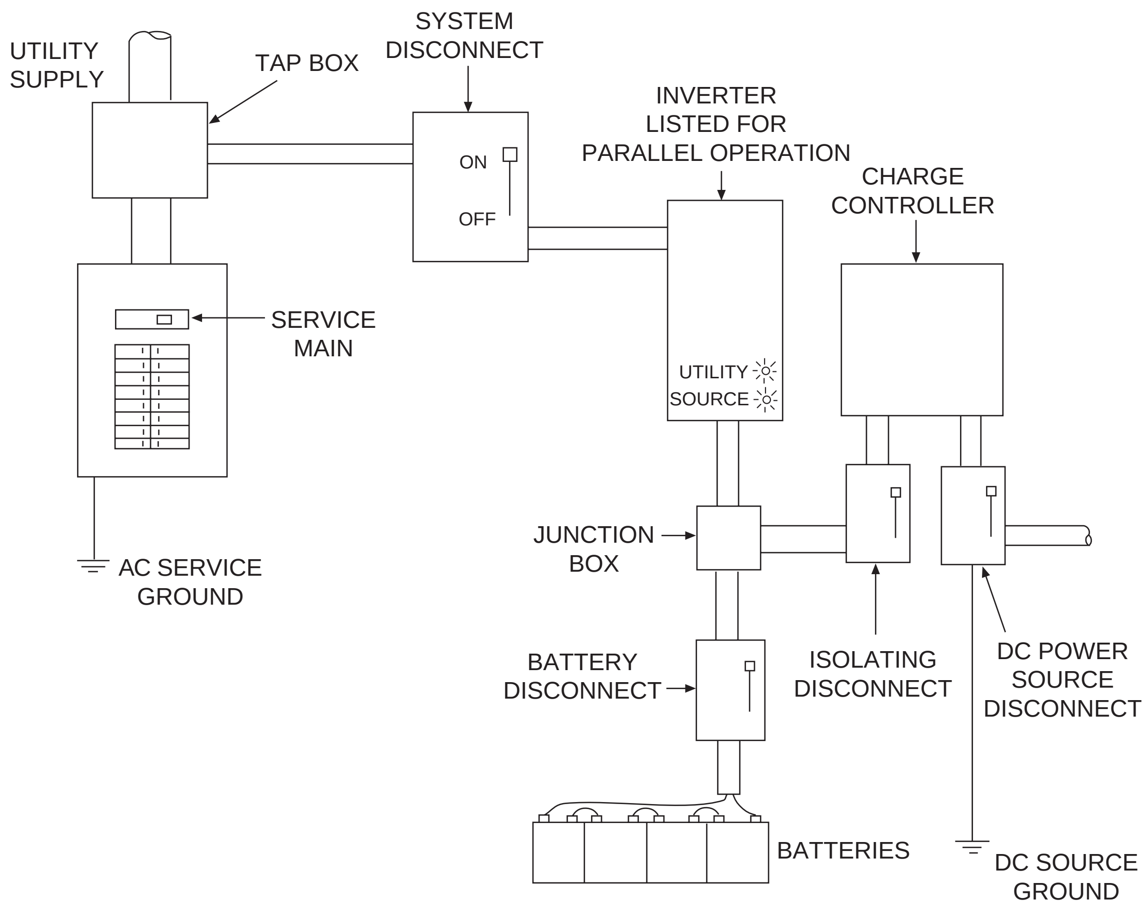


Figure 11.33 A dc power source is connected in parallel with a utility supply and tapped ahead of the service disconnect.

13. A dc power source is operated as an interconnected electric power production system in parallel with the utility supply through an inverter and connected as shown in Figure 11.33. The system disconnect is:
    A. required to be a manual switch.
    B. permitted to contain fuses that at times may be energized with the switch in the off position and marked with a warning.
    C. required to be kept locked in the open position.
    D. not permitted to be a circuit breaker.
    E. required to be power operable.

    Code reference ___________________

14. Fire alarm cables in a room with a non–fire-rated suspended ceiling grid of an existing building are not permitted to be supported by the ceiling grid:
    A. unless there are no more than three cables in any 10 ft by 10 ft (3 m by 3 m) area.
    B. except where there is a maintenance electrician.
    C. unless the cables have a diameter not more than 1/2 in. (13 mm) and there are no more than three cables across any one ceiling tile.
    D. unless only one cable is across any one ceiling tile.
    E. in any type of building.

    Code reference ___________________

15. The initiation circuit conductors of a non–power-limited fire alarm system are stranded copper and run in Electrical Metallic Tubing throughout a building. The continuous supervisory current flow in the circuit conductors is 0.2 amperes. The minimum size conductor permitted for this installation is:

    A. 24 AWG.
    B. 20 AWG.
    C. 18 AWG.
    D. 16 AWG.
    E. 14 AWG.

    Code reference ___________________

UNIT 12

Industrial Electrical Applications

OBJECTIVES

After completion of this unit, the student should be able to:

- determine the minimum dimensions of cable tray permitted for given sizes and numbers of wires and cables.
- describe the conductor insulating method for integrated gas spacer cable.
- determine the maximum ampacity of wires and cables to be installed in cable tray.
- determine the minimum current rating of the supply conductors for an electric welder.
- determine the maximum ampacity for wires to be installed in cablebus.
- define the different methods of electrically heating pipelines and vessels.
- determine the maximum ampacity of branch-circuit conductors for a noncontinuous motor on a crane, hoist, or monorail hoist.
- explain the application of *Article 665* on induction heating and dielectric heating to the types of facilities.
- explain how dielectric heating works in comparison with induction heating.
- describe facilities to which *Article 668*, dealing with electrolytic cells, and *Article 669*, dealing with electroplating, shall apply.
- determine the minimum size supply conductor permitted for an industrial machine if the nameplate information is given.
- describe the different types of optical fiber cables and their applications.
- answer wiring installation questions from *Articles 326*, *368*, *370*, *392*, *427*, *490*, *610*, *630*, *665*, *668*, *669*, *670*, *727*, and *770*.
- state at least three changes that occurred from the 2005 to the 2008 Code for *Articles 392*, *427*, *490*, *610*, *665*, *727*, and *770*.

CODE DISCUSSION

This unit deals with wiring methods and materials commonly used in industrial installations but not necessarily limited to industrial use. Several wiring methods are discussed from *Chapter 3* of the Code that are used most frequently in industrial and commercial wiring. Installation of electric heating equipment for pipelines and vessels is also described. *Chapter 6* of the Code deals with the wiring of special equipment. Several types of special equipment for industrial applications are covered in this unit.

Article 326 deals with integrated gas spacer cable where pressurized sulfur hexafluoride gas and dry kraft paper tapes are used as the conductor insulation. The conductor or conductors are contained within a flexible nonmetallic conduit. The pressurized gas-filled cable assembly helps prevent contaminants from entering the assembly and causing cable failure. As stated in *326.104*, the minimum conductor size permitted is 250 kcmil solid aluminum. A single solid aluminum conductor not smaller than 250 kcmil is permitted in the cable, or the conductor is permitted to be formed using up to nineteen 250 kcmil solid aluminum rods laid parallel.

Article 368 covers busways, which is a form of an electrical distribution system that provides flexibility for future changes. Busway is especially well suited for manufacturing facilities where exact placement of equipment may not be known at the time of construction or where equipment is periodically rearranged. Busway is a factory-assembled metal enclosure containing electrical conductors, usually in the form of copper or aluminum bars insulated from the metal enclosure. Busway is frequently used in commercial and industrial work areas by attaching to the ceiling with a spacing not to exceed 5 ft (1.5 m), *368.30.* Circuit breaker or fusible tap boxes are attached to the busway, and various raceway or cable wiring methods listed in *368.56(A)* are permitted to extend down to a workstation, machine, motor control center, or electrical panelboard. *NEC® 364.56(B)* permits suitable cord and cable assemblies rated for extra-hard usage or hard usage to be used as drops from a busway tap box to equipment. There is also a listed bus drop cable for this purpose. A suitable tension take-up support device is required to be used with cord and cable assemblies. The maximum distance from the cord or cable termination to the strain relief take-up device or intermediate support is 6 ft (1.8 m) as shown in Figure 12.1. *NEC® 368.17(C)* requires that plug-in devices to tap for branch-circuits and feeders contain overcurrent protection. The plug-in tap device is required to contain a circuit breaker or a fusible switch, which shall by some means be operable for the floor level. Generally, these plug-in tap devices are located high in the room and out of reach of an operator. The busway will have a nameplate current rating and it is required to be protected in accordance with the busway ampacity. *NEC® 368.17(B) Exception* does permit the reduction in size of a busway without overcurrent protection at the point where the size is reduced. Under these circumstances, a length of reduced ampacity busway is required to be adequate to supply the load and not more than 50 ft (15 m) in length.

Article 370 covers the installation of cablebus. Cablebus is a factory-made cable and ventilated metal framework system that is usually field-assembled. *NEC® 370.3* permits cablebus to be used for services, feeders, and branch-circuits. The minimum permitted size of insulated conductors is size 1/0 AWG, which is covered in *370.4(C).* The conductors are supported periodically on insulating blocks made for the cablebus. The maximum permitted support spacing for horizontal and vertical runs of cablebus is covered in *370.6.* Figure 12.2 shows a

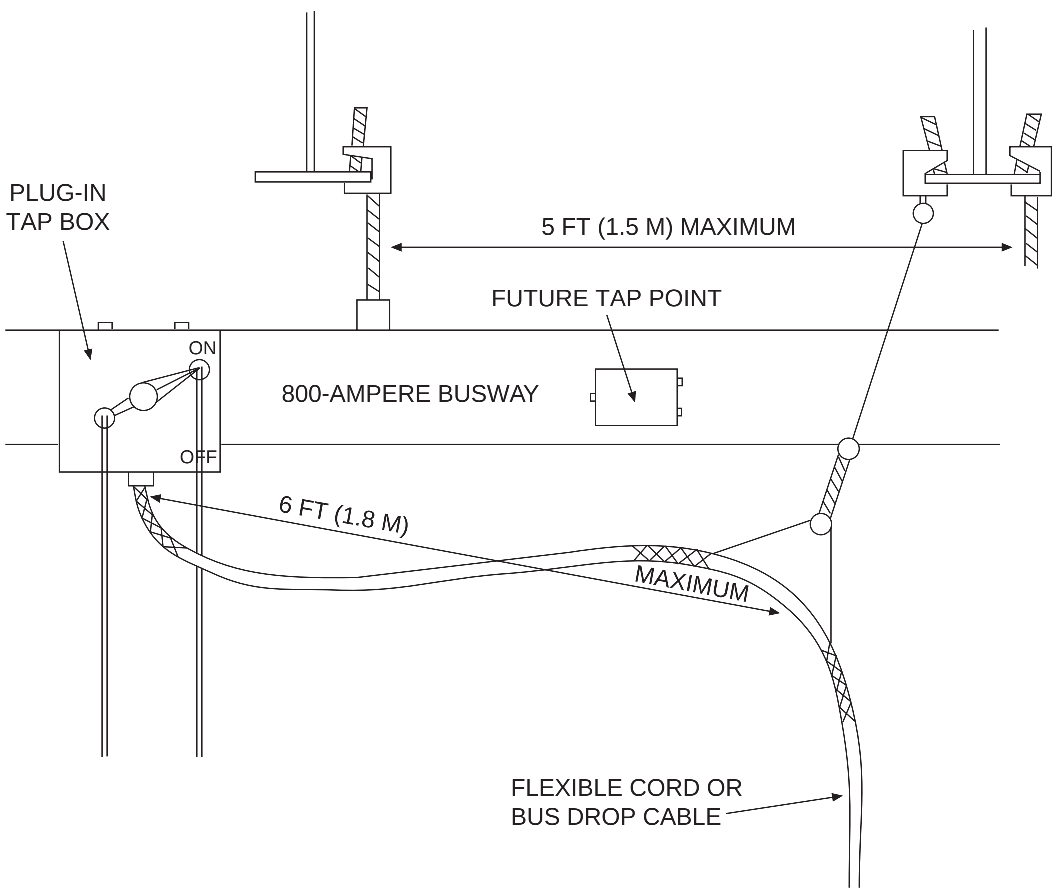


Figure 12.1 Flexible cord or cable drops from a busway are required to be supported at intervals of not more than 6 ft (1.8 m) and within a distance of 6 ft (1.8 m) from the strain relief take-up device.

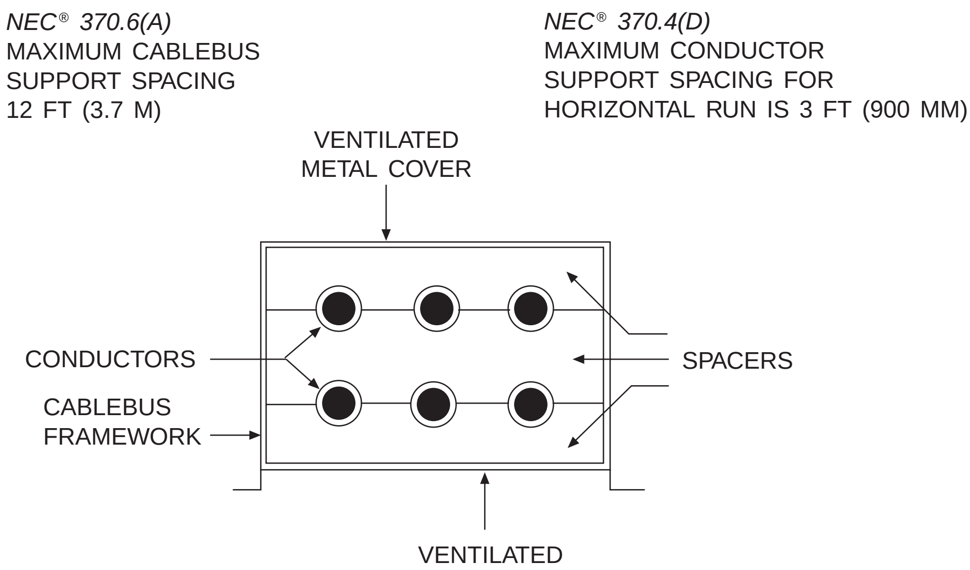


Figure 12.2 Cross-sectional view of a cablebus which is permitted to be used for branch-circuits, feeders, and services.

cross section of cablebus. The metal framework of cablebus is permitted to be used as an equipment grounding conductor, as stated in *370.3* and *250.118(12).* The grounding requirements are covered in *370.9.*

The ampacity of the conductors is permitted to be determined using *Tables 310.17* and *310.19*, which are for single-insulated conductors in free air. For circuits operating at more than 600 volts, *Table 310.69* and *Table 310.70* shall be used. Also, it should be noted in *370.5* that the next standard rating overcurrent device is permitted to be used when conductor ampacity does not correspond to a standard rating overcurrent device provided the rating does not exceed 800 amperes. For example, a Type THWN copper wire size 700 kcmil with a rating of 755 amperes, found in *Table 310.17,* is permitted to be protected with an 800-ampere overcurrent device.

Article 392 deals with cable trays, which are defined in *392.2.* A cable tray has a rectangular cross section and is a form of support system for conductors, cables, conduit, and tubing. A typical ladder-type cable tray is illustrated in Figure 12.3. Single-conductor cable installed in cable tray is not permitted to be smaller than size 1/0 AWG, as stated in *392.3(B)(1).* All single-conductor cable installed in cable tray is required to be marked for use in cable tray on the exterior of the cable. Generally single-conductor cables size 1/0 AWG and larger of types such as XHHW, THHN, THWN, THW, RHH, and RHW are listed for use in cable trays. Multiconductor cables Type TC and Type MC with three or four Type XHHW insulated conductors plus an equipment grounding conductor are in common use. Individual conductor sizes range from size 8 AWG copper to 1000 kcmil. Cables rated over 600 volts are usually Type MV or Type MC with conductors appropriate for the circuit voltage.

Standard widths of ladder-type and trough-type cable trays are 6, 9, 12, 18, 24, 30, and 36 in. (150, 225, 300, 450, 600, 750, and 900 mm). Typical lengths are 10 ft (3 m) and 12 ft (3.7 m). There is no specific support spacing required in the Code. In addition to the ladder type, cable tray is available as a solid bottom and a ventilated trough. Channel-type cable tray is available in widths of 2, 3, 4, and 6 in. (50, 75, 100, and 150 mm).

Figure 12.3 A ladder-type cable tray is permitted to support single-conductor cables, marked for use in cable trays, and multiconductor cables as listed in *392.3(A)(1).*

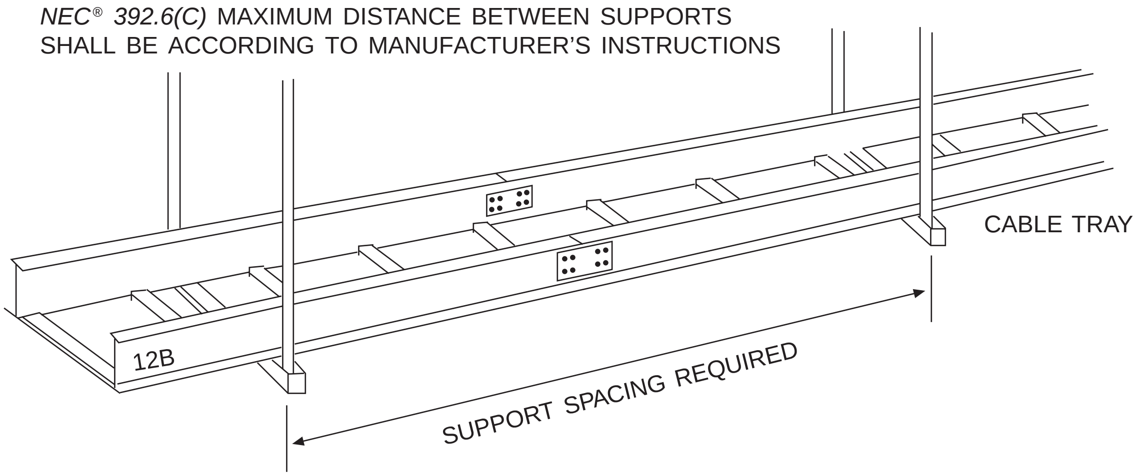


Figure 12.4 Cable tray is required to be supported at regular intervals according to manufacturer's instructions.

Channel type cable tray is often used for conductor and cable drops from the main cable tray to loads. It is available with a solid bottom and ventilated. *NEC® 392.6(C)* requires cable tray support to be according to the manufacturers instructions as shown in Figure 12.4. For a particular support spacing, cable tray is rated by the manufacturer for a maximum load on a pounds-per-linear-ft basis (1 pound per linear foot = 1.49 kilograms per linear meter) for cables and raceways supported by the cable tray and any other environmental loads. Standard support spacings for cable trays are 8, 12, 16, and 20 ft (2.5, 3.7, 4.9, and 6 m). A manufacturer will provide a load class designation for a particular cable tray consisting of a number and a letter. The number is the recommended maximum support spacing. The letter is the working load category, which is A for a 50-pound-per-linear-ft (75 kg/m) load, B for 75 pounds per linear ft (112 kg/m), and C for 100 pounds per linear ft (150 kg/m). Assume an aluminum ladder-type cable tray has a load classification 8B. The recommended maximum support spacing is every 8 ft (2.5 m), and with that spacing the load is not permitted to exceed 75 pounds per linear ft (112 kg/m) Figure 12.4.

When installed outside, it may be necessary to calculate the side pressure on a linear-ft basis for wind or a vertical loading expected from ice or snow. In northern climates, ice and snow load is added to the conductor loading. Support spacing may be determined on the availability of points within a building from which to anchor supports. When spanning open areas, the cable is usually supported in a trapeze style. When run adjacent to a wall, a cantilever support to the wall is frequently used. These supports are illustrated in Figure 12.5. If the desired support spacing is not practical to achieve, cable trays are available with

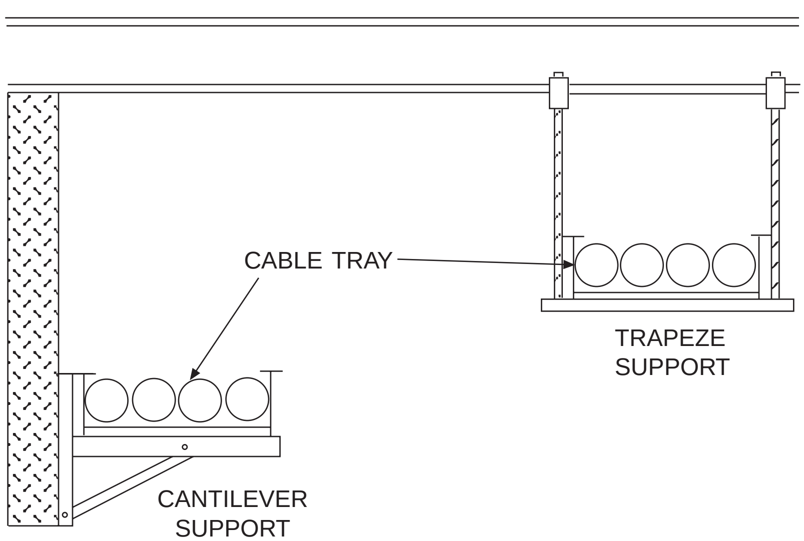


Figure 12.5 Typical means of support for cable trays are the cantilever support when attaching to side walls, and the trapeze support when attaching to structural members above the cable tray.

stronger side rails to support the weight for longer spans. Cable trays are not required to be mechanically continuous, but bonding is required. Thermal expansion and contraction may also need to be considered in some locations where the cable tray will be installed in an area where the temperature will change.

NEC® 392.7 covers the situation in which the cable tray is permitted to serve as the equipment grounding conductor. *Table 392.7(B)* gives the maximum circuit rating for a given cable tray cross-sectional area for which the cable tray may act as the equipment grounding conductor. Much of the remainder of the article deals with the number of wires and cables permitted to be installed in cable trays. Examples of conductor installation and determination of the minimum permitted width of cable tray are explained later in this unit.

Methods for determining the width of cable tray for the types and sizes of cables to be installed are explained in *392.9* for multiconductor cables in the cable tray, and in *392.10* when single-conductor cables are installed. How the cables are installed in the cable tray influences the method to be used to determine the conductor ampacity. If multiconductor cables are installed so that the cables have a space between them of at least one cable diameter, then conductor ampacity can be determined using the method of *392.11(A)(3)*. If the minimum spacing between conductors is not maintained, the ampacity is determined according to *392.11(A)(1)*. A similar situation exists for single-conductor cables supported by cable tray. Two different methods are used to determine the ampacity of the same conductors. If the minimum spacing is maintained between conductors, the ampacity will be higher than if the spacing is not maintained. However, when the minimum spacing is maintained, a wider cable tray is frequently required.

A portion of a circuit run in cable tray is frequently also run in raceway. *NEC® 392.11(A)* and *(B)* is a reminder that the ampacity of the conductors run in cable tray is to be determined based upon *310.15(A)(2)*. When a set of conductors is subject to two different conditions for the purpose of determining conductor ampacity, the most restrictive condition shall be used. This is illustrated in Figure 12.6. For example, a set of single copper conductors with 75°C insulation and terminations size 1/0 AWG run in ladder-type cable tray with a maintained spacing between the conductors has an allowable ampacity based upon *Table 310.17* of 230 amperes. The portion of the circuit run that is in raceway, based upon *Table 310.16*, only has an allowable ampacity of 150 amperes.

Article 427 covers the installation of fixed electric heating equipment for pipelines and vessels. Several types of heating are defined in *427.2*. One type is a resistance heating element attached to or inserted into a pipeline or vessel. An impedance heating system is one where electrical current flows through the wall of the pipeline or vessel, and the heat is produced by the impedance of the wall and the current flow. Skin-effect heating uses a ferromagnetic envelope attached to a pipeline or vessel, and electrical current flow through the envelope produces the heat. The impedance of the envelope and the current flow produce the heat.

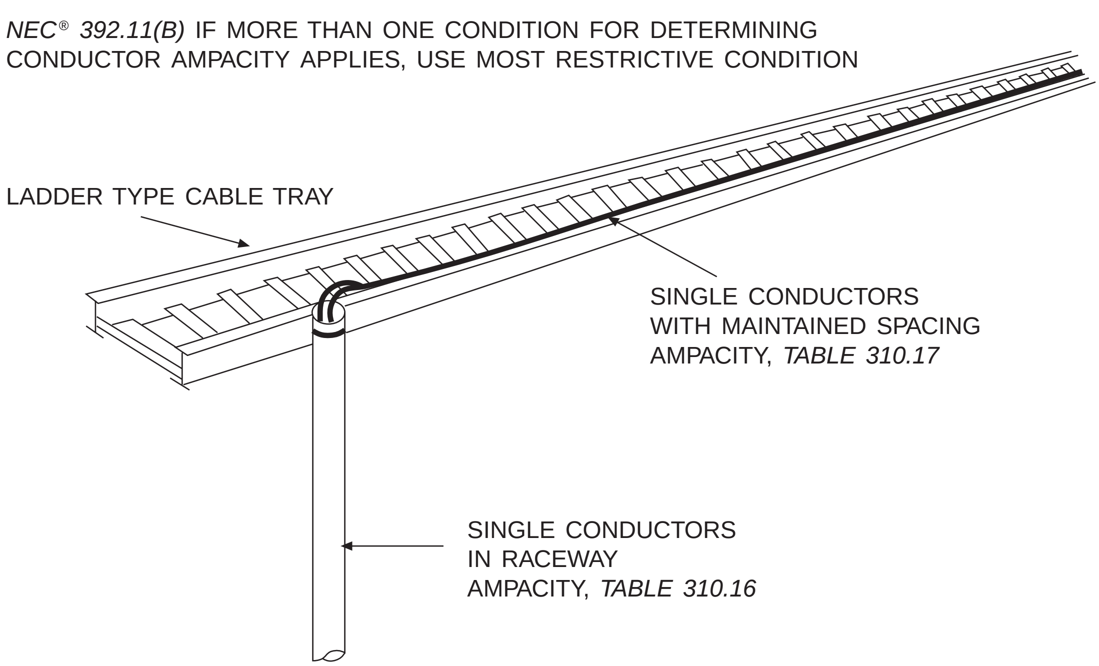


Figure 12.6 When determining the ampacity of a set of conductors run in cable tray, consideration must be given to the entire circuit and other conditions that may result in a different ampacity for the same conductors.

Induction heating is accomplished by using an external induction coil. Electric current is caused to flow in a pipeline or vessel wall by electromagnetic induction similar to a transformer. Induced wall current flow and the impedance of the wall produce the heat.

The minimum permitted ampacity of circuit conductors is required to be 125% of the total load of the heaters. This requirement is covered in *427.4,* which points out that it is permitted to round up the conductor ampacity to the next standard size of overcurrent device as permitted by *240.4(B).* The type of disconnecting means permitted for the heating is covered in *427.55.*

Special consideration is required for equipment grounding depending on the type of heating involved. In the case of resistance heating, the grounding requirements of *Article 250* shall apply. Grounding for impedance heating is covered in *427.29. NEC® 427.48* covers grounding for skin-effect heating. It is pointed out that the grounding requirement of *250.30* for a separately derived system does not apply in the case of skin-effect heating.

Article 490 provides basic rules for sizing, selection, and installation of equipment and conductors operating at more than 600 volts. The latter portion of the article provides rules for some specific high-voltage applications. Interrupting current at high voltage is much more difficult than interrupting current for loads operating at 600 volts or less. Current-interrupting devices are covered in *490.21* and consist of circuit breakers, power fuses, expulsion-type cutouts, and oil-filled cutouts. When working with equipment that operates at more than 600 volts, safety is of the highest importance and isolation of equipment for inspection, maintenance, and repair is essential. Equipment isolation is covered in *490.22.* Rules for the construction and installation of metal-enclosed power switchboards and industrial control assemblies are in *Part III.* Guarding of live parts and clearances between live parts and between live parts and ground is an important consideration for equipment construction, and when performing maintenance procedures near live parts. Some heavy industrial equipment is mobile and operates from a high-voltage power source. This creates the need for mobile or portable high-voltage distribution equipment, the rules for which are covered in *Part IV.* A unique high-voltage application is the electrode-type boiler where electrodes are placed in a liquid with heat generated by the passage of current through the liquid. The rules for applying high-voltage power for such an application are found in *Part V.*

Article 610 deals with the wiring methods and wiring requirements for cranes, hoists, and monorail hoists. Motors powering this equipment may have a duty cycle rating. That is, the motor may only be permitted to operate for 15 minutes, 30 minutes, or 60 minutes until it is required to cool before being operated again. If the motor has a duty cycle, then the conductor to the motor is permitted to carry a higher level of current than would be typical for a general circuit or a continuous load. *Table 610.14(A)* is used to determine the minimum wire size for time-rated motors. The article deals with the installation, support, and grounding of open and insulated conductors on hoists, cranes, and monorail hoists. All exposed noncurrent-carrying metal parts are required to be grounded.

Article 630 provides the requirements for wiring electrically powered welders. A nameplate or rating plate is required to be provided on the welder. Electric welders are of the arc-type and the resistance-type. Arc welders are of the ac transformer-type and the motor-generator type. With the arc-type, the metal parts to be joined are brought together and an arc is struck between the metal parts and a metal electrode. The metal electrode is melted away by the heat of the arc to provide extra metal for joining the parts. The actual load on a transformer-type arc welder is intermittent, which is taken into consideration when sizing the circuit components. Even during a continuous weld, current flows in pulses. Current flow is on for several cycles and off for several cycles. The duty cycle for a welder is determined based upon the number of cycles the welder is operating in a one-hour period of time. At the end of *630.31* is a FPN called explanation of terms. Duty cycle is explained in the third paragraph of that FPN.

The rules for determining the size of conductors for an individual arc welder or a feeder supplying a group of arc welders are found in *Part II.* Overcurrent protection is required for the welder and for the conductors supplying the welder. One overcurrent device may provide protection for both the conductors and the welder, in which case the minimum value is determined according to *630.12.*

Rules for sizing components for a resistance-type electric welder are found in *Part III.* With a resistance-type, the metal pieces to be joined are clamped between two electrodes and current flows from one electrode to the other through the metal. Because the area of contact is small and the current level is high, the area is heated to the melting point due to the resistance of the metal. The weld is actually accomplished with only a few cycles but at very high current. Voltage drop is an important consideration when sizing conductors for a resistance welder. The number of cycles the resistance welder delivers depends upon the particular weld. Duty cycle for a resistance welder is determined by multiplying the number of cycles required for a weld times the number of welds per hour and dividing by 216,000, which is the total number a 60-hertz cycles per hour.

Information on the welder rating plate or nameplate needed for determining conductor size, overcurrent rating, and disconnect rating is based on the effective rated primary current, or the rated primary current times a multiplying factor obtained from a table in either *630.11* or *630.31*. The welder duty cycle is also needed to find the multiplier from the table. Duty cycle is permitted to be calculated based upon the weld to be performed, and the FPN to *630.31(B)* explains how duty cycle can be determined. Here is how duty cycle and the rated primary current on the welder rating plate is used to determine the minimum supply conductor ampacity.

Example 12.1 One transformer arc welder has a primary current marked on the rating plate as 40 amperes. The welder is to be operated at a duty cycle of 70%. Determine the minimum current rating of the supply conductors for the welder.

Answer: This is a transformer-type arc welder. Therefore, use the nonmotor generator column of *Table 630.11(A)* to find the multiplying factor, which is 0.84 for a 70% duty cycle. Next multiply the factor and the 40-ampere primary current to get the minimum conductor ampacity of 33.6-amperes ($40 \text{ A} \times 0.84 = 33.6 \text{ A}$).

Welders draw some current when running idle (not welding) and a higher current when welding. Effective rated primary current (I_{1eff}) combines the conductor heating due to these two levels of current. The effective rated primary current (I_{1eff}) may be given on the welder rating plate. The FPN to *630.12(B)* gives a formula for determining the effective rated primary current. It is based on the rated supply current for the welder, the no-load supply current, and the duty cycle. Duty cycle for a welder may be fixed, or it may be adjustable. If it is adjustable, then effective primary current can be calculated. Because heat in a conductor is proportional to the square of the current (Equation 1.16), the rated supply current with load is squared and multiplied by the duty cycle. That value is added to the square of the no-load current times the percentage of time remaining, which is one minus the duty cycle. The square root of the sum of those two values is taken to get the effective primary current. The heating of the supply conductor is considered to be proportional to this value. The rated supply current under load and the rated no-load supply current can be measured, but proper instrumentation is needed because during welding the current is flowing in pulses not continuously.

Determining the minimum size of conductor for a welder and the maximum rating of overcurrent protection permitted is based upon the maximum rated supply current and the effective rated supply current (rated primary current and duty cycle may also be used). The welder is required to be protected from overcurrent at a level not exceeding 200% of either the maximum rated supply current or the rated primary current, whichever is given on the nameplate. The conductor is not permitted to be protected at a level greater than the ampacity of the supply conductor. It is permitted to round up to the next standard rating of overcurrent device if this value does not correspond to a standard rating overcurrent device as listed in *240.6*. The minimum permitted rating of supply conductor is determined from *Table 310.16* based upon the nameplate value of the effective rated primary current or the rated primary current and a multiplier found in *630.11(A)*. The supply conductors are likely to have an ampere rating less than the maximum rated supply current. Therefore, the overcurrent device sized to protect the conductors will frequently have a rating less than the maximum required to protect the welder. If a single overcurrent device is used to protect both the conductors and the welder as shown in Figure 12.7, the minimum

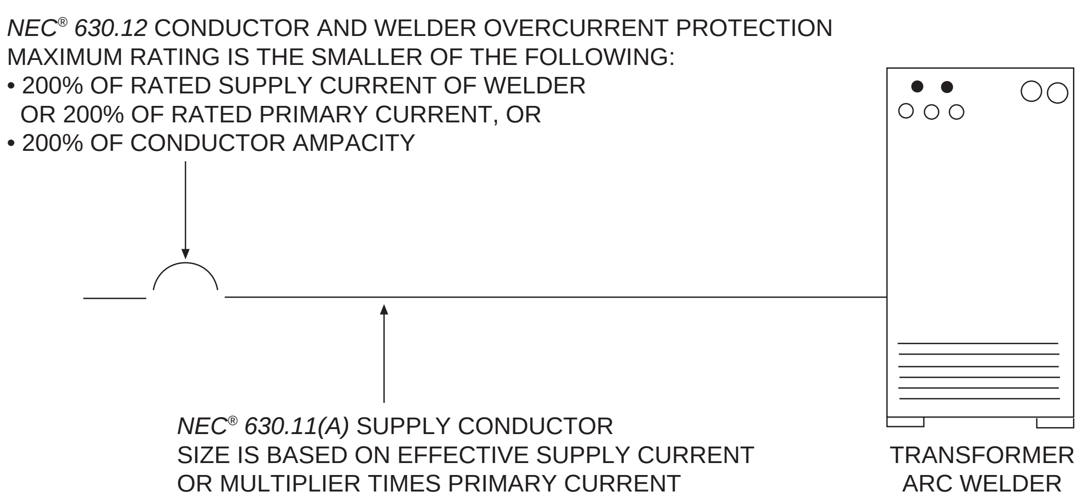


Figure 12.7 One overcurrent device is permitted toprotect both the supply conductor and the arc welder if the overcurrent device rating is not more than 200% of the ampacity of the conductor or 200% of the maximum rated supply current of the welder.

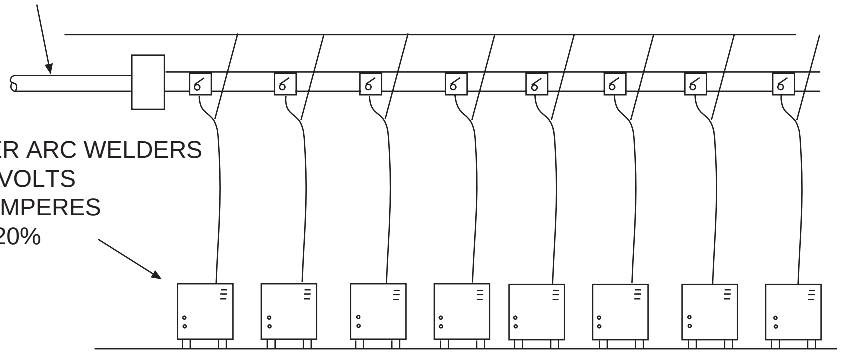


Figure 12.8 A method was specified for determining the minimum feeder ampacity for a group of arc welders.

rating is used unless the device opens under normal operation, in which case the next standard rating is permitted. If a feeder supplies a group of arc welders, the method for determining the minimum size of feeder conductor is found in *630.11(B)*. The following example will show how *630.11(B)* can be used to determine the minimum ampacity of the feeder supplying a group of arc welders. There are cases where the duty cycle is fixed and a smaller feeder is permitted.

Example 12.2 Eight transformer arc welders are supplied by one feeder. The welders are 3-phase, 460 volts, with a primary supply current of 56 amperes marked on the rating plate, and the duty cycle is 20%, as shown in Figure 12.8. The conductors are copper with 75°C insulation and terminations. Determine the minimum ampacity required for the feeder supplying these welders.

Answer: First find the supply current rating of the conductors for each welder using *630.11(A)*. Multiply the rated primary current of the welder by the factor found in *Table 630.11(A)*, which is 0.45. This is a transformer-type arc welder. Therefore, use the nonmotor generator column. The individual welder current is 25.2 amperes (56 A × 0.45 = 25.2 A). Next use *630.11(B)* to determine the minimum ampacity of the feeder for all eight welders. The first two welders are taken at 100%, the next at 85%, the next at 70%, and all remaining at 60% to obtain 149.9 amperes as the minimum feeder ampacity.

$$[2 \times 25.2\text{ A} + 0.85 \times 25.2\text{ A} + 0.70 \times 25.2\text{ A} + 0.60 \times (4 \times 25.2\text{ A})]$$
$$[50.4\text{ A} + 21.4\text{ A} + 17.6\text{ A} + 60.5\text{ A}] = 149.9\text{ A}$$

The secondary conductors of a welder are not considered as premises wiring, and the grounding requirements for these conductors are not those stated in *Article 250*. In particular, a welder is not to be considered as a separately derived premises system, and *250.30* containing grounding requirements for separately derived systems does not apply. A FPN in *630.15* points out the potential of parallel paths for the welder secondary current in cases where the return conductor is grounded to the building grounding system. The workpiece terminal of the welder should be connected to the workpiece or to the workpiece table but not to the grounding system of the building. The potential for objectionable currents on the building grounding conductors is illustrated in Figure 12.9.

Article 665 deals with equipment for induction heating and dielectric heating of materials in industrial processes and scientific applications. An electrical conducting material is heated by the induction heating process. The material is placed in an electromagnetic field operating at a frequency of a few kilohertz to several hundred kilohertz. Electrical current is induced into the material and with the impedance of the material results in heating.

The dielectric process is used when the material to be heated is not an electrical conductor. The material to be heated is placed between two electrical plates to which is applied a varying electric field in the range of a few megahertz to over 100 megahertz. The varying electric field vibrates the molecules of the material, thus producing heat. The high-frequency electromagnetic field or the electric field may be produced by a motor-generator, or it may be produced by some other type of field-producing equipment.

With the use of electromagnetic and electric fields of an output circuit at frequencies in the kilohertz and megahertz range to produce heat, there are specific requirements of the various systems to protect personnel from exposure to these fields or from electrical shock. Also, it is important that requirements be followed to prevent unintended heating of components and wiring of the system. Requirements for guarding and grounding are covered in *Part II*.

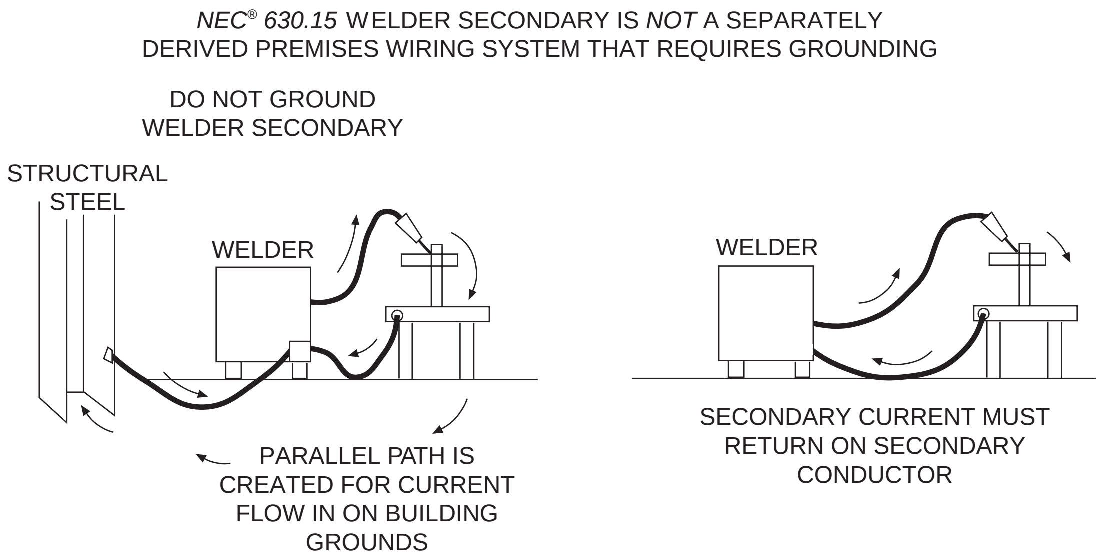


Figure 12.9 A welder is not considered to be a separately derived premises wiring system, and therefore, is not required to be grounded as a separately derived system. If it is improperly grounded, objectionable current paths can be established, and welder current can flow on equipment grounding conductors throughout the building.

Article 668 deals with the wiring to electrolytic cells for the production of a particular metal, gas, or chemical compound. Definitions important for the application of the article are found in *668.2. NEC® 668.1* states that this article does not apply to the production of hydrogen, electroplating, or electrical energy. This article provides some general wiring requirements for electrolytic cells, but each process is unique and requires engineering design for the specific material and process. This article allows for individual process design. A FPN in *668.1* refers to the IEEE standard *463-1993* for *Electrical Safety Practices in Electrolytic Cell Line Working Zones.* Electrolytic cell line is defined in *668.2,* and the cell line conductors shall meet the provisions of *668.3(C)* and *668.12.*

Article 669 deals with the installation of wiring and equipment for electroplating processes. *NEC® 669.9* requires overcurrent protection to be provided for the direct current conductors. Bare conductors are permitted to be run to the electroplating cells. *NEC® 669.6(B)* requires that when bare cell conductors operate at more than 50 volts, the conductors shall be guarded against accidental contact. When there is more than one power supply to the electroplating tanks, there shall be a means of disconnecting the direct current output of the power supply from the conductor to the electroplating tanks, as required by *669.8.*

Article 670 covers the wiring requirements for industrial machinery, the definition of industrial machinery, and required nameplate information. Industrial machinery is defined in *670.2. NEC® 670.3(A)* states the nameplate information to be provided on industrial machinery. The full-load current of the machine is required to be provided on the nameplate, as well as the full-load current of the largest motor or load. There is a separate NFPA standard for electrical wiring of the actual industrial machinery *(NFPA 79).* If the industrial machine is provided with overcurrent protection, as permitted in *670.3(B)* and *670.4(C)* at the supply terminals, the supply conductor to the machine is permitted to be considered a feeder or tap from a feeder. When overcurrent protection is provided at the supply terminals, *670.3(B)* requires that a label be placed on the machine stating that overcurrent protection is provided at the machine supply terminals, as shown in Figure 12.10. *NEC® 670.4(A)* specifies the minimum permitted ampacity of supply conductors to industrial machinery. The supply conductor ampacity shall not be less than the sum of 125% of the full-load current of resistance heating loads, 125% of the full-load current of the largest motor, and the full-load current of all other loads.

Article 727 provides specifications for the use and installation of instrument tray cable. It is permitted to be used in industrial facilities per *727.2.* Instrument tray cable is not permitted to be installed with power, lighting, and non-power-limited circuits, as stated in *727.5.* There is an exception where the Type ITC Cable is permitted with other types of circuits when the Type ITC Cable has an approved outer metal sheath. Spacing requirements and other installation specifications are not provided to define what the Code means by Type ITC Cable not being installed with power, lighting, and non-power-limited circuits.

Type ITC Cable is not permitted to be used for circuits operating at more than 150 volts or more than 5 amperes, as stated in *727.5.* The 150 volts is between conductors as well as to ground. The conductor material for Type ITC Cable is only permitted to be copper or a thermocouple alloy. A thermocouple is a junction of two dissimilar metals that produce a small voltage that changes as the temperature changes. In industry and research, thermocouples are used to measure the temperature of materials and processes. *NEC® 727.7*

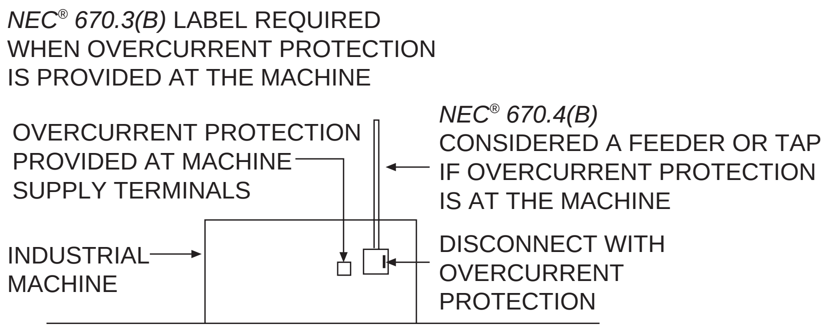


Figure 12.10 When overcurrent protection is provided at the supply conductor terminals of the industrial machine, the supply conductors are permitted to be a feeder or a tap from a feeder.

requires that the cable be marked as Type ITC on the outer nonmetallic sheath. If the cable has a metal sheath, the marking is permitted to be on the nonmetallic sheath beneath the outer metal sheath.

Instrumentation Tray Cable that does not have a metallic sheath is permitted to extend outside a cable tray to connect equipment. The cable is required to be marked Type ITC-ER, which signifies that the cable is permitted for exposed routing. This cable is permitted to extend to any distance required to connect to equipment; however, it must be continuously supported and secured at intervals not to exceed 6 ft (1.8 m).

Article 770 covers the markings and installation of optical fiber cable. Conductive optical fiber cable contains a noncurrent-carrying material, which may be a metallic vapor barrier, or a metal member may be present to add mechanical strength. Composite cables contain current-carrying electrical conductors. Nonconductive optical fiber cable is permitted to occupy the same raceway or cable tray with conductors for light, power, and heating circuits. Conductive optical fiber cable is not permitted to occupy the same cable tray or raceway with conductors of electric light, power, or Class 1 circuits, as stated in *770.133(A)*.

Optical fiber cable run in buildings shall be listed as stated in *770.113*. The listing requirements, which are essentially the uses permitted of the various types, are summarized in *Table 770.179* and described in *770.154* and *770.179*. Conductive optical fiber cable for general-purpose use is marked as Type OFC and nonconductive optical fiber cable for general-purpose use is marked as Type OFN. When the letter **P** is included at the end of the type marking, such as Type OFCP, the cable is suitable for installation in air-handling spaces, as described in *770.154(A)*. The letter **R** at the end of the type marking, such as Type OFNR, designates that the cable is permitted to be run as cable from one floor to another of a building. Cable Types OFC and OFN are permitted to be run from one floor to another of a building if contained in metal conduit or in a shaft with fire stops at each floor. In the case of a one- or two-family dwelling, as stated in *770.154(B)(3)* Types OFC and OFN are permitted to be installed between floors without metal raceway protection. Cable substitutions are permitted, as stated in *Table 770.154(E)*.

CABLE TRAY WIDTH AND CONDUCTOR AMPACITY

When cables are supported by cable tray, the allowable ampacity of the conductors depends upon whether the installation allows for cooling of the conductors when they are carrying current. If a solid cover for a length more than 6 ft (1.8 m) is placed over a ventilated channel or ladder type cable tray, the conductor ampacity will be lower than if the top of the cable tray is open. Spacing of the conductors in the cable tray is also important. If a minimum width of space between the cable is maintained as described in *392.11(A)(3)*, *392.11(B)(3)*, and *392.11(B)(4)*, the conductor ampacity will be higher. In all cases where the conductor spacing is maintained, the minimum width of the cable tray depends upon the diameters of the cables laid out in a single layer. In some cases, a single layer of cables is required but space is not required to be provided between the cables. In other cases, the cables are permitted to be placed in multiple layers. These rules are found in *392.9* for multiconductor cables and in *392.10* for single-conductor cables. The following several examples will illustrate the relationship between ampacity of conductor and width of cable tray.

> **Example 12.3** A feeder consisting of four single-conductor cables size 500 kcmil copper with Type XHHW insulation and 75°C terminations is run in aluminum ladder-type cable tray as shown in Figure 12.11. The cables are placed in the cable tray without maintaining a space between the cables. Determine the ampacity of the conductors and the minimum permitted width of cable tray.

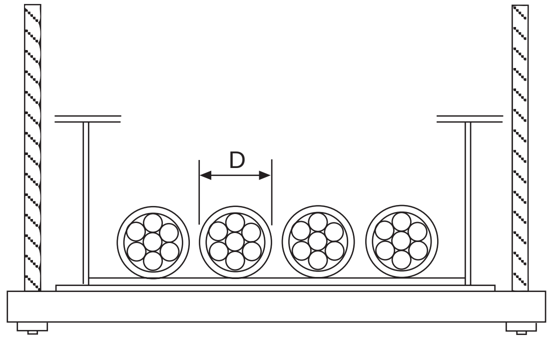


Figure 12.11 Four size 500 kcmil Type XHHW copper conductors are supported by aluminum ladder-type cable tray with no maintained spacing between the conductors.

Answer: The minimum width of cable tray is determined by the method in *392.10(A)(2)* for single conductor cables. The cross-sectional area of the conductors is not permitted to exceed the area given in column 1 of *Table 392.10* for each width of cable tray. Look up the cross-sectional area of a 500 kcmil Type XHHW conductor in *Table 5, Chapter 9* and find 0.6984 sq. in. (450.6 mm^2). The total area of the conductors is 2.7936 sq. in. (1802 mm^2). According to column 1 of *Table 392.10,* a cable tray with a 6 in. (150 mm) width is permitted to have a single-conductor cable fill of 6.5 sq. in. (4200 mm^2). The minimum width, then, is 6 in. (150 mm).

4 conductors $\times$ 0.6984 in.^{2} = 2.7936 in.^{2}
4 conductors $\times$ 450.6 mm^2 = 1802 mm^2

Next, determine the ampacity of the conductors according to *392.11(B)(2).* The ampacity is permitted to be 0.65 times the ampacity found in *Table 310.17,* which is 403 amperes.

0.65 $\times$ 620 A = 403 A

Example 12.4 Determine the minimum width of cable tray and ampacity of the conductors when the conductors are installed in a single layer with a space between the conductors not less than the diameter (d) of the conductors as prescribed by *392.11(B)(3)* and shown in Figure 12.12. Four single-conductor cables size 500 kcmil copper with Type XHHW insulation and 75°C terminations are run in aluminum ladder-type cable tray.

Answer: *NEC® 392.11(B)(3)* specifies that this method of determining conductor ampacity requires a maintained space between the conductors placed in a single layer. First look up the diameter of the conductor in *Table 5, Chapter 9* and find 0.943 in. (23.95 mm). The minimum width of cable tray is then seven times the cable diameter, which is 6.60 in. (168 mm). Choose a 9 in. (225 mm) minimum cable tray width. The width of cable trays is listed in the left-hand two columns of *Table 392.9* and *Table 392.10.*

7 $\times$ 0.943 in. = 6.60 in.
7 $\times$ 23.95 mm = 168 mm

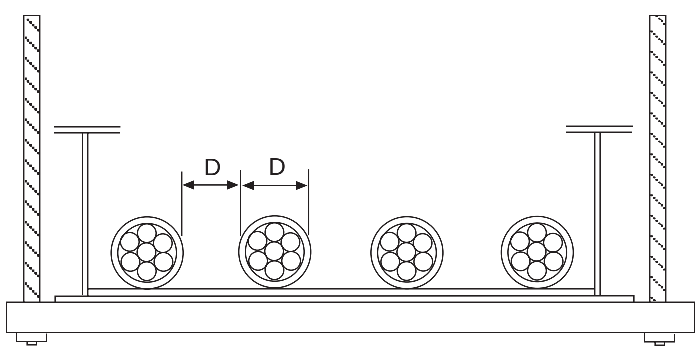


Figure 12.12 Four size 500 kcmil Type XHHW copper conductors are run in aluminum ladder-type cable tray with a space maintained between the conductors equal to the cable diameter.

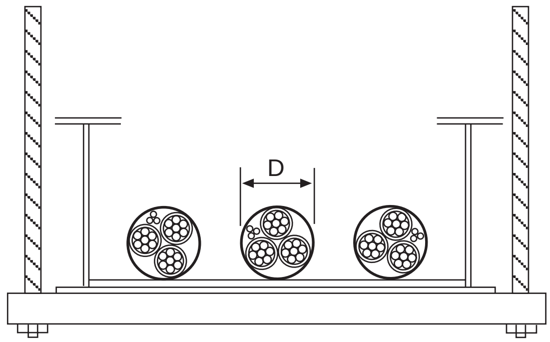


Figure 12.13 Three Type TC multiconductor cables, with size 250 kcmil Type XHHW copper insulated conductors and a bare equipment grounding conductor, are supported by an aluminum ladder-type cable tray without a maintained spacing between the cables.

NEC® 392.11(B)(3) simply specifies the minimum conductor ampacity can be found in *Table 310.17*, which is 620 amperes. Note the big difference in conductor ampacity between the previous example and this example when a space is maintained between the conductors.

Example 12.5 Three Type TC cables with three size 250 kcmil XHHW copper conductors and an equipment grounding conductor are to be supported by aluminum ladder-type cable tray where a space is not maintained between the individual cables, as illustrated in Figure 12.13. All conductor terminations are rated 75°C, and the cable diameter is 1.76 in. (44.7 mm). Determine the minimum width of cable tray permitted, and the ampacity of the insulated conductors in the cable.

Answer: The minimum width of the cable tray is determined according to *392.9(A)(1)*. The cables are required to be in a single layer, but no space is required between the cables. The minimum width of cable tray is not permitted to be less than the sum of the diameters of the cables in the cable tray, which is 5.28 in. (134 mm). Therefore, a 6 in. (150 mm) cable tray is adequate.

3×1.76 in = 5.28 in
3×44.7 mm = 134 mm

Next determine the ampacity of the size 250 kcmil copper conductors in the cables according to *392.11(A).* Note in *392.11(A)(1)* that the derating factors do not apply unless there are more than three current-carrying conductors in any one cable, and then they apply only to that particular cable. In this case, conductor ampacity is determined according to *Table 310.16*, and it is 255 amperes.

Example 12.6 For the cable tray installation of Figure 12.14, the three Type TC 3-conductor cables are installed with a space maintained between them of one cable diameter. Each cable contains three XHHW insulated conductors size 250 kcmil copper and has a diameter of 1.76 in. (44.7 mm). All

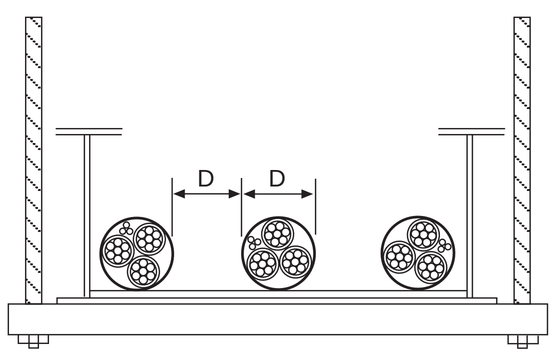


Figure 12.14 Three Type TC multiconductor cables, with size 250 kcmil Type XHHW copper insulated conductors and a bare equipment grounding conductor, are supported by an aluminum ladder-type cable tray with a space maintained between the cables equal to the diameter of the cable.

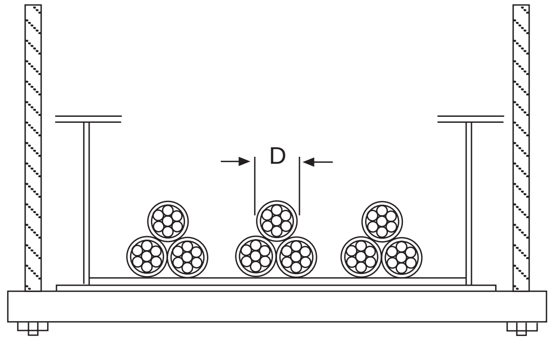


Figure 12.15 Three triplexed single conductor cable bundles with size 4/0 AWG Type THWN copper conductors are installed in aluminum ladder-type cable tray with no maintained space between the conductors.

conductor terminations are rated 75°C. Determine the minimum permitted width of aluminum ladder-type cable tray and the ampacity of the insulated conductors in the cable.

Answer: There is no rule for determining the minimum width of cable tray. It is simply a matter of adding the cable diameters. There are three cables of the same diameter and there are two spaces between the cables of the same diameter. The minimum width of cable tray is not permitted to be less than 8.8 in. (224 mm); therefore, the minimum standard width is 9 in. (225 mm).

5×1.76 in. = 8.8 in.

5×44.7 mm = 224 mm

The conductor ampacity is determined according to *392.11(A)(3)*, which specifies the method of *310.15(C)*. That section is one that requires engineering supervision, but the ampacity is usually determined from *Table B.310.3* in *Annex B*, and in this case is 274 amperes.

Example 12.7 Three sets of triplexed conductors are installed in an aluminum ladder-type cable tray as shown in Figure 12.15. The individual conductors are type THWN, size 4/0 AWG copper, and all terminations are rated 75°C. *NEC® 392.8(E)* permits these conductors to be bundled rather than installed in a single layer. Determine the minimum width of cable tray permitted and ampacity of the conductors.

Answer: The minimum width of cable tray is specified in *392.10(A)(4).* The width is not permitted to be less than the sum of the diameters of all of the conductors in the cable tray. Look up the diameter of a size 4/0 AWG Type THWN conductor in *Table 5, Chapter 9;* it is 0.642 in. (16.3 mm). Then multiply by nine conductors to get the minimum width of 5.78 in. (147 mm). A 6 in. (150 mm) wide cable tray is permitted.

9 conductors $\times$ 0.642 in. = 5.78 in.
9 conductors $\times$ 16.31 mm = 147 mm

The ampacity of the individual conductors is determined according to *392.11(B)(2)*. The ampacity found in *Table 310.17* is multiplied by 0.65 to get 234 amperes.

0.65×360 A = 234 A

Example 12.8 Three triplexed bundles of Type THWN copper conductors are installed in aluminum ladder-type cable tray with a space maintained between each bundle equal to 2.15 times the individual cable diameter, as shown in Figure 12.16. All conductor terminations are rated 75°C. Determine the minimum permitted width of cable tray and the ampacity of the conductors.

Answer: The width of the cable tray is simply the physical dimension necessary to accommodate the conductors when installed as required by *392.11(B)(4).* There are three bundles of cables; therefore, there will be two spaces with a minimum dimension of 2.15 times the individual conductor diameter. The bundles will lay in the cable tray with two conductors touching the cable tray. Therefore, space must be allowed for a minimum of six conductors, as shown in Figure 12.16. Look up the diameter of a size 4/0 AWG Type THWN conductor in *Table 5, Chapter 9;* it is 0.642 in. (16.31 mm). The calculated minimum width permitted is 6.612 (168 mm), which requires at least a 9 in. wide (225 mm) cable tray.

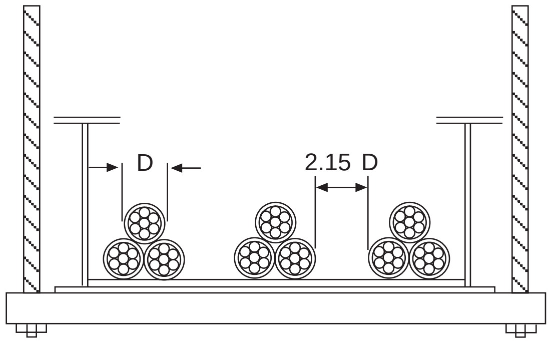


Figure 12.16 Three triplexed single conductor cable bundles with size 4/0 AWG Type THWN copper conductors are installed in aluminum ladder-type cable tray with a space not less than 2.15 times the individual cable diameter maintained between the cable bundles.

$$\begin{aligned}\text{Width} &= 2 \times (2.15 \times \text{D}) + 6 \times \text{D}\\ &= 2 \times (2.15 \times 0.642 \text{ in.}) + 6 \times 0.642 \text{ in.}\\ &= 2 \times 1.380 \text{ in.} + 3.852 \text{ in.}\\ &= 2.760 \text{ in.} + 3.852 \text{ in.} = 6.612 \text{ in.}\\ &= 2 \times (2.15 \times 16.31 \text{ mm}) + 6 \times 16.31 \text{ mm}\\ &= 70 \text{ mm} + 98 \text{ mm} = 168 \text{ mm}\end{aligned}$$

Because a space between the triplexed bundles is maintained for cooling, the ampacity is permitted to be looked up in *Table 310.20* and, in this case, is 287 amperes.

When multiconductor cables of different sizes are placed in a cable tray together, the method of determining the width of cable tray required depends upon the size of conductors in the cables. There is one simple method when all cables contain conductors size 4/0 AWG and larger. *NEC® 392.9(A)(1)* requires that the cables be arranged in a single layer. The width of the cable tray is equal to the sum of the diameters of the cables.

When the conductors in the cables are size 3/0 AWG and smaller, a single layer of conductors is not required. The cables can be placed in multiple layers as long as they are not stacked on top of any cables in the same cable tray that have conductors size 4/0 AWG and larger. Cables with conductor size 3/0 and smaller are not permitted to have a cross-sectional area greater than approximately 40% of the cross-sectional area of a standard usable depth cable tray, which is approximately 3 in. (75 mm). If a cable tray contains only cables with conductors that are size 3/0 and smaller, then the method of determining the cable tray width is specified in *392.9(A)(2)*. The total cross-sectional area of the conductors is not permitted to exceed the value given in column 1 of *Table 392.9*. The values given in column 1 of *Table 392.9* are approximately 40% of the usable cross-sectional area of a standard cable tray.

Example 12.9 A ladder-type cable tray contains 10 Type TC multiconductor cables that each have three copper conductors size 2/0 AWG. The total cross-sectional area of the cables is 1.35 sq. in. (870 mm^2). Remember that how the cables are arranged in the cable tray determines the allowable ampacity of the cables. In this case assume the cables are installed in multiple layers in the cable tray. Determine the minimum width of the cable tray required for these cables.

Answer: The method of sizing the cable tray is described in *392.9(A)(2)*. First determine the total cross-sectional area of the cables in the cable tray, which is 13.6 sq. in. (8700 mm^2). Next select the minimum size cable tray from column 1 of *Table 392.9* and find 12 in. (300 mm).

When cables with conductors larger and smaller than size 4/0 AWG are placed in the same cable tray, two methods are combined to determine the minimum width of cable tray. The rule is found in *392.9(A)(3)*, and utilizes column 2 of *Table 392.9*. An example is shown in Figure 12.17 which shows a cable tray arranged into two sections; one with cables with conductor sizes 4/0 AWG and larger, and the other section with cables with conductor sizes 3/0 AWG and smaller. The cables with conductor sizes 4/0 AWG and larger are required to be arranged in a single layer. The cables with conductor sizes

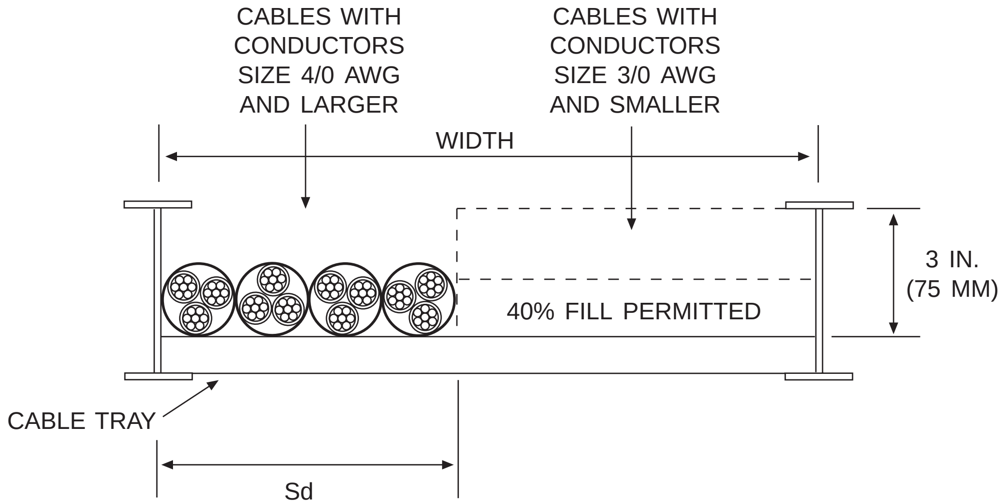


Figure 12.17 After the diameters of the cables with size 4.0 AWG and larger conductors are subtracted from the width of the cable tray, the cables with conductors size 3/0 AWG and smaller are permitted to fill only 40% of the remaining portion of the cable tray.

3/0 and smaller are permitted to be in multiple layers. In either case, the cable tray is not permitted to have a conductor cross-sectional area that exceeds 40% of the usable cross-sectional area of the cable tray. Cable trays have a standard depth of approximately 3 in. (75 mm). Therefore, the total cable cross-sectional area is not permitted to exceed 40% of the cable tray width times 3 in. (75 mm). Those values are given in column 1 of *Table 392.9.* The formulas in column 2 of *Table 392.9* essentially subtract the diameters of the single layer of cables from the total width, and then calculates 40% of the remaining area of the cable tray. This process is illustrated in Figure 12.17. This is accomplished by determining the total width of the cables with conductors size 4/0 and larger (this value is **Sd**) and multiplying by 1.2, which is actually 1.2 in. assuming the usable depth of a cable tray is 3 in. The value 1.2 in. is 40% of 3 in. When worked out in metrics, the usable depth of the cable tray is 75 mm, of which 30 mm is 40%. The metric formulas in column 2 of *Table 392.9* multiplies **Sd** by 30, while the in.-pound formula multiplies **Sd** by 1.2. The result of the calculation using the formula in column 2 of *Table 392.9* is compared with the actual cross-sectional area of the cables with conductors size 3/0 AWG and smaller. If the value from the calculation is larger than the cross-sectional area of the conductors, then the cable tray is wide enough for the application.

> **Example 12.10** A cable tray contains two Type TC cables with three size 350 kcmil conductors with a cable diameter of 1.98 in. (50.3 mm), and six Type TC cables with three size 2/0 AWG conductors with a cable cross-sectional area of 1.35 sq. in. (870 mm^2) as shown in Figure 12.18. Determine the minimum permitted width of ventilated-trough cable tray for this installation.

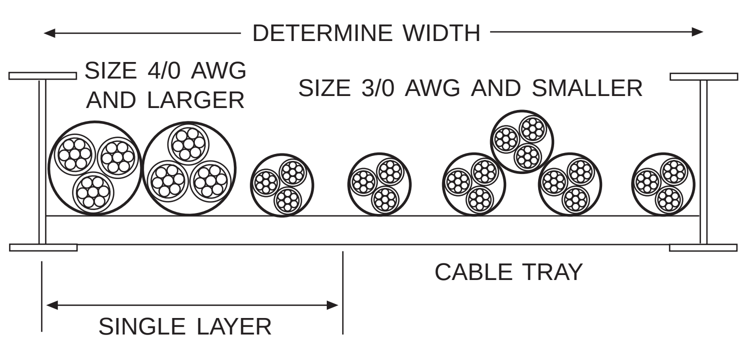


Figure 12.18 The cable tray contains two Type TC cables with size 350 kcmil conductors and size Type TC cables with size 2/0 AWG conductors.

Answer: The method is described in *392.9(A)(3)*. The cross-sectional area and diameter of multiconductor cables are not given in the Code. The best source for this information is to contact the cable manufacturer. Some manufacturers provide cable technical data on their web sites. The symbol **Sd** in column 2 of the *Table 392.9* is the sum of the diameters of all cables with conductors size 4/0 AWG and larger, which is multiplied by 1.2 to convert to sq. in. (multiply by 30 to convert to square millimeters). In this example, there are two cables, so multiply the diameter by two to get 3.96 in. (100 mm).

Sd = (sum of cable diameters with conductors size 4/0 AWG and larger)
Sd = 2 × 1.98 in. = 3.96 in.
Sd = 2 × 50.3 mm = 100.6 mm

Next determine the cross-sectional area of all conductors size 3/0 AWG and smaller. There are six that are size 2/0 AWG, so multiply their area, which is 1.36 sq. in. (870 mm^2), by six to get the total cross-sectional area of the conductors which is 8.10 sq. in. (5225 mm^2).

6 cables × 1.35 in.^{2} = 8.10 in.^{2}
6 cables × 870 mm^2 = 5225 mm^2

The method is described in the text is a trial and error method. Choose one of the standard cable tray widths believed to be wide enough and do the calculation. Start with a 12 in. (300 mm) width for this example. The formula is in column 2 of *Table 392.9.*

14 – (1.2 × Sd) = cross-sectional area of cables with conductors size 3/0 and smaller

The result from this calculation must not be smaller than the cross-sectional area of the cables with conductors size 3/0 AWG and smaller as determined earlier.

14 in.^{2} – (1.2 × 3.96 in.) = 14 in.^{2} – 4.75 in.^{2} = 9.25 in.^{2}
9000 mm^2 – (30 × 100 mm) = 9000 mm^2 – 3000 mm^2 = 6000 mm^2

The cables with conductor size 3/0 AWG are only 8.10 in.^{2} (5225 mm^2); therefore, the 12 in. (300 mm) wide cable tray is adequate for the application.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC*® that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only, and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 392 Cable Trays

392.8(A): The previous edition of the Code did not permit splices in conductors made in cable tray to project above the side rails of the cable tray. Now splices are permitted to project above the side rails where they are not subject to physical damage.

392.9(A)(1): When multi-conductor cable ampere rating is determined from *Table B310.3* and a free air space is provided between each cable with a width not less than the cable diameter, the minimum width of the cable tray could be determined by logic, but the rule was not actually stated. Now the rule is stated that the minimum width of the cable tray is to be not less than the sum of the cable diameters plus the sum of the required spaces between the cables. An example is shown in Figure 12.14.

392.11(C): This is a new section that provides a rule for determining the minimum size of a cable tray that contains a combination of single-conductor cables and multi-conductor cables. The previous edition of the Code did not provide a method of making this determination. An example of this type of installation is shown in Figure 12.19.

Article 427 Fixed Electric Heating Equipment for Pipelines and Vessels

427.13: Caution signs are required on pipelines and vessels that are equipped with electric heating. The change is that the posting of the warning sign is now required at intervals of not more than 20 ft (6 m)

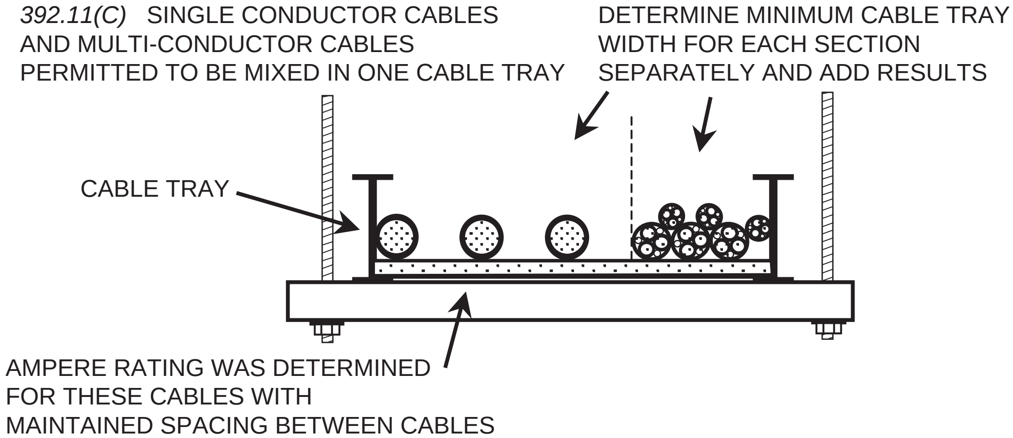


Figure 12.19 There is a new method for determining the minimum width of cable tray where the cable tray contains both single-conductor cables and multi-conductor cables.

and adjacent to equipment in the piping system that requires periodic servicing. In the past, there was no warning sign spacing interval required.

Article 490 Equipment, Over 600 Volts, Nominal

490.44(C): There is a new provision for locking a fused interrupt switch in the open position. The locking provision shall be of a type that remains in place when the lock is not present. Portable locking devices are no longer permitted.

490.46: This is a new section that requires all high-voltage circuit breakers, even the drawout type, to be capable of being locked in the open position, and the locking means shall be of a type that remains in place when the lock is removed.

Article 610 Cranes and Hoists

610.31(2): The switch or circuit breaker that serves as the disconnecting means for the runway conductors is now required to be of a type that is a fixed part of the switch or circuit breaker and remains in place when the lock is removed. Portable means of locking the runway conductor disconnect in the open position is no longer permitted.

610.32: The switch or circuit breaker that serves as the disconnecting means for cranes and monorail hoists is now required to be of a type that is a fixed part of the switch or circuit breaker and remains in place when the lock is removed. Portable means of locking the crane or monorail hoist power disconnect in the open position is no longer permitted.

Article 665 Induction and Dielectric Heating Equipment

665.12: The disconnecting means required for heating equipment must now be of a type where the locking means remains in place with the lock removed. Portable means of locking the disconnect in the open position is not permitted.

665.22: Panels and doors that allow access to energized parts of heating equipment with terminals of 150 volts shall be capable of being locked. Now the locking means shall be of a type that remains with the panel or door even with the lock removed. It is not stated whether the voltages are to ground or between conductors. It must be assumed that if there is some combination of terminals or terminal to ground of 150 volts or more, this rule applies.

Article 727 Instrumentation Tray Cable, Type ITC

727.4(5): Cable without a metallic sheath or armor is not permitted to be installed exposed unless it is marked ITC-ER. The suffix -ER signifies that the cable is suitable for exposed routing, which means it can be installed outside a cable tray in accordance with the protection requirements of this paragraph. The cable is continuously supported and protected from physical damage. The cable is supported at intervals not exceeding 6 ft (1.8 m). The limitation of distance it could be installed from the cable tray was deleted. Now it is permitted to be installed any reasonable length to connect from the cable tray to supplied equipment provided the support requirements are satisfied.

Article 770 Optical Fiber Cables and Raceways

770.2: The definition of *exposed to accidental contact* was changed. This definition only applies to conductive optical fiber cable that has normally non–current-carrying metallic strength members, metallic vapor barrier, or metallic outer sheath or armor. Accidental contact means these metal components make contact with circuit conductors due to failure of support or insulation.

770.2: Optical fiber cable is defined as an assembly of one or more optical fibers with an overall covering.

770.2: Cable sheath is a new definition, and it consists of one or more jackets and may include one or more metallic components for strength.

770.3(A): Composite cables consisting of optical fibers and current-carrying conductors are to be listed and marked according to the appropriate type of cable described in *Chapter 3* of the Code.

770.24: Cable ties are now specifically mentioned as a means of supporting optical fiber cables to the structure.

770.25: When an optical fiber cable is not in use and is not terminated at equipment if it is not to be considered to be abandoned, the required marking tag now must have the durability required to withstand the environment in which it is place.

770.26: This section is not new material, but is a repeat of *300.21*. The prevention of spread of fire and spread of products of combustion is of such importance that rather than making a reference to *300.21*, the actual text of *300.21* is placed in this section. This is not a change from the previous edition of the Code.

770.93(B): This is a new paragraph dealing with the grounding of optical fiber cables with metal members that do not enter the building, but are terminated on the outside of a building. This situation was not covered in the previous edition of the Code. Where the cable is exposed to contact with light and power wiring, the metal members are either required to be grounded or isolated near the point of termination.

770.100: This is a new section that provides specific requirements for the termination of non–current-carrying metal members in fiber optic cables at the point of entry to a building or structure. A grounding conductor should be run from the termination point preferably to the intersystem grounding point located on the outside of a building by the electrician installing the wiring in the building. That grounding conductor is to be insulated copper or other corrosion-resistant metal not smaller than size 14 AWG, run in as straight a line as practical, and protected from physical damage. Such a grounding installation is shown in Figure 12.20. If an intersystem grounding terminal is not available, directions are provided to describe acceptable means of creating an intersystem grounding connection. In the case where creating an intersystem grounding connection is not practical, directions are provided for establishing a grounding

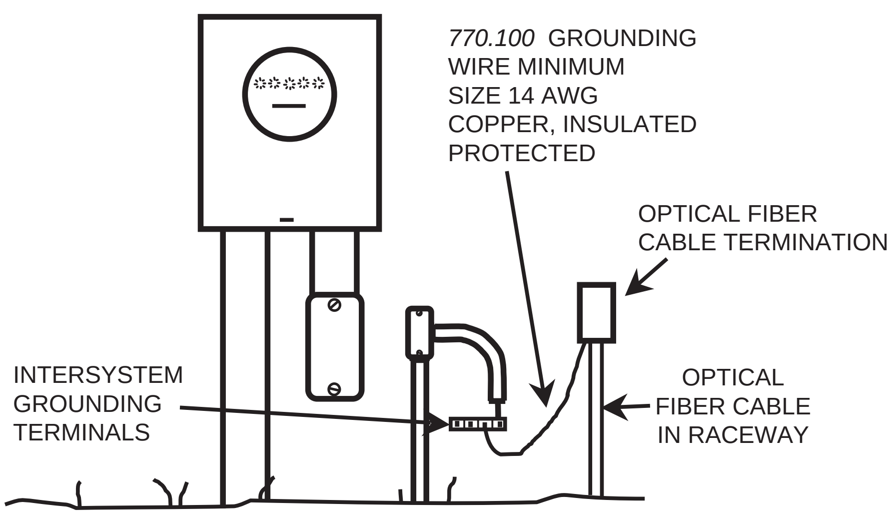


Figure 12.20 When an optical fiber cable enters a building, any conductive elements in the cable are required to be connected to a grounding electrode, preferably at the intersystem grounding terminals, if present.

electrode for the optical fiber entrance cable. If a separate grounding electrode is established for the optical fiber cable entry, it is required to be bonded to the electrical system grounding electrode with a size 6 AWG copper conductor.

770.101: This section is not new, but was *770.133(C)* in the previous edition of the Code. It requires metal members of optical fiber cable to be grounded. The previous edition of the Code did not provide directions as to how this was to be accomplished other than a general reference to *Article 250.* Now it is made clear that the grounding of metal members of all cables is to be to the grounding point described in *770.100.*

770.106: This section provides directions for grounding the optical fiber entrance cable metal members for a mobile home. If the mobile home wiring is installed according to *Article 550,* then this is easy since the mobile home service is adjacent to the mobile home and within 30 ft (9 m) of the mobile home. Basically, this section describes how to ground the optical fiber cable entering a mobile home when the service does not meet the requirements of *Article 550.*

770.133(A) Ex 5: Non-conductive optical fiber cable is not permitted to be terminated in the same box, cabinet, or enclosure with electric light and power wires, and conductive optical fiber cable is not permitted to be run in the same cable tray with electric light and power wires. A new *Exception 5* was added that permits these installations, provided the electric light and power wires and optical fiber cables are separated by permanent barrier or listed divider.

770.133(C): Optical fiber cables are not permitted to be attached to the outside of raceways as a means of support. The exception is to support an overhead span of optical fiber cable to a riser used for the entrance of the cable into a building or structure. This rule is illustrated in Figure 12.21.

770.154(F): Optical fiber cables installed such that they enter a classified hazardous location are subject to the same sealing requirements as light and power circuit conductors. Care must be taken to make sure flammable vapor does not leak past a sealing fitting through the interior of the cable assembly. The subject of sealing optical fiber cable in the previous edition of the Code was not covered.

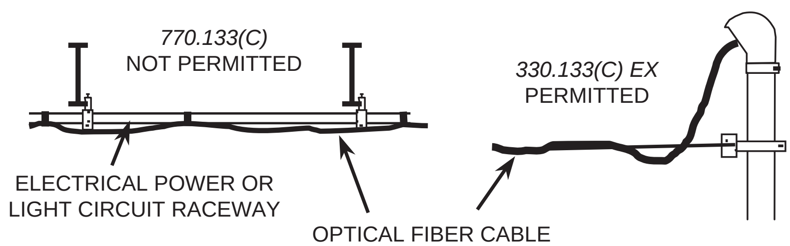


Figure 12.21 Optical fiber cables are not permitted to be attached to raceways for support, except where aerial cable is supported to a mast riser for entry into a building or structure.

WORKSHEET NO. 12—BEGINNING INDUSTRIAL ELECTRICAL APPLICATIONS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A machine in a factory is supplied power from an overhead busway by a bus drop cable. A tension take-up device connected to the structure of the building supports the bus drop cable as shown in Figure 12.22. The distance from the busway plug-in device to the tension take-up device where no intermediate supports are provided is not permitted to exceed:
   A. 6 ft (1.8 m).
   B. 10 ft (3 m).
   C. 12 ft (3.7 m).
   D. 15 ft (4.5 m).
   E. 25 ft (7.5 m).

   Code reference__________________

2. A cablebus is used as the service-entrance conductor from a transformer located outside a building with the cablebus running from the transformer to the service equipment inside the building, as shown in Figure 12.23. The cable bus is not specifically designed for extra-long spans. The maximum distance permitted between supports is:
   A. 5 ft (1.5 m).
   B. 6 ft (1.8 m).
   C. 8 ft (2.5 m).
   D. 10 ft (3 m).
   E. 12 ft (3.7 m).

   Code reference__________________

3. When single-conductor cables size 4/0 and smaller are installed in ladder-type cable tray, the rung spacing is not permitted to be greater than:
   A. 6 in. (150 mm).
   B. 9 in. (225 mm).
   C. 12 in. (300 mm).
   D. 16 in. (400 mm).
   E. 18 in. (450 mm).

   Code reference__________________

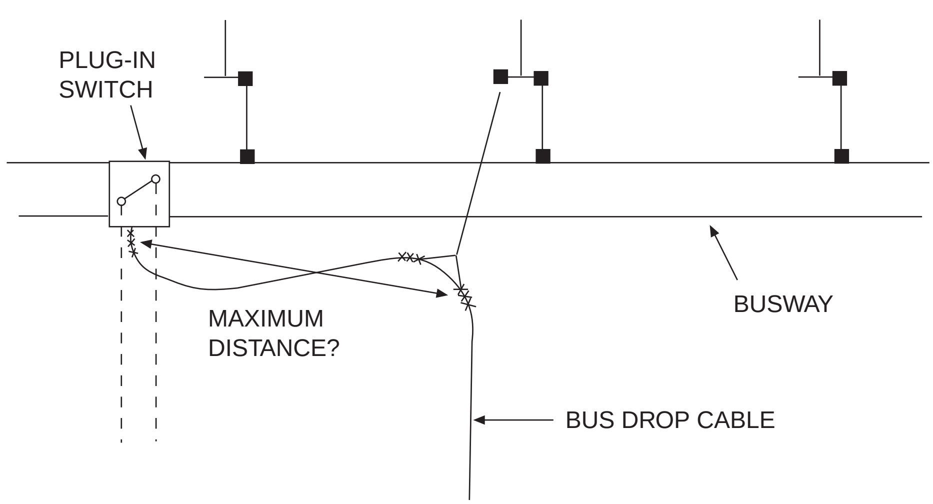


Figure 12.22 Determine the maximum length of bus drop cable permitted between the take-up support and the plug-in switch.

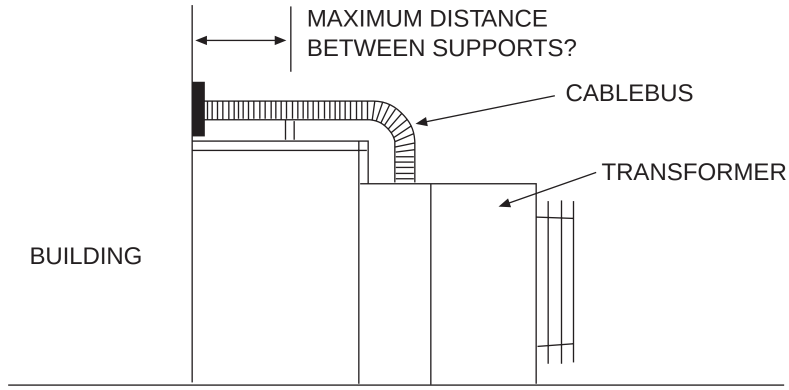


Figure 12.23 Determine the maximum distance between supports of an outside installation of cablebus that is not specifically designed for a longer support distance.

4. Conductors are permitted to be run through the open provided they are not exposed to physical damage. The conductors are permitted to pass from one cable tray section to another, from the cable tray to equipment, or from the cable tray to a raceway as shown in Figure 12.24. The maximum distance permitted for open spans of conductors from cable trays is:
   A. 18 in. (450 mm).
   B. 3 ft (900 mm).
   C. 4$^1/_2$ ft (1.4 m).
   D. 6 ft (1.8 m).
   E. 8 ft (2.5 m).

   Code reference ______________

5. The cable tray shown in Figure 12.24 is aluminum ladder-type and contains three feeder circuits rated 200, 400, and 800 amperes. Two sections of the cable tray do not join and a copper conductor is used to bond the two sections of cable tray. The minimum size bonding jumper permitted for the installation is:
   A. 4 AWG.
   B. 2 AWG.
   C. 1/0 AWG.
   D. 3/0 AWG.
   E. 4/0 AWG.

   Code reference ______________

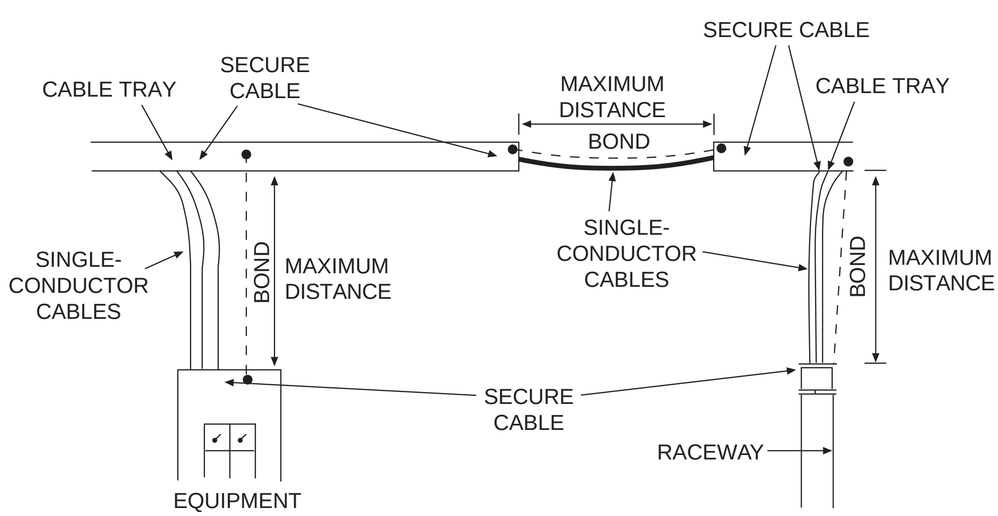


Figure 12.24 Cable tray installation in an industrial building where two sections of cable tray do not join and conductors are in the open between the cable tray and equipment or conduits.

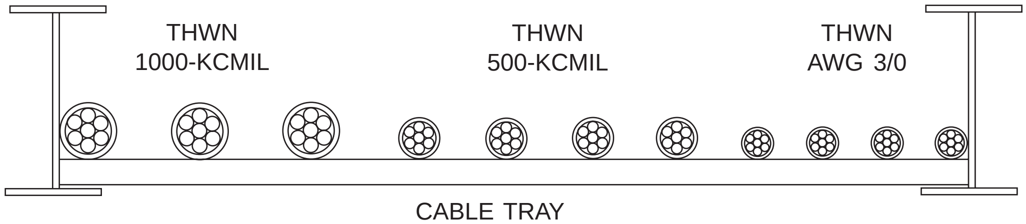


Figure 12.25 A cable tray in an industrial building that contains single-conductor cables arranged in a single layer with an air space between the cables with a width equal to the diameter of the largest adjacent cable. The cables are tied to the cable tray so they will not move after installation.

6. Ventilated-trough cable tray contains only single copper conductor cables installed in a single layer with an air space maintained between the cables not less than the width of the largest adjacent cable, as shown in Figure 12.25. There are three 1000-kcmil conductors, four 500-kcmil conductors, and four size 3/0 AWG conductors all with THWN insulation. The cables are arranged in this manner to achieve maximum ampacity from the conductors. The cables are tied down to the cable tray so they will not move. The minimum width of cable tray required for this installation is:
   A. 9 in. (225 mm).
   B. 12 in. (300 mm).
   C. 18 in. (450 mm).
   D. 24 in. (600 mm).
   E. 30 in. (750 mm).

   Code reference ___________________

7. The size 500 kcmil, Type THWN conductors run in the cable tray of Figure 12.25 have a maintained spacing of one cable diameter between the cables for the entire circuit run in ventilated-trough cable tray with no cover. The allowable ampacity of the conductors is:
   A. 380 amperes.
   B. 403 amperes.
   C. 500 amperes.
   D. 560 amperes.
   E. 620 amperes.

   Code reference ___________________

8. The nonheating lead wires provided with an electric resistance type pipeline heating cable are longer than required to make the connections to the wiring system. The non-heating leads are:
   A. required to be kept at the original length.
   B. permitted to be shortened to the desired length provided the lead markings are not removed.
   C. required to be shortened only to the length needed to make the connections.
   D. permitted to be shortened to not less than 24 in. (600 mm).
   E. permitted to be shortened but required to be 4 ft (1.2 m) in length to prevent conduction of heat to the terminal box.

   Code reference ___________________

9. If a cable tray is to be used as an equipment grounding conductor for the circuit and feeder conductors that it supports, the cable tray shall be:
   A. constructed of aluminum.
   B. of the solid bottom or ventilated type.
   C. marked to show the cross-sectional area of the cable tray or side rails, which is sufficient for the circuit rating.
   D. mounted not less than 12 ft (3.7 m) above the floor
   E. installed in lengths not to exceed 100 ft (30 m).

   Code reference ___________________

10. A resistance welder makes repetitive spot welds and has a duty cycle of 4%. The actual primary supply current during the weld is 620 amperes at 460 volts. If the supply conductors for the welder are copper, Type THWN with 75°C terminations, the minimum permitted size conductor is:
    A. 3 AWG.
    B. 2 AWG.
    C. 1 AWG.
    D. 1/0 AWG.
    E. 2/0 AWG.

    Code reference ___________________

11. An industrial machine is to be installed where only qualified persons will service the equipment. An area of the machine contains control wiring, operating at under 150 volts, that may require servicing while energized. The minimum clearance in front of the access to the live parts is required to be not less than:
    A. 2½ ft (750 mm).
    B. 3 ft (900 mm).
    C. 3½ ft (1 m).
    D. 4 ft (1.2 m).
    E. 4½ ft (1.4 m).

    Code reference ___________________

12. The secondary output conductors of an industrial arc welder consist of an electrode conductor and a workpiece conductor. The workpiece conductor:
    A. shall be grounded to the metal frame of the building in the area of the welder.
    B. shall be grounded to the equipment grounding conductor of the supply to the welder.
    C. is not required to be grounded to any premises electrical system grounding conductor or grounding electrode.
    D. is required to be connected to a ground rod in the area of the welder.
    E. is considered to be a separately derived system and is to be grounded accordingly.

    Code reference ___________________

13. In an existing building, optical fiber cable is to be installed where the most convenient way of running the necessary cables is across the upper side of a permanent suspended ceiling in a hallway. There is one communications cable and no other cables run across the same ceiling. The maximum number of optical fiber cables permitted to be installed by running them across the suspended ceiling from one end of the hallway to the other is:
    A. one.
    B. two.
    C. three.
    D. zero because this practice is not permitted.
    E. as many as desired.

    Code reference ___________________

14. A new optical fiber cable is installed in a building to replace an existing cable that will be abandoned. The abandoned cable:
    A. shall be removed where accessible.
    B. shall be removed only in places where it is visible.
    C. is permitted to be left in place provided it does not limit access to equipment.
    D. shall be completely removed from the building.
    E. is permitted to remain in place provided the ends are properly sealed.

    Code reference ___________________

15. For new construction, optical fiber cables are required to be secured to the structure of the building.
    A. within 12 in. (300 m) of terminations and at intervals not exceeding $4^1/2$ ft (1.4 m).
    B. within 12 in. (300 m) of terminations and at intervals not exceeding 5 ft (1.5 m).
    C. at intervals not exceeding 10 ft (3 m).
    D. only in areas that will not be accessible.
    E. with straps, staples, cable ties, hangers, or similar fittings designed and installed so as not to damage the cable.

Code reference ___________________

WORKSHEET NO. 12—ADVANCED INDUSTRIAL ELECTRICAL APPLICATIONS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A set of integrated gas spacer cables, trade size 4500 kcmil are run underground for the service entrance of an industrial building. Assuming that the cable is installed such that derating of the ampacity is not required, the allowable ampacity of the Type IGS Cable is:
   A. 505 amperes.
   B. 519 amperes.
   C. 550 amperes.
   D. 600 amperes.
   E. not specified in the Code.

   Code reference ___________________

2. An 800-ampere busway suspended from the ceiling of an industrial area is to be extended to serve an additional load. A 400-ampere busway is adequate to supply the load and the 400-ampere section is added to the 800-ampere busway without over-current protection provided for the 400-ampere section of busway as shown in Figure 12.26. This practice is permitted provided the busway of reduced ampacity does not extend beyond the point of ampacity reduction more than:
   A. 25 ft (7.5 m).
   B. 50 ft (15 m).
   C. 75 ft (22.5 m).
   D. 100 ft (30 m).
   E. 200 ft (60 m).

   Code reference ___________________

3. A cablebus system protected by a 1200-ampere circuit breaker is used as feeder conductors from a disconnect at a transformer to the main distribution panelboard. The cablebus will contain one set of 3-phase, 480/277-volt conductors, as shown in Figure 12.27. The calculated demand load on the conductors is 960 amperes. The minimum size Type THWN copper conductors permitted to be installed for this cablebus is:
   A. 1000 kcmil.
   B. 1250 kcmil.
   C. 1500 kcmil.
   D. 1750 kcmil.
   E. 2000 kcmil.

   Code reference ___________________

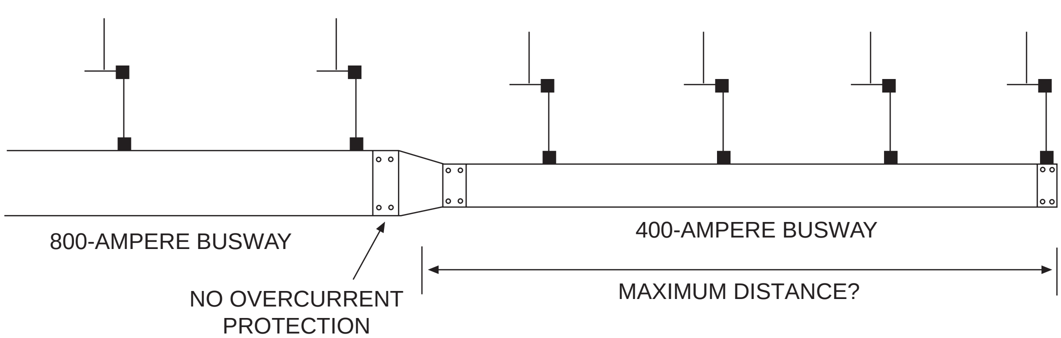


Figure 12.26 A 400-ampere rated busway is added to an 800-ampere busway to supply a load within the rating of the 400-ampere busway.

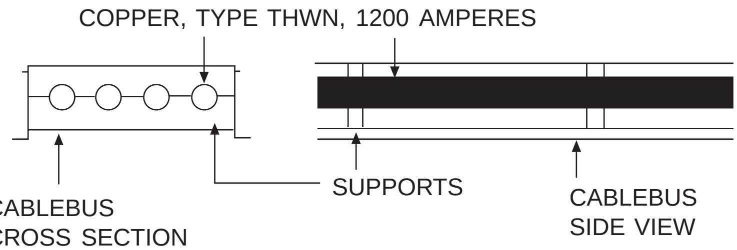


Figure 12.27 A 1200-ampere cablebus is used as a feeder from a transformer to a distribution panelboard.

4. The smallest size ungrounded or grounded single-circuit conductors permitted to be installed in ladder-type cable tray is:
   A. not specified as long as rung spacing does not exceed 6 in. (150 mm).
   B. 6 AWG.
   B. 4 AWG.
   C. 2 AWG.
   D. 1/0 AWG.

   Code reference ___________________

5. A feeder is run with three size 500 kcmil copper conductors in raceway for a portion of the circuit and in aluminum ladder-type cable tray for a portion of the circuit. The conductors have 75°C insulation and terminations and are arranged in a single layer but a space is not provided between the conductors. The maximum allowable ampacity of the conductors is:
   A. 380 amperes. C. 540 amperes. E. 650 amperes.
   B. 403 amperes. D. 620 amperes.

   Code reference ___________________

6. Single-conductor cables are permitted to be run in ladder, ventilated trough, solid bottom, or ventilated channel cable tray:
   A. in any type of building.
   B. only in commercial buildings.
   C. only in industrial buildings.
   D. in commercial buildings where there is a permanent maintenance staff to maintain the wiring system.
   E. only in approved industrial buildings with an engineer available to supervise maintenance.

   Code reference ___________________

7. Type TC multiconductor cables with three copper Type XHHW insulated power conductors are run in uncovered ladder-type cable tray in a single layer with no maintained spacing between the conductors, as shown in Figure 12.28. There are two other cables—one cable with copper size 3/0 AWG conductors. All conductor terminations are 75°C rated. The minimum size copper conductor in the other cable required for a 225-ampere feeder is:
   A. 2/0 AWG. C. 4/0 AWG. E. 300 kcmil.
   B. 3/0 AWG. D. 250 kcmil.

   Code reference ___________________

8. The cable tray in Figure 12.28 is aluminum ladder-type and it is installed in an industrial building where only qualified maintenance staff will service the wiring. The highest rated circuit in the cable tray is 400 amperes. The cable tray is permitted to

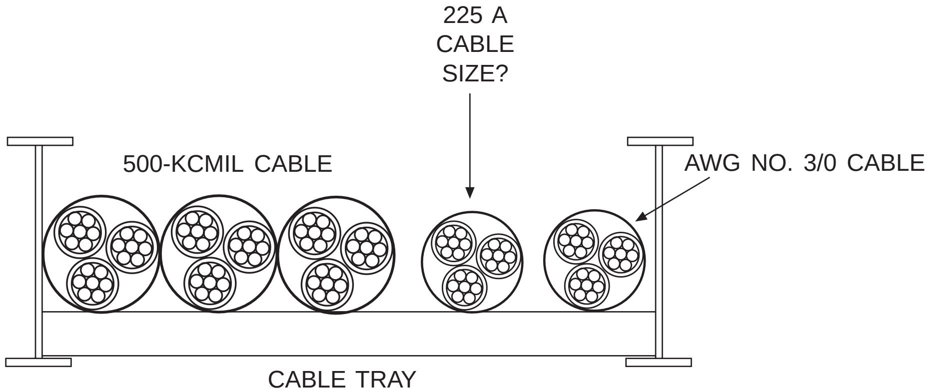


Figure 12.28 A cable tray contains several multiple conductor cables arranged in a single layer but without a maintained air space between the cables. One of the cables is to be sized as a 225-ampere feeder circuit.

serve as the equipment grounding conductor for the circuits if it is listed as suitable for equipment grounding and it has a total cross-sectional area of the side rails of not less than:

A. 0.40 in.^{2} (258 mm^2).
B. 0.60 in.^{2} (387 mm^2).
C. 0.70 in.^{2} (451 mm^2).
D. 1.00 in.^{2} (645 mm^2).
E. 1.50 in.^{2} (967 mm^2).

Code reference ____________________

9. A ladder-type cable tray supports TC multiconductor power cables with Type XHHW copper conductors. There are two 3-conductor cables size 500 kcmil with a diameter of 2.26 in. (57.4 mm), three 4-conductor cables size 250 kcmil with a diameter of 1.93 in. (49.0 mm), and five 4-conductor cables size 3/0 AWG with a diameter of 1.58 in. (40.1 mm) and a cross-sectional area of 1.96 sq. in. (1264 mm^2). An air space between the conductors, as shown in Figure 12.29, is not maintained. The minimum width of cable tray permitted for the installation is:

A. 9 in. (225 mm).
B. 12 in. (300 mm).
C. 18 in. (450 mm).
D. 24 in. (600 mm).
E. 30 in. (750 mm).

Code reference ____________________

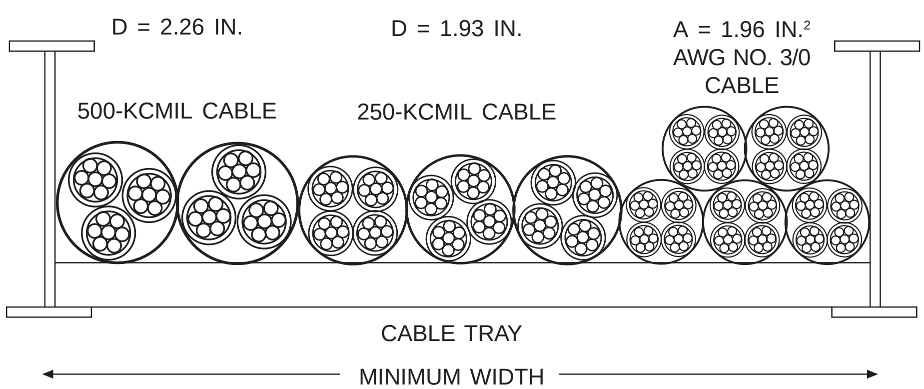


Figure 12.29 A cable tray contains only Type TC multiconductor cables, several of which are larger than size 4/0 AWG and several of which are size 3/0 AWG. Determine the minimum width permitted for the cable tray.

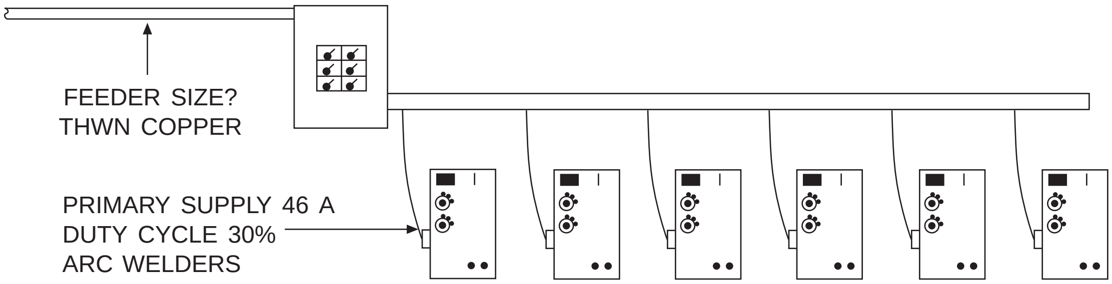


Figure 12.30 Six transformer type arc welders in an industrial plant are supplied by a common feeder, and the welders have a primary supply current of 46 amperes and a duty cycle of 30%.

10. A 460-volt, 3-phase transformer arc welder with a duty cycle of 50% has a primary current listed on the rating plate as 40 amperes. The conductors supplying the welder are size 8 AWG copper with THWN insulation and conductor terminations are rated 75°C. A single overcurrent device protects both the welder and the circuit. The maximum rating permitted for the overcurrent device for this welder circuit is:
    A. 50 amperes.
    B. 60 amperes.
    C. 70 amperes.
    D. 80 amperes.
    E. 100 amperes.

    Code reference ___________________

11. Six transformer arc welders are supplied by one feeder. The welders are 3-phase, 460-volt, with a primary supply current of 46 amperes marked on the rating plate, and the duty cycle is 30% as shown in Figure 12.30. The minimum recommended size of THWN copper feeder conductors to supply these welders, if all terminations are rated 75°C and no other load pattern information is available, is:
    A. 1 AWG.
    B. 2 AWG.
    C. 3 AWG.
    D. 1/0 AWG.
    E. 2/0 AWG.

    Code reference ___________________

12. The branch-circuit conductors for an electroplating installation supply a load of 320 amperes and the conductors are solid copper busbars with a rectangular cross-section. The minimum busbar cross-sectional area permitted for this electroplating load is:
    A. 0.25 in.^{2} (161 mm^2).
    B. 0.30 in.^{2} (194 mm^2).
    C. 0.32 in.^{2} (206 mm^2).
    D. 0.36 in.^{2} (232 mm^2).
    E. 0.40 in.^{2} (258 mm^2).

    Code reference ___________________

13. Type ITC-ER Cable, without a metallic sheath, that is installed exposed but continuously supported with strut and protected from physical damage is also required to be secured at intervals not to exceed:
    A. 3 ft (900 mm).
    B. 4$^1/_2$ ft (1.4 m).
    C. 6 ft (1.8 m).
    D. 10 ft (3 m).
    E. 12 ft (3.7 m).

    Code reference ___________________

14. An industrial machine has a full-load current rating of 42 amperes, 3-phase, 480 volts, and the largest motor of the machine is 15 horsepower with a full-load current of 21 amperes. One additional motor has a full-load current rating of 11 amperes. The remainder of the load is 10 amperes of resistance heating. Copper wire in conduit with overcurrent protection at the supply end of the conductor is properly sized for the machine. All conductor terminations are 75°C rated. The minimum size of Type THWN supply conductors permitted for the industrial machine is:
    A. 10 AWG.
    B. 8 AWG.
    C. 6 AWG.
    D. 4 AWG.
    E. 3 AWG.

    Code reference ___________________

15. When installing optical fiber cables in raceway with no electrical conductors in the raceway:
    A. only one cable is permitted for each raceway.
    B. the cross-sectional area of the cables is not permitted to exceed 20% of the area of the raceway.
    C. the cross-sectional area of the cables is not permitted to exceed 40% of the area of the raceway.
    D. a maximum of three cables are permitted in a raceway.
    E. the fill requirements that apply to electrical conductors do not apply to optical fiber cables.

    Code reference ___________________

UNIT 13

Commercial Wiring Applications

OBJECTIVES

After completion of this unit, the student should be able to:

- state the requirements when multioutlet assembly passes through a partition.
- give a general description of underfloor raceway, cellular metal floor raceway, and cellular concrete floor raceway.
- explain the purpose of an insert for a floor raceway.
- explain what shall be done with wires remaining in use when a receptacle outlet is removed for cellular metal or concrete floor raceway.
- explain how wires are to be connected to outlet devices for underfloor raceway installations.
- describe a Flat Cable Assembly.
- state the maximum branch-circuit rating for a circuit of Flat Cable Assembly.
- explain a method used to connect building section wiring when assembling a manufactured building where the connection will be concealed.
- describe the wiring materials from which a manufactured wiring system is constructed.
- explain the requirements for conductor insulation when used for elevators, dumbwaiters, escalators, and moving walks.
- explain the minimum wire size and the number of circuits required for elevator car lighting.
- answer wiring installation questions from *322, 372, 374, 380, 384, 390, 518, 545, 600, 604, 605, 620, 645,* and *647*.
- state at least three changes that occurred from the 2005 to the 2008 Code for *Articles 518, 600, 604, 620, 645,* and *647*.

CODE DISCUSSION

The Code articles studied in this unit deal with installations most frequently encountered in commercial areas and buildings. These applications are not necessarily limited to commercial areas and buildings. Obviously, other articles of the Code also apply to commercial areas and buildings.

Article 322 covers the use and installation requirements for Type FC, Flat Cable Assembly installed in surface metal raceway identified for use with Type FC Cable. Figure 13.1 shows Type FC Cable installed in channel to supply lighting fixtures. This type of cable is permitted only for branch-circuits rated at not more than 30 amperes.

Article 372 deals with the use of the hollow cells of cellular concrete floor slabs as electrical raceways. Once the cellular concrete slabs are in place, a header is installed to provide access to the desired cells. A separate header and cells are used when communications wires are to be run in the floor. Splices and taps are only permitted to be made in header access units and floor junction boxes. When an outlet is abandoned, the

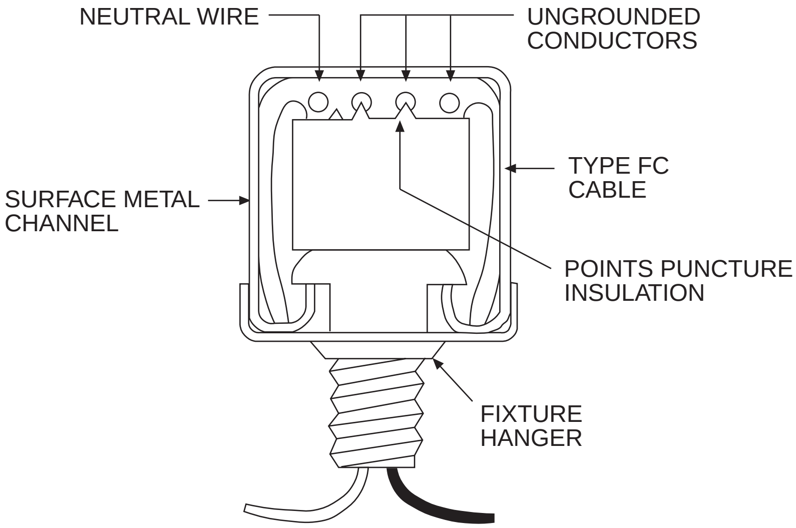


Figure 13.1 Cross-sectional view of Type FC Cable in channel-type surface metal raceway.

wire supplying the outlet shall be removed. Reinsulation of the wire is not permitted. If the wire is needed to supply other outlets, it will have to be removed and replaced with a new wire.

The raceway in cellular concrete floor slabs is not metal; therefore, an equipment grounding conductor is required to be run from insert receptacles to the header and connected to an equipment grounding conductor. This requirement is found in *372.9.* Figure 13.2 is a cross-sectional view of a cellular concrete floor slab and a header making access to two of the cells.

Article 374 covers the use of the cells of cellular metal floor as electrical raceways. Cellular metal floor decking is sometimes used as the structural floor support between main support beams. Concrete is then poured on this decking to form the finished floor. The Code permits these metal floor cells to be used as electrical raceways. A header is installed before the concrete is poured to provide access to the desired cells. Figure 13.3 is a cross-sectional view of a cellular floor used as an electrical raceway with the header shown connected to two of the cells. The header may connect directly to the supply panelboard, or this connection may be made with a suitable raceway. Splices and taps in wires are only permitted to be made in a header or in a floor-mounted junction box. Wiring requirements for cellular metal floor raceway are similar to those for underfloor raceway. An important requirement of this type of installation is that when an outlet is abandoned, the wire supplying the outlet shall be removed. Reinsulation of the wire is not permitted. If the wire is needed to supply other outlets, it will have to be removed and replaced with a new wire.

Article 380 covers the installation of multioutlet assemblies, which are raceway assemblies containing wiring and outlets. Multioutlet assembly is available factory-assembled, or it may be assembled on location. This wiring method is permitted only in dry locations. *NEC® 380.2* provides a list of uses permitted and not

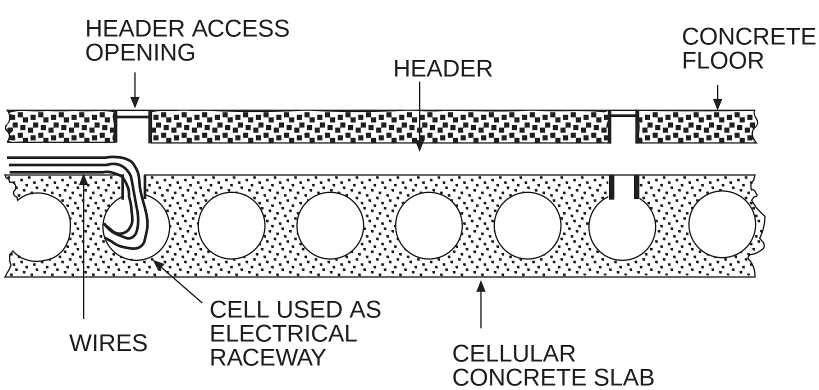


Figure 13.2 Cross-sectional view of header connecting to two cells of a cellular concrete floor slab.

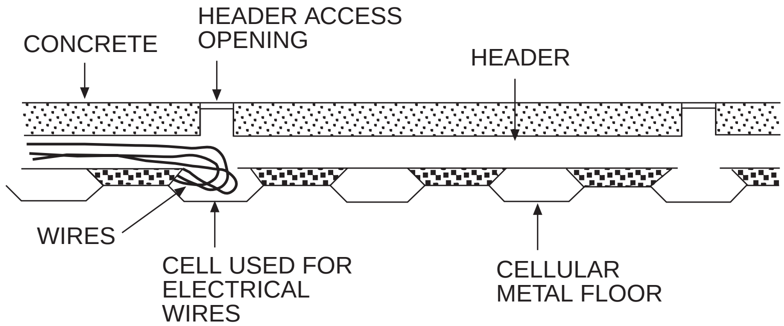


Figure 13.3 Cross-sectional view of cellular metal floor used as an electrical raceway.

permitted. Metal multioutlet assembly is permitted to pass through a dry partition provided no outlet is within the partition and caps or coverings on all exposed portions of the assembly can be removed.

Article 384 provides installation rules for strut-type channel raceway. This is a common support system material used both as a support system, and if listed as such, as a raceway for conductors. It is ideal for the support of luminaires (lighting fixtures) and acting as the raceway for the lighting circuit conductors. It is also permitted to be fastened to the floor and installed vertically as a power pole. Receptacle units are available that attach to the strut channel, and there are receptacles that are made to fit into the channel opening to allow the finished installation to have flush mounted receptacles. *NEC® 384.30(A)* requires that the strut-type channel be mounted to a surface or suspended from a structural member using straps and hangers that are external from the channel. Fixture support hangers are also available that are external to the channel. A strut-type channel showing the internal conductors and support hanger is shown in Figure 13.4. *NEC® 384.21* leaves the maximum permitted wire size up to the individual strut-channel listing. Generally, the maximum wire size for the larger area strut channels is 6 AWG.

The strut channel, when used as a raceway, can have the individual sections connected with joiners that are internal or external. This determines the percentage conductor fill. If the joiners are external, the maximum fill is 40% of the strut channel inside cross-sectional area. If the joiners are internal, the maximum fill is 25% of the inside cross-sectional area. *Table 384.22* gives values for the internal cross-sectional area for the common strut-channel trade sizes. These are trade sizes given with in. dimensions and do not have a practical metric equivalent. The ampacity adjustment factors of *310.15(B)(2)(a)* apply when there are more than three current-carrying conductors in the strut channel. If the fill does not exceed 20%, the number of conductors does not exceed 30 and the internal cross-sectional area is greater than 4 sq. in. (2500 mm^2), then the adjustment factors of *310.15(B)(2)(a)* do not apply. The temperature adjustment factors at the bottom of the ampacity tables may apply, depending upon the installation. Luminaires (lighting fixtures) will produce heat.

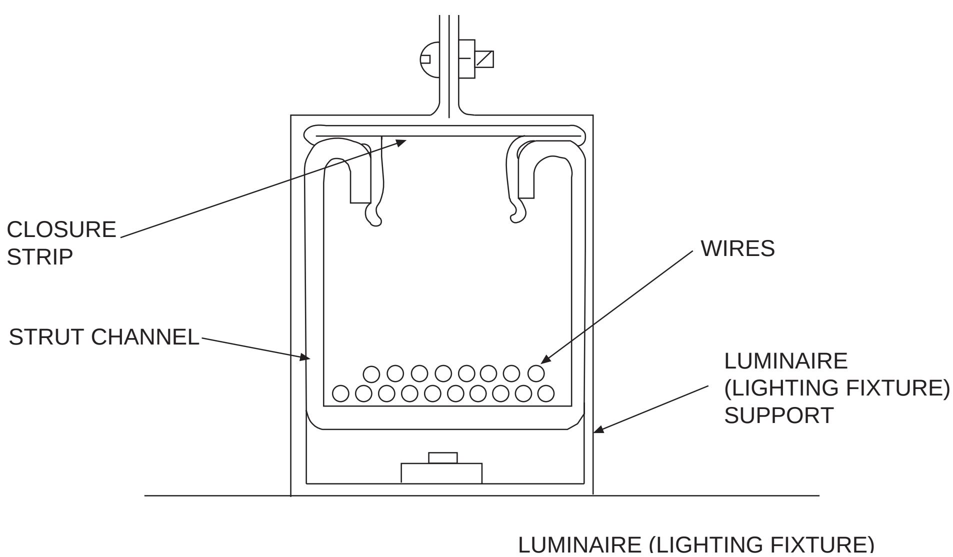


Figure 13.4 Cross-sectional view of strut-type channel raceway.

Therefore, follow the strut-channel manufacturer's specifications for mounting fixtures. In some cases a 1/2 in. (13 mm) spacing from the back of the luminaire (lighting fixture) to the strut channel is required. In most cases using 75°C conductors and terminations, a 1/8 in. (3 mm) spacing is considered adequate for fluorescent luminaires (lighting fixtures) to avoid being required to apply a temperature adjustment factor. The following example will show how to determine the maximum number of conductors permitted for an installation. The size of strut is generally determined based upon required strength for the application rather than the minimum required for the number of conductors.

Example 13.1 A 1 5/8 by 1 5/8 in. strut-type channel is used to support a row of fluorescent luminaires (lighting fixtures) and serve as the raceway for the circuit conductors. The multiwire branch-circuits rated 120/240-volt single-phase supply the luminaires (lighting fixtures). Boxes listed for the purpose and containing a receptacle are mounted to the strut-channel to supply the plug and cord luminaires (lighting fixtures) as shown in Figure 13.5. Determine the maximum number of size 12 AWG copper, Type THHN conductors permitted to be installed in this strut-channel raceway where the strut-channel joiners are internal.

Answer: First look up the cross-sectional area of a size 12 AWG, Type THHN conductor in *Table 5, Chapter 9* and find 0.0133 sq. in. (8.581 mm^2). Use the formula given in *384.22* to determine the maximum number of conductors using a 25% fill. The footnote at the bottom of *Table 384.22* directs the use of the 25% column when the joiners fit inside the strut channel. The maximum number of conductors is 38.

$$\text{Number of wires} = \frac{0.507 \text{ in.}^2}{0.0133 \text{ in.}^2} = 38 \text{ wires}$$

$$\text{Number of wires} = \frac{327 \text{ mm}^2}{8.581 \text{ mm}^2} = 38 \text{ wires}$$

Splices and taps are permitted to be made in the strut channel provided the cross-sectional area at any point does not exceed a 75% fill. *NEC® 384.30* requires the strut channel to be supported at intervals not to exceed 10 ft (3 m) and within 3 ft (900 mm) of a termination. A strut channel is permitted to serve as an equipment grounding means. At the transition between other types of wiring such as EMT to strut channel, a means of effective bonding for equipment grounding must be provided.

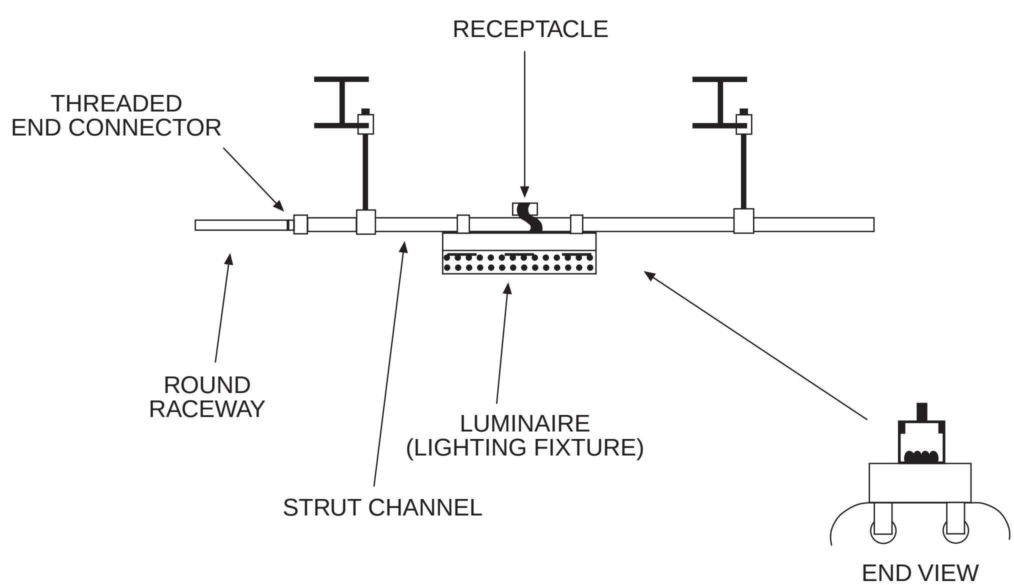


Figure 13.5 A 1 5/8 in. by 1 5/8 in. strut-type channel used as a raceway for the conductors suppling a row of fluorescent luminaires (lighting fixtures) also serving as support for the luminaires (lighting fixtures).

Article 390 deals with the installation of raceways installed under the floor. A raceway listed for the purpose is permitted to be installed in concrete floors. Installation is not limited to concrete floors. Underfloor raceway is permitted to be installed in a floor with a 3/4-in. (20-mm) minimum thickness wood covering, provided the raceway is not more than 4 in. (100 mm) wide. There is a minimum covering for underfloor raceway depending on the width and type of installation. More than one raceway may be run parallel in the floor, with one containing power wires and another containing communications wires. Underfloor raceway listed for the purpose is permitted to be run flush with the floor of an office building and covered with linoleum or an equivalent surface.

When an outlet is to be installed on the floor and have access to the underfloor raceway, an insert is installed. Splices are not permitted to be made at outlets. Connection to a receptacle outlet, for example, is done by means of stripping the insulation from the wire and looping the wire around the terminal of the device, as shown in Figure 13.6. Splices are permitted only in junction boxes, except in the case of flush-mounted underfloor raceway with removable covers, *390.6.*

Article 518 specifies the type of wiring method that is permitted in buildings or portions of structures where 100 or more persons are likely to assemble. Examples of assembly occupancies are given in the article. Extra care is taken in these areas to make the wiring system more resistant to fire ignition, fire spread, or the production of toxic vapors. The critical factor for emergency egress is the number of people in an area. It takes time to get a large number of people out of a building during an emergency. If less than 100 persons are in the building or area, egress can be expedited rapidly with a lesser danger to human life. The primary intent here is to buy extra time to get the people out of the building. Electrical Nonmetallic Tubing and Rigid Nonmetallic Conduit are permitted to be installed as concealed wiring in walls, ceilings, and floors of some types of areas where separated from the public by a listed 15-minute finish fire-rated surface, *518.4(C).*

Article 545 covers the installation of wiring components in manufactured buildings. Building components, such as complete wall sections, are constructed (including the wiring) in a manufacturing facility and assembled at a building site. The components are of closed construction, which means the wiring is not accessible for inspection at the building site without disassembling the building components. All raceway and cable wiring methods in the Code are permitted for use in manufactured buildings. Other wiring methods shall be listed for the purpose. Receptacle outlets and switches with integral boxes are permitted if listed for the purpose. At the point where building sections are joined, fittings listed for the purpose and intended to be concealed at the time of on-site assembly shall be permitted to join the conductors of one section to the conductors of another section.

Article 600 deals with electric signs and outline lighting. This article is broken up into two parts, general information given in *Part I* and field-installed skeleton tubing in *Part II*. Skeleton lighting is actually neon tubing that is not mounted in a support structure or enclosure. Each commercial building that is accessible to patrons is required to have at least one outlet that is dedicated for signs or outline lighting, *600.5(A)*. When a building or structure houses more then one commercial establishment, each occupancy must be provided with their own outlet. The minimum rating of this circuit is 20 amperes but the Code also places maximum ratings on these circuits. In *600.5(B),* the maximum permitted branch-circuit ratings for these signs and outline lighting circuits is 30 amperes for neon and 20 amperes for incandescent and fluorescent forms of lighting.

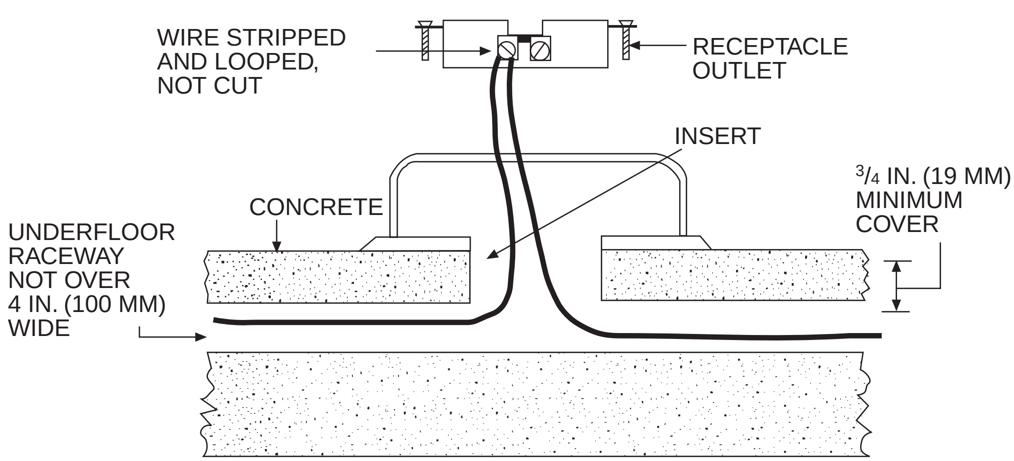


Figure 13.6 A receptacle outlet installed on the floor and supplied with underfloor raceway.

Signs and outline lighting are also required to be provided with a disconnect that is within sight of the equipment. If the disconnect is placed in a location that is not within sight from the sign, a disconnect that is capable of being locked in the open position is required, *600.6(A)*. The disconnecting means is permitted to be a switch, circuit breaker, or may consist of an attachment plug.

NEC® 600.32 provides the requirements for the installation and protection of the neon secondary conductors for field-installed skeleton tubing, operating above 1000 volts. The materials permitted for these conductors are listed in *600.32(A)(1)*. However, it is important to note that there are length restrictions depending on the material selected. This section also specifies that only one secondary conductor is to be installed in each run of raceway, as shown in Figure 13.7. The maximum length of these secondary conductors from the output of the power supply to the electrode is dependent on the power supply and the material used to protect the secondary conductors, *600.32(J)*.

Article 604 covers the use and construction of manufactured wiring systems. These are assemblies of sections of Type AC Cable, Type MC Cable, or wires in Flexible Metal Conduit or Liquidtight Flexible Conduit with integral receptacles and connectors for connecting electrical components in exposed locations, as shown in Figure 13.8. These manufactured wiring systems are permitted to extend into hollow walls for direct termination at switches and other outlets. The conductors in the manufactured wiring system are not permitted to be smaller than size 12 AWG copper, except for taps to single lighting fixtures. A common application has been the connection of lay-in fluorescent fixtures in suspended ceilings. Manufactured wiring systems can be listed for installation in outdoor locations as illustrated in Figure 13.9.

Article 620 deals with the wiring of elevators, dumbwaiters, escalators, and moving walks. A major issue is that wiring associated with this equipment shall have flame-retardant insulation, even when installed in a raceway, *620.11(C)*. This is of particular importance to minimize the spread of fire from one floor to another. *NEC® 620.21* specifies wiring methods for electrical conductors and optical fiber cables permitted to be installed in an elevator machine room, machine space, and hoistways. It also specifies wiring methods for wellways for escalators and moving walks and for wheelchair and stairway lift runways. The required wiring method is Rigid Metal Conduit (RMC), Intermediate Metal Conduit (IMC), Electrical Metallic Tubing (EMT), Rigid Nonmetallic Conduit (RNC), and wireway. Type MC, AC, and MI Cables are also permitted. Some flexible conduits are permitted where flexibility is needed. *NEC® 620.21* gives specific rules for the use of flexible conduits. Sometimes these materials are only permitted for specific applications. All flexible conduits are limited to lengths not greater than 6 ft (1.8 m) except in some applications such as machine room spaces. Liquidtight Flexible Nonmetallic Conduit (LFNC) in some situations is permitted to be installed in lengths greater than 6 ft (1.8 m).

When wireways are installed for conductors supplying elevator circuits, the current flow is generally intermittent and not continuous. Conductor heating takes time. Therefore, in the case of wireways, the fill for

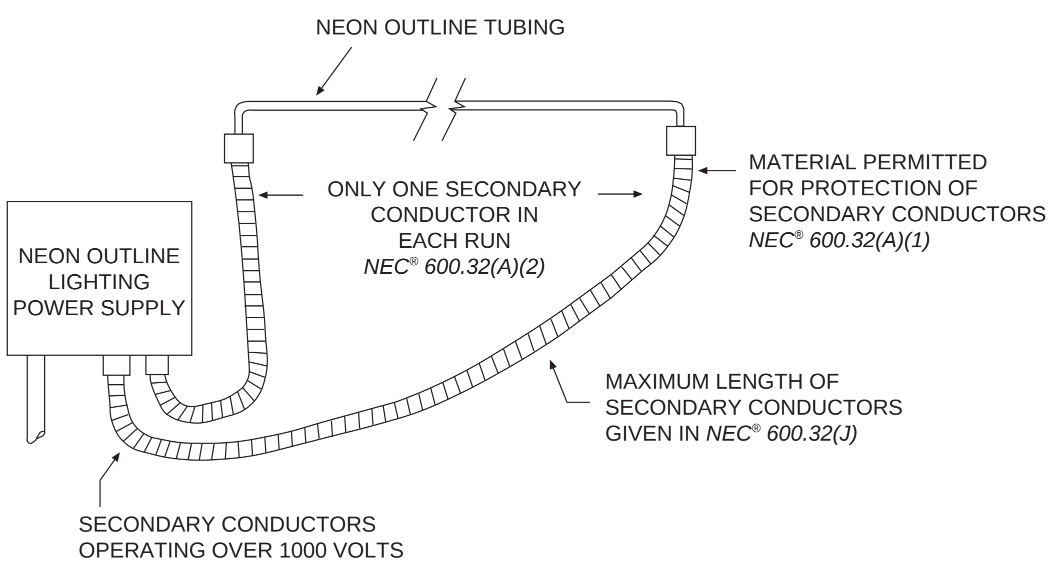


Figure 13.7 Field-installed skeleton tubing with secondary circuit conductors operating in excess of 1000 volts.

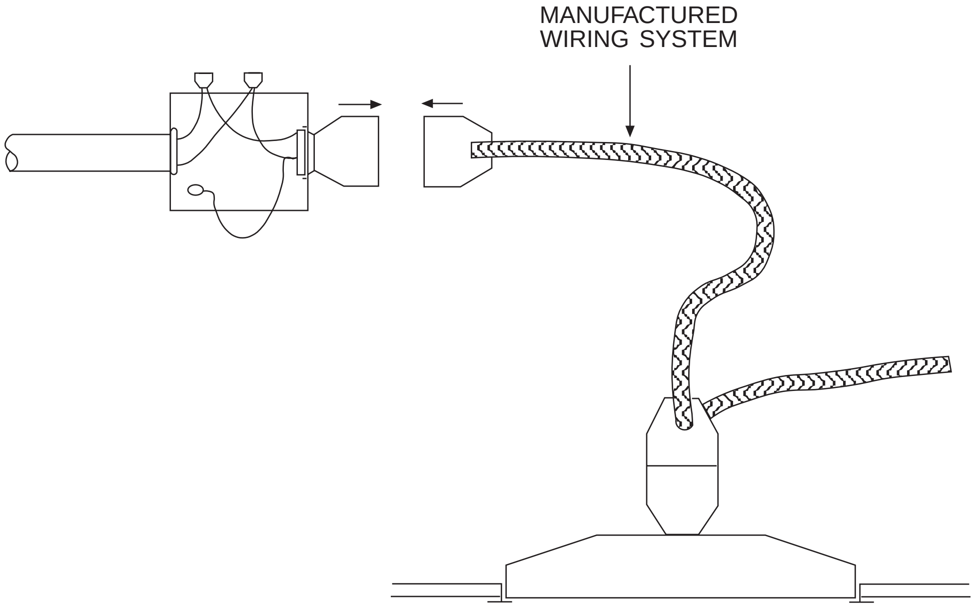


Figure 13.8 A manufactured wiring system is a prewired assembly of conductors and connectors in Type AC or Type MC Cable, Flexible Metal Conduit, or Liquidtight Flexible Conduit.

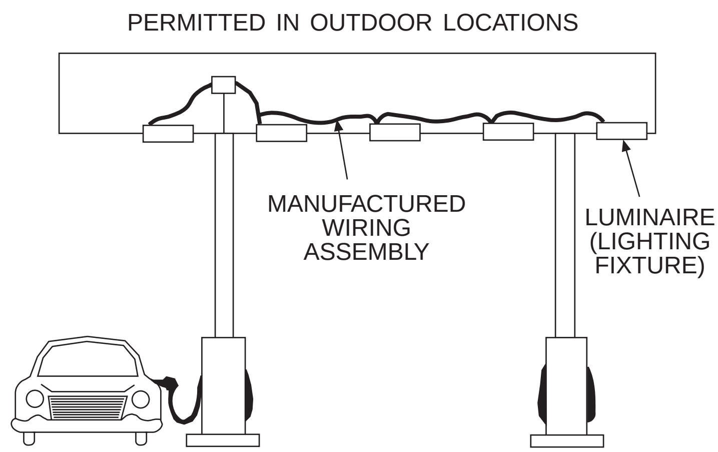


Figure 13.9 Manufactured wiring systems listed for the purpose are permitted to be installed in an outdoor location.

a wireway is a higher percentage than for other installations. *NEC® 620.32* permits the total cross-sectional area of the conductors to be up to 50% of the cross-sectional area of the wireway. For other raceways, such as conduit and tubing, the percent fill is 40% as is the case with most other installations.

NEC® 620.61(B) states that elevator and dumbwaiter driving motors shall be classed as intermittent duty. In the case of escalator and moving walk driving motors, they shall be considered as continuous duty. Another code contains the requirement that a 3-phase drive motor be prevented from starting in the event there is a phase rotation reversal. If there is a phase rotation reversal, the drive motor will reverse direction. This can cause the elevator to run in reverse. In the case of a hydraulic drive, overheating will occur. Interchanging any two phase conductors of a 3-phase system of the building wiring or on the primary electrical system supplying power to the building will result in a phase rotation reversal.

Requirements for the wiring of wheelchair lifts and stairway chair lifts are also contained in *Article 620*. One complex task involved in the wiring of an elevator system is the determination of the minimum size of feeder required in the system. *Example D9* and *Example D10* show how the feeder conductor is sized in two different situations. Several factors concerning elevator installations are not obvious by reading *Article 620.* Example 13.2 will help illustrate how the feeder conductor selection current is determined.

Example 13.2 Four passenger elevators are powered with motor-generator sets with the motor-generator set powered by 30-horsepower, 3-phase, 460-volt motors. In addition to this load, 12 amperes continuous load per elevator is required for operation control equipment. The motor-generator sets have a continuous-duty rating. Determine the minimum feeder conductor selection current.

Answer: *NEC® 620.13* states that for a motor-generator set, the feeder conductor shall be determined based on the ampacity of the drive motor. *NEC® 620.13(B)* can be misleading because passenger elevator motors are actually rated as intermittent duty motors. Start by looking up the 30-horsepower, 3-phase, 460-volt motor full-load current in *Table 430.250,* which is 40 amperes. The load consists of several motors plus other load; therefore, *430.24* is used to determine the feeder current rating. The feeder current is the sum of the full-load current of all the motors, plus other load, plus 25% of the full-load current of the largest motor. If all motors are the same size, then take one of them as the largest. But it is not quite so easy. *Exception 1* to *430.24* states that if the motors are used for short-time, intermittent, periodic, or varying duty, the motor current shall be as determined by *430.22(E). Table 430.22(B)* states that a passenger elevator motor is considered to be intermittent duty. If the actual motor is a continuous-duty motor, then it can be overloaded without damage if operated intermittently. Therefore, the continuous full-load current rating of the motor is multiplied by 1.4 for use in the feeder calculation because it will be overloaded for short periods of time. In this case, the current to use for the motors is 56 amperes.

$$40 \text{ A} \times 1.4 = 56 \text{ A}$$

The feeder selection current calculation is determined according to *430.24, Exception 1* as follows:

$$4 \times 56 \text{ A} = 224 \text{ A}$$

According to *620.14,* a demand factor can be applied to that portion of the feeder current determined according to *620.13*. The demand factor for four elevators as determined in *Table 620.14* is 0.85. To get the actual feeder selection current, multiply the motor load calculated by this demand factor and then add the operation control load according to *Sections 430.24* and *215.2(A).*

$$\begin{aligned} 0.85 \times 224 \text{ A} &= 190 \text{ A} \\ 4 \times 12 \text{ A} \times 1.25 &= \underline{\ 60 \text{ A}} \\ & \quad\ 250 \text{ A feeder selection current} \end{aligned}$$

An elevator machine room or machine space is required to be provided with at least one separate branch-circuit that supplies both the lighting for equipment, and at least one duplex receptacle. This rule is found in *620.23*. The switch for the lighting is required to be at the point of entry to the machine room or space. *NEC® 620.85* requires that each of these receptacles be of the ground-fault circuit-interrupter type. *NEC® 620.23(A)* requires that the lighting be tapped to the supply side of the ground-fault circuit interrupter. The same rules apply to an elevator hoistway pit. A separate circuit is required to supply a light and duplex receptacle in an elevator hoistway pit. *NEC® 620.24* requires that each hoistway pit area light be controlled by a switch at the entrance to the pit. The hoistway pit is also required to be provided with one ground-fault circuit-interrupter type receptacle. The light in the pit is required to be tapped from the supply side of the ground-fault circuit-interrupter receptacle, as illustrated in Figure 13.10.

Article 647 provides rules for establishing a unique type of separately derived electrical system called **technical power**. In the past, it was only permitted to be installed in motion picture and television studios. Technical power systems are now permitted to be installed in any commercial or industrial building where there is concern for electrical noise that affects audio and video signals. Much of the sound and video processing, recording, and reproduction equipment operates at 120 volts with one circuit conductor grounded. The reality is that grounds are sources of electrical noise. Even a properly installed and well-maintained electrical system can have differences in potential between different points on the grounding system that give rise to current flow. A technical power system operates at 120 volts with both conductors ungrounded. The system is grounded by connecting the midpoint of a 120-volt secondary winding of an insulating transformer

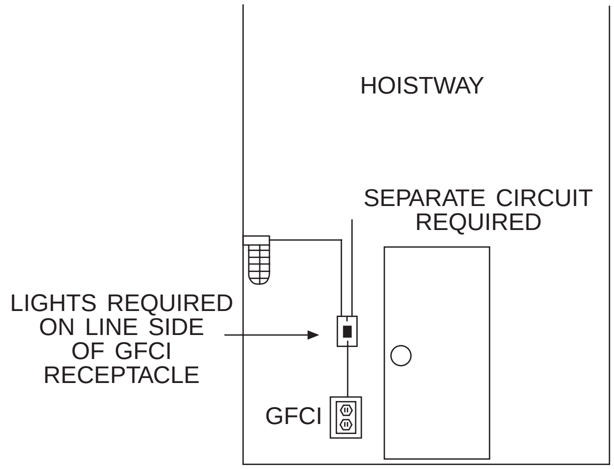


Figure 13.10 The lighting serving an elevator hoistway is required to be tapped on the line side of any ground-fault circuit-interrupter protecting receptacles.

to ground. This creates a system that has 60 volts to ground from either ungrounded conductor as shown in Figure 13.11. This is sometimes called a balanced 120-volt system.

NEC® *647.4(A)* requires the technical power to be distributed with a single-phase, 3-wire panelboard. The two ungrounded lines with 120 volts between them are fed into the main circuit breaker. The center-tap grounded conductor is fed into the neutral terminal block. All branch-circuit breakers are 2-pole common-trip. The output to each piece of equipment will be 120 volts with two ungrounded conductors. *NEC*® *647.4(C)* requires that all branch-circuit and feeder conductors be color coded or marked in some effective manner that the conductors can be identified as to the originating panelboard and the conductor at that panelboard. *NEC*® *647.4(B)* requires that all junction boxes be identified as to the voltage of the conductors, and the panelboard from which the conductors originate.

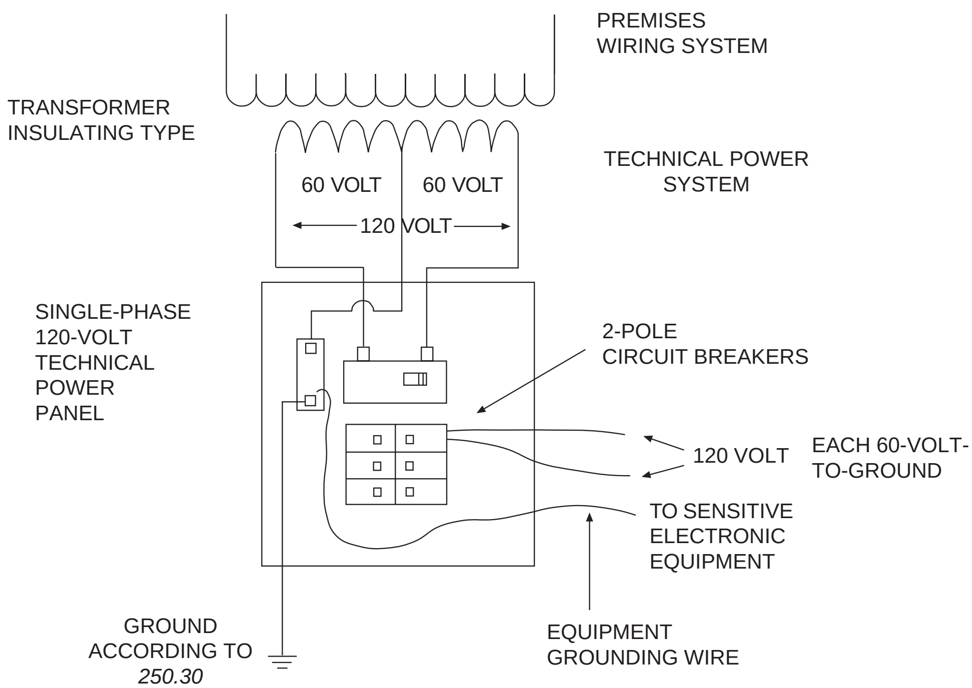


Figure 13.11 A technical power system is a separately derived grounded system operating at 60/120 volts with 60 volts measured line-to-ground and 120 volts line-to-line.

NEC® *647.6(A)* clearly states that a technical power system is a separately derived system. This means the rules of *250.30* will apply with respect to grounding the system. Refer to *Unit 8* for a detailed discussion of grounding separately derived systems. *NEC*® *647.6(B)* explains that the grounded conductor from the center tap of the transformer is required to be grounded on the supply side of the first disconnecting means of the separately derived system. That would mean the neutral terminal of the technical power panelboard is connected to a grounding electrode, as shown in Figure 13.11.

NEC® *647.7(A)(1)* requires that all 15- and 20-ampere receptacles supplied from the technical power system be ground-fault circuit-interrupter protected. The concern is that there is no grounded neutral circuit conductor. What may be identified as a neutral conductor in connected equipment is actually 60 volts to ground. *NEC*® *647.7(A)(4)* requires receptacles for technical power to have a unique configuration. The configuration is not specified. This same paragraph does permit standard 15- and 20-ampere rated 125-volt receptacles to be used in areas where only qualified personnel will work on the equipment. This essentially describes all areas. Therefore, standard receptacles are used for technical power systems, as shown in Figure 13.12. The circuit conductors are required to be color coded or identified but no specific colors are to be used. It is important to be consistent with respect to which conductor will be connected to the silver screw on receptacles and which will be connected to the brass-colored screw. These are both ungrounded conductors. Therefore, white is not used. There will be an equipment grounding conductor run to the grounding terminal of the receptacle and that wire will be either bare or green. Grounding of these circuits will be done in the same manner as grounding of other circuits. If there is concern about mixing receptacle and equipment grounds with box and raceway grounds, it is permitted to use insulated ground receptacles. In this case, a green insulated conductor is run to the grounding terminal of every receptacle and the boxes and raceways are grounded separately.

NEC® *647.7(A)(2)* requires labeling of all receptacles that are supplied by the technical power system. It is important these receptacles not be used for any purpose other than supplying sensitive electronic equipment. To help ensure this is not violated, *647.7(A)(3)* requires a standard 15- or 20-ampere, 125-volt receptacle with a grounded neutral conductor be located within 6 ft (1.8 m) of every technical power receptacle. This is illustrated in Figure 13.12. One regular receptacle, if properly placed, can fill this requirement for many technical power receptacles in a given area.

If lighting equipment is also supplied from the technical power system, there are some special requirements because there is no grounded-circuit conductor. *NEC*® *647.8(C)* requires that in the case of screw shell lamps, the screw shell of a lamp is not permitted to be exposed to contact while it is making contact with the screw shell of the lamp socket. This will prevent a person changing lamps from making contact with a 60-volt conductor. There will be cases where lighting units are a part of electronic sound and video processing, recording, or reproduction equipment. Some equipment may have electric discharge lighting with a ballast. The ballast is required to be one that is identified for use with a separately derived system. Avoiding connecting lighting equipment to the technical power system is desirable if practical.

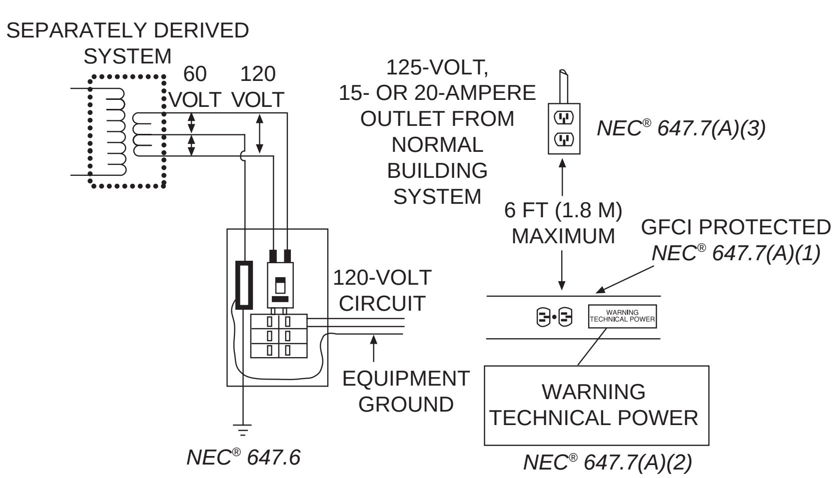


Figure 13.12 Spacing requirements between receptacles supplied by a technical power system and 125-volt, 15- and 20-ampere receptacles served by the normal building electrical system.

In facilities with 3-phase power available, it may be desirable to supply the technical power system from a 3-phase supply. This is permitted by *647.5*, which specifies using a wye 3-phase system. The Code refers to this as a 6-phase separately derived system. An example of how this can be accomplished is shown in Figure 13.13. The 208-volt output of each set of phases from the wye transformer is supplied to the primary of a single-phase transformer that has a 120-volt output with a center tap. The single-phase output of each transformer is fed to a separate 3-wire, single-phase panelboard in a manner similar to Figure 13.11. It would be necessary to keep the conductors from each technical power panel uniquely identified to avoid mixing up the conductors. Each panelboard is grounded to the same separately derived system grounding electrode, and therefore, a circuit will be completed if the conductors are not kept separated.

Voltage drop, especially on grounded conductors, creates the conditions that lead to objectionable ground currents. With technical power systems, it is important to make sure the source of the technical power is *grounded only at one point.* Some electronic equipment is extremely voltage sensitive and will not function properly if input voltage deviates from sometimes very narrow tolerances. Maximum voltage-drop requirements are placed on the conductors of a technical power system. *NEC® 647.4(D)* restricts voltage drop on technical power branch-circuits to specific fixed equipment to not more than 1.5%. The current draw of the equipment would need to be known in order to determine the voltage drop. The total voltage drop on feeders and branch-circuits is not permitted to exceed 2.5% There is no specific voltage drop

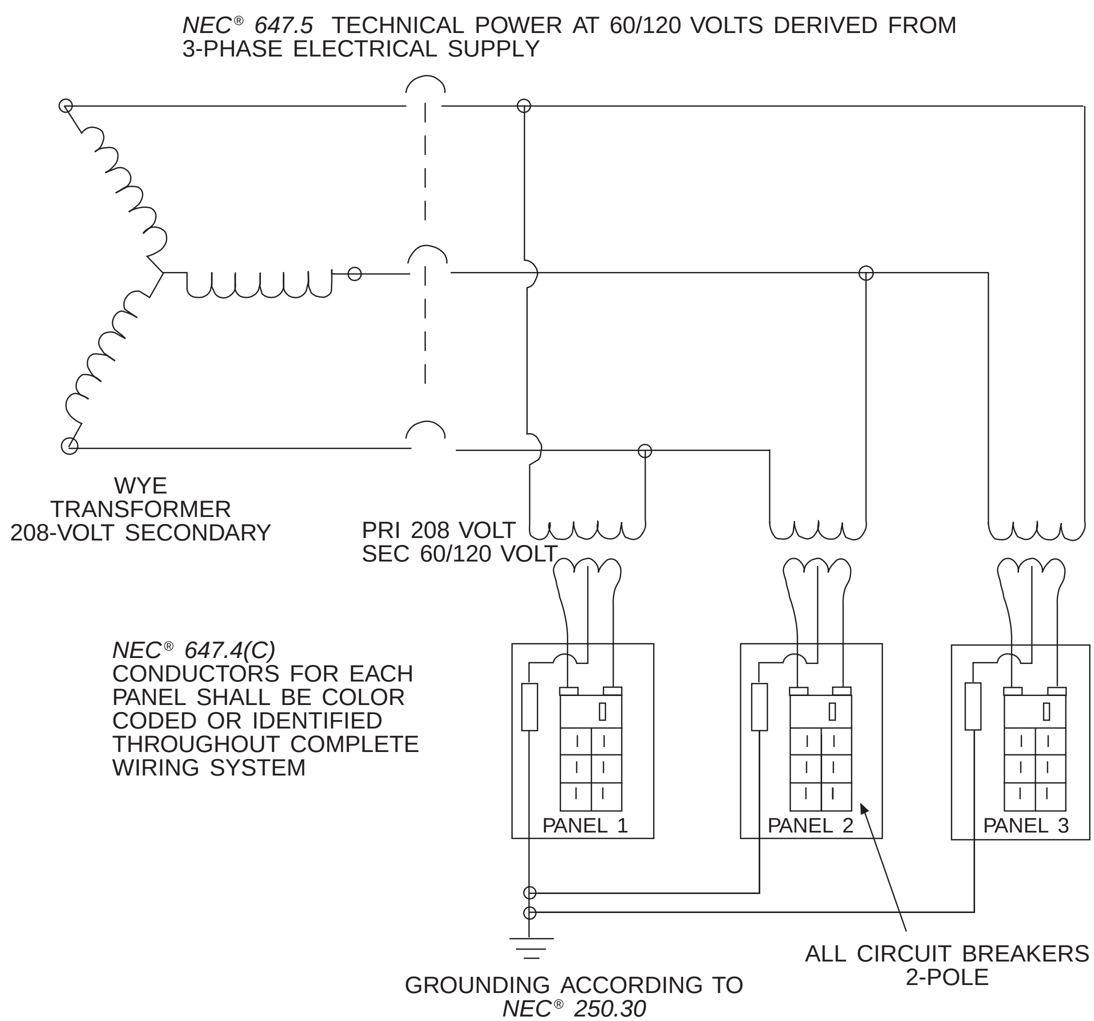


Figure 13.13 A 60/120-volt technical power system derived from a 3-phase electrical system.

required on the feeder. Therefore, if the feeder voltage drop exceeds 1%, then less than 1.5% is permitted on the branch-circuits.

In the case where the actual equipment load is not known, and several receptacles are placed to supply the equipment, only 1% voltage drop is permitted on those circuits. The reason for this is that there is a power cord at equipment that will also result in some voltage drop. The voltage drop on a circuit supplying receptacles where the load is not known is based upon 50% of the rating of the branch-circuit. For a 20-ampere branch-circuit, the load is based on 10 amperes. Voltage-drop calculations were discussed in detail in *Unit 6*. These are single-phase circuits operating at 120 volts. Use Equation 6.4 to determine the voltage drop if the load, wire size, and circuit length are known. Use Equation 6.6 to determine the cross-sectional area of the conductor necessary to limit the voltage drop to a specific percentage such as 1% when the load and length of circuit are known. Then look up the wire size in *Table 8* in the Code. The following example will show how the minimum wire size is determined for a receptacle circuit supplied from a technical power system. Values of resistivity (**K**) of copper and aluminum will be needed for a voltage-drop calculation using Equation 6.4 or Equation 6.6. Values of **K** are given in Table 1.2 of *Unit 1*. The technical power circuits will most likely be copper. Therefore, it is recommended for these calculations to use a value of 12 ohm cmil/ft (0.02 ohm mm^2/m) in the equations. These values are for a conductor operating temperature of approximately 50°C which, for a technical power circuit, is most likely higher than it will ever operate.

Example 13.3 A 20-ampere, technical power, branch-circuit supplies several receptacles located in a small area near where electronic equipment will be connected. The distance from the transformer to the technical power panelboard is short and the voltage drop on the feeder will not exceed 1%. The distance from the panelboard to the receptacle location is 40 ft (12.19 m). Determine the minimum size copper conductor with 75°C insulation and terminations required for this circuit.

Answer: *NEC® 647.4(D)(2)* only permits a 1% voltage drop on a circuit supplying receptacles. That same section specifies for receptacles that the load to be used in the calculation is 50% of the rating of the circuit, which in this case is 10 amperes. Choose a value of 12 for resistivity of the conductor and use Equation 6.6 to determine the wire cross-sectional area needed to limit voltage drop to 1%. The wire must have a cross-sectional area of not less than 8000 circular mils (4.06 mm^2). Then look up the minimum conductor size in *Table 8, Chapter 9* of the Code and find size 10 AWG.

$$\text{Cross-sectional area of wire} = \frac{2 \times 12 \times 10\text{ A} \times 40\text{ ft}}{0.01 \times 120\text{ V}} = 8000\text{ cmil}$$

$$\text{Cross-sectional area of wire} = \frac{2 \times 0.02 \times 10\text{ A} \times 12.19\text{ m}}{0.01 \times 120\text{ V}} = 4.06\text{ mm}^2$$

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC®* that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 518 Assembly Occupancies

518.4(A): The wiring installed in a building, or area of a building, considered an assembly occupancy is required to be in metal raceway, Type MI cable, Type MC cable, or Type AC cable. The change in this section is that the wiring method is required to qualify as an equipment grounding conductor according to *250.118*, or it will be necessary to install an insulated equipment grounding conductor properly sized for the branch circuit or feeder.

518.5: An assembly occupancy is frequently provided with power outlets for the connection of portable switchboards and power distribution equipment. Typical loads are audio equipment and lighting. Depending upon the power available in the assembly occupancy, these outlets are often 120/240 volt, 3-wire, single-phase or 208/120 volt, 4-wire, 3-phase. Outlets rated up to 400 amperes are common. Lighting in particular and some other equipment are controlled through solid-state dimming equipment. There are two basic types of dimming equipment available: one called phase-control, where the current with respect to the voltage is considered to be a non-linear load, and the other type, which is known as sine-wave dimming, produces an output current that is considered to be a linear load. Where the current is considered to be a linear load, there is cancellation of currents on the neutral conductor, and with non-linear loads this neutral cancellation does not occur, resulting in a significant current on the neutral conductor, even when the phase loads are balanced.

The past edition of the Code required the neutral of feeders supplying dimmer systems to be considered a current-carrying conductor for the purposes of ampere adjustment. The change is that for the cases where the only portable load will be a sine-wave dimmer, the neutral is not required to be considered a current-carrying conductor. The outlet may be one that could use either type of dimmer, and in those cases the *Exception* to this section requires the feeder neutral to be considered to be a current carrying conductor. The output of a sine-wave dimmer is a series of pulses forming a sine wave as shown in Figure 13.14. The phase-control type dimmer allows the current to flow only for a portion of the cycle.

Article 600 Electric Signs and Outline Lighting

600.4(C): Signs that are supplied in separate sections that must be field connected to form the complete sign are now required to be provided with a label on the sign sections indicating that field wiring and installations instructions are required to be followed.

600.6(A)(1): The disconnecting means for a sign now must be fitted with a locking means that remains with the disconnect when the lock is removed. Portable locking means are no longer acceptable.

600.6(B)(2)(3): The locking means for the sign controller disconnect is now required to be such that when the lock is removed the locking means remains with the disconnect. Portable means of locking the disconnect is no longer permitted as meeting the locking requirement of the Code.

600.7(A)(1): The equipment grounding conductor for a sign and metal equipment of an outline lighting system is now required to be of a type specified in *250.118*. The previous edition of the Code simply required it to be grounded with no specific instructions. There is a new exception that does not require grounding for double insulated signs that are distinctively marked.

600.7(A)(2): Now the equipment grounding conductor for a sign or outline lighting system is required to be sized according to *250.122* based upon the rating of the overcurrent device protecting the branch circuit or feeder. The previous edition of the Code did not specify a minimum size for the equipment grounding conductor, except that it was intended that the rules of *Article 250* would apply.

600.7(A)(3): All connections are to be made the same as equipment grounding connections for all other circuits as described in *250.8*. This was the intention in the previous edition of the Code, except it was assumed the installer would refer to *Article 250* for any information that was not specifically stated in *Article 600*.

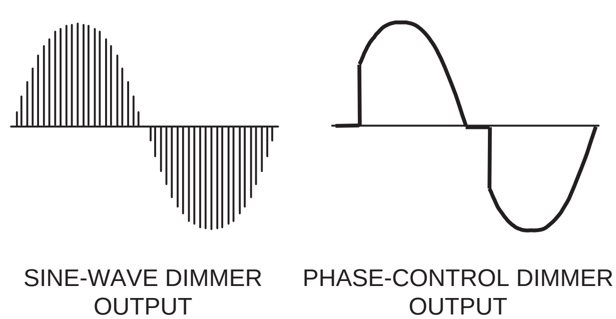


Figure 13.14 Typical output from a phase-controlled dimmer regulates power to the load by controlling the on-time of the current flow, while the sine-wave dimmer regulates power by varying the magnitude of a sine-wave consisting of a series of pulses.

600.7(A)(4): An auxiliary grounding electrode is permitted to be installed and bonded to the equipment grounding conductor. This was always the case, as stated in *250.54*.

600.7(B)(3): Metal parts of a building or structure are not permitted to be used as a means of bonding individual parts of a sign or outline lighting, or as a means of bonding the equipment to the equipment grounding conductor of the circuit or feeder.

600.12(C): This is a new section that describes permitted wiring methods for field installed secondary circuits operating at less than 50 volts.

600.21(E): A ballast, transformer, or electronic power supply is permitted to be installed in an attic or soffit if minimum access requirements are provided. The width of the opening has been reduced from 24 in. (600 mm) to 22 1/2 in. (562.5 mm). This change was made because structural members are typically installed on 24 in. (610 mm) centers, which only permit a 22 1/2 in. (562.5 mm) opening if standard building materials are used. There is an additional requirement that a lighting outlet be provided near the ballast, transformer, or electronic power supply and that a switch be provided at the point of entry to the space, as illustrated in Figure 13.15.

600.24: Class 2 transformers, power supplies, and power sources are now required to be listed for use with electric signs and outline lighting. There is now a requirement specifying the installation of Class 2 wiring with respect to sign and outline lighting circuits.

600.32(K): Splices in neon sign secondary circuits that operate at over 1000 volts are required to be made in enclosures rated for over 1000 volt installations, and the enclosures must be accessible after installation.

600.41(B): Neon tubing is now required to be supported not more than 6 in. (150 mm) from the electrode connection.

600.41(D): Neon skeleton tubing that is field installed is not permitted to be exposed to physical damage. If the neon skeleton tubing is readily accessible to other than qualified personnel, then suitable guards are required to be installed.

600.42(A): The point where high-voltage conductors emerge from the wiring method used for neon skeleton installations of a listed enclosure shall be installed at the point of transition to the neon tubing.

600.42(H): Electrode enclosures not only shall be listed, but they shall be listed for wet locations if installed in a wet or damp location.

Article 604 Manufactured Wiring Systems

604.6(A)(1)(3): Listed Type MC cable with a grounding conductor and metal sheath that is listed as an equipment grounding conductor in accordance with *250.118(10)*. The previous edition of the Code only recognized Type MC cable with an insulated equipment grounding conductor.

604.6(A)(3) Exception: Flexible cord smaller than size 12 AWG copper is permitted as a manufactured wiring system to supply a luminaire where the luminaire meets the requirements of *410.62(C)*.

604.6(A)(4): A busway is permitted to be used as a wiring method for the support of and supply to luminaires where the busway consists of factory mounted wires and plug-in units are rated continuous duty.

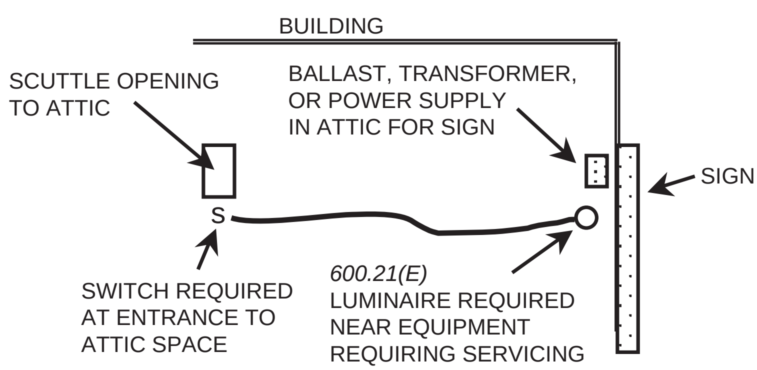


Figure 13.15 When a sign ballast, transformer, or power supply is installed in an attic or soffit, a luminaire is required to be installed near the equipment requiring servicing with a switch at the entrance to the space.

Article 620 **Elevators, Dumbwaiters, Escalators, Moving Walks, Platform Lifts, and Stairway Chairlifts**

620.2: There are new definitions of remote machine room and control room, and remote machinery space and control space.

620.21(A)(1)(d): This paragraph deals with flexible wiring connections installed in a hoistway. The paragraph was rewritten to make the meaning clear; however, it may seem as though there has been a change since the language in the previous edition of the Code was difficult to understand. Whether the flexible connection was raceway, cord, cable, or cabled individual conductors, the maximum length permitted was and still is 6 ft (1.8 m).

620.21(A)(1)(e): A sump pump or oil-recovery pump installed in a hoistway pit is permitted to be connected with a hard usage cord with a length not to exceed 6 ft (1.8 m).

620.21(A)(2)(d): This paragraph deals with flexible wiring connections installed on elevator cars. The paragraph was rewritten to make the meaning clear; however, it may seem as though there has been a change since the language in the previous edition of the Code was difficult to understand. Whether the flexible connection was raceway, cord, cable, or cabled individual conductors, the maximum length permitted was and still is 6 ft (1.8 m).

620.21(A)(3)(e): This is a new section that permits flexible connections in a machine room, control room, or machinery space to be made with flexible cord or cable in lengths not to exceed 6 ft (1.8 m) to listed equipment, driving machine, or driving machine brake. The flexible cord or cable is required to be of a flame-retardant type and protected from physical damage. The previous edition of the Code required that flexible connections in these spaces be made using flexible raceway.

620.21(A)(4): This paragraph deals with flexible wiring connections installed on a counterweight assembly. The paragraph was rewritten to make the meaning clear; however, it may seem as though there has been a change since the language in the previous edition of the Code was difficult to understand. Whether the flexible connection was raceway, cord, cable, or cabled individual conductors, the maximum length permitted was and still is 6 ft (1.8 m).

620.21(C)(3): This is a new paragraph that now permits flexible cords and cables to be installed in lengths up to 6 ft (1.8 m) as components of listed equipment for platform lifts and stairway chair lifts. Circuits are limited to 30 volts rms or 42 volts dc.

620.44: This section specifies a distance of 6 ft (1.8 m) from the point at which a traveling cable is supported near the terminations to the point at which the conductors are terminated or run within raceway. The language in the previous edition of the Code was not clear enough to convey a uniform interpretation and was rewritten with no change in original intent.

620.51(A): The disconnecting means for power to the driving units and associated equipment is required to be capable of being locked in to open position. The change is that the locking means shall be of a type where the locking provision at the disconnect be of a type that remains with the disconnect when the lock is removed. Portable locking devices are no longer permitted. A switch generally is manufactured with a means of locking the contacts in the open position, but circuit breakers generally must have a locking means added such as the one shown in Figure 13.16.

620.51(A) Exception 2: This is a new exception that permits the electric power disconnecting means for a stairway chairlift to be a cord and plug, where the cord does not exceed a length of 6 ft (1.8 m) and the lift is on an individual branch circuit.

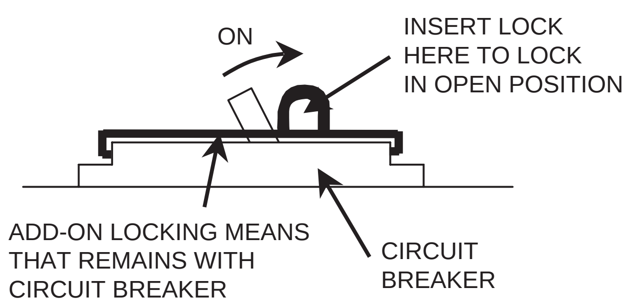


Figure 13.16 Circuit disconnects that are required to be capable of being locked in the open position must be of a type where the locking means remains with the disconnecting means, even when the lock has been removed. Locking means for circuit breakers meeting these requirements are available as add-on attachments.

620.51(C)(1): For elevators with motors that do not have generator field control, a disconnecting means is required to be located within sight of the controller and is required to be capable of being locked in the open position. The change deals with the case where the driving motor controller is located in the hoistway. The circuit disconnecting means is required to be located in the machine room, machine space, or control space. An additional non-fused motor circuit switch is required to be located in the hoistway within sight of the driving motor. These disconnecting means are now required to be of a type where the locking means remains with the disconnect when the lock is removed.

620.53: The disconnecting means for power to an elevator car for lights, receptacle, and ventilation is now required to be of a type capable of being locked in the open position where the locking means is of a type that remains with the disconnect when the lock is removed.

620.54: The disconnecting means for power to an elevator-car–heating and air-conditioning unit is now required to be of a type capable of being locked in the open position where the locking means is of a type that remains with the disconnect when the lock is removed.

620.55: The disconnecting means for power to other utilization equipment is now required to be of a type capable of being locked in the open position where the locking means is of a type that remains with the disconnect when the lock is removed.

Article 645 Information Technology Equipment

645.2: A new section was added for definitions, and a new definition of abandoned supply circuit and interconnecting cable was added. These are cables not terminated at equipment and not tagged for future use.

645.5(D): This section lists the types of cables that are permitted to be installed under a raised floor of an information technology equipment room. Added to the list was supply cords for listed equipment.

645.5(F): This was *645.5(D)(6)* in the previous edition of the Code with some modifications. Cables are required to be removed only if abandoned and accessible.

645.5(G): It is often a common practice to install cables for future use. These cables are now required to be provided with a durable tag. The tag is required to provide the date installed, the date of intended use, and the intended future use. An example of a permanent tag that provides the required information is shown in Figure 13.17.

645.10: This section relates to the disconnecting means for the HVAC equipment and information technology equipment in a dedicated room. Some rooms are large, and zones within the room may be controlled by a disconnecting means that does not disconnect all equipment in the room. The change is that the zone controlled by the disconnecting means is required to be indicated at the location of the disconnecting means. There is also a requirement that such rooms that are divided into zones must have means to confine fire and products of combustion to that particular zone.

Article 647 Sensitive Electronic Equipment

647.8(A): Any luminaire (lighting fixture) supplied from a technical power system and any controls for the luminaire are required to be provided with a disconnecting means. Since there are two ungrounded wires for these 120 volt circuits, both ungrounded conductors must be disconnected. The change is that means for locking the disconnect in the open position must be of a type that remains in place with the lock removed. If the luminaires are on an individual circuit, the 2-pole circuit breaker can be fitted with a locking device.

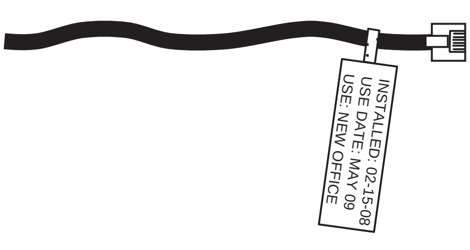


Figure 13.17 Spare cables that are part of an information technology system and are left in place or are added for future use are required to be durably marked with the date installed or designated as for future use, the estimated date of future use, and the intended future use.

WORKSHEET NO. 13—BEGINNING COMMERCIAL WIRING APPLICATIONS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A portion of a building has a precast cellular concrete floor that is being used for an electrical raceway. The cells in the concrete floor that are being used as a raceway are 3 in. (76.2 mm) in diameter with a cross-sectional area of 7.07 sq. in. (4560 mm^2). Four Type THWN copper conductors are to be run through the concrete cells as shown in Figure 13.18. The maximum size conductors permitted is:
   A. 2 AWG.
   B. 1/0 AWG.
   C. 3/0 AWG.
   D. 250 kcmil.
   E. 500 kcmil.

   Code reference __________________

2. Multioutlet assemblies are permitted to be installed:
   A. in damp, but not wet, locations.
   B. in an environment where corrosive vapors are present.
   C. in hoistways.
   D. through walls that are dry, provided the cover can be removed on all exposed assembly.
   E. where exposed to physical damage.

   Code reference __________________

3. A strut-type channel raceway is surface mounted to a ceiling and used to support luminaires (lighting fixtures) as well as serve as the raceway for the conductors. The sections of strut channel are secured within 3 ft (900 mm) of ends and terminations and shall be secured at intervals not greater than:
   A. 3 ft (900 mm).
   B. 4 1/2 ft (1.4 m).
   C. 5 ft (1.5 m).
   D. 8 ft (2.5 m).
   E. 10 ft (3 m).

   Code reference __________________

4. Grounding of receptacles and luminaires (lighting fixtures) attached to a strut-type channel raceway is:
   A. required to be accomplished using a bare equipment grounding wire.
   B. required to be accomplished using an insulated equipment grounding wire.
   C. only permitted to be accomplished by the strut channel if made of aluminum.
   D. required to be by means of a copper equipment grounding wire if the circuit operates at more than 150 volts to ground.
   E. permitted to be accomplished by the strut channel.

   Code reference __________________

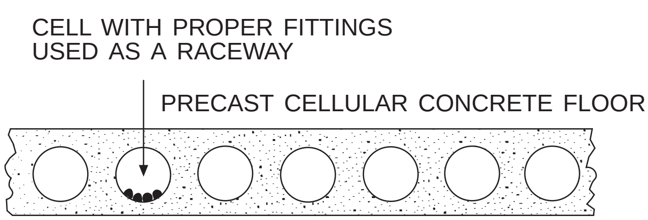


Figure 13.18 Determine the maximum size conductors permitted to be installed in a 3 in. (75 mm) diameter cell used as raceway in precast cellular concrete floor.

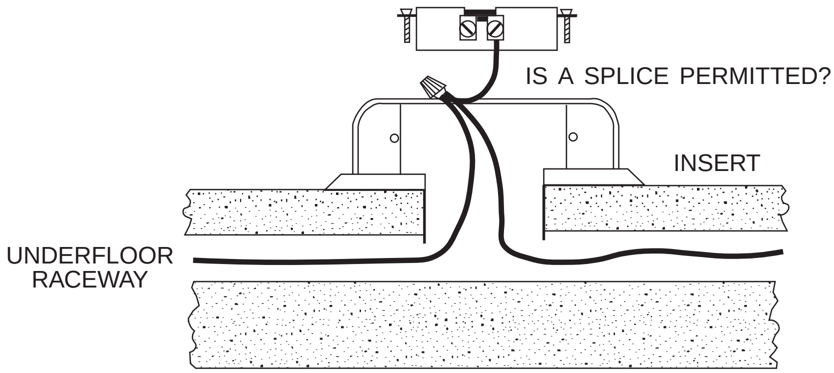


Figure 13.19 What type of connection is required for the wires to a receptacle outlet at an insert installed in underfloor raceway?

5. An insert is installed into underfloor raceway of an office building for electrical outlets at a workstation as shown in Figure 13.19. The connection of the individual wires to the receptacle at the insert:
   A. is permitted to be spliced with a pigtail connected to the receptacle.
   B. shall be made with the main conductor stripped, but not cut, with a short pigtail soldered to the main conductor and connected to the receptacle.
   C. is permitted to be the main conductor stripped and looped around the terminal screw of the receptacle.
   D. is permitted to cut the main circuit wire and connect one to each terminal screw of the receptacle.
   E. is permitted to cut the main circuit wire and push the wire into the receptacle provided a screw terminal is provided at the receptacle to ensure a tight connection.

   Code reference ___________________

6. A restaurant will be classified as an assembly occupancy if it is ruled to have a seating capacity of not less than:
   A. 75 persons.
   B. 100 persons.
   C. 150 persons.
   D. 200 persons.
   E. 500 persons.

   Code reference ___________________

7. An area of a motel is used for conferences and meetings and as required by the local jurisdiction is classified as an assembly occupancy and is to be of fire-rated construction. A wiring method not permitted to be run as exposed wiring on the surface of walls and ceilings is:
   A. Type AC Cable with an insulated equipment grounding conductor.
   B. Flexible Metal Conduit.
   C. Type MC Cable.
   D. Electrical Metallic Tubing.
   E. Rigid Nonmetallic Conduit.

   Code reference ___________________

8. An electric sign is not protected from physical damage, and it is located above an area accessible to vehicles, as shown in Figure 13.20. The minimum clearance from the bottom of the sign to the paved vehicle surface shall not be less then:
   A. 10 ft (3 m).
   B. 12 ft (3.7 m).
   C. 14 ft (4.3 m).
   D. 18 ft (5.5 m).
   E. 20 ft (6 m).

   Code reference ___________________

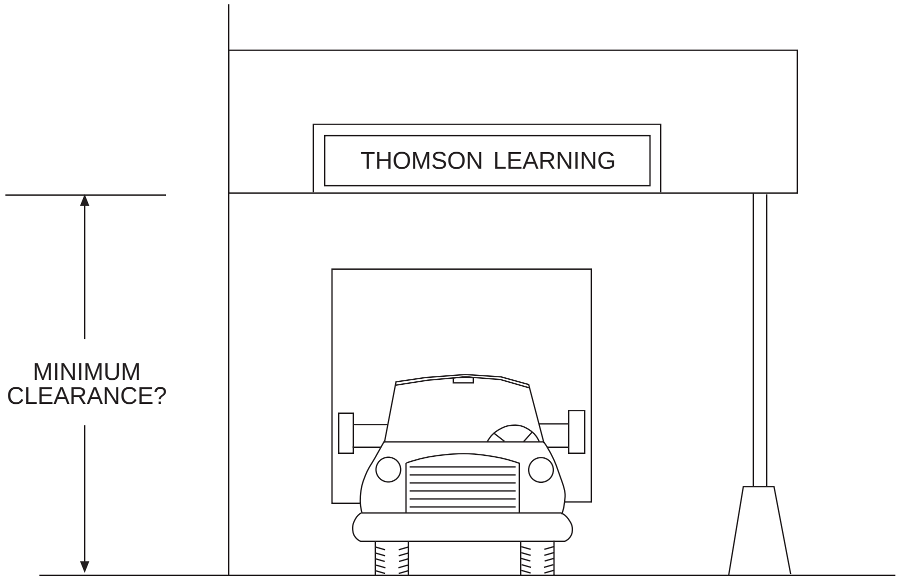


Figure 13.20 Determine the minimum height of a sign permitted when the area under the sign is open to vehicular traffic.

9. An electric sign that contains either incandescent or fluorescent luminaires (lighting fixtures) shall be supplied from a branch-circuit that has a rating not to exceed:
   A. 15 amperes.
   B. 20 amperes.
   C. 30 amperes.
   D. 40 amperes.
   E. 50 amperes.

   Code reference ___________________

10. A neon sign on the outside of a building has the transformer installed inside the building with only a short distance between the transformer and the sign. The transformer is to be installed in a space:
    A. that is 3 ft wide (900 mm), 3 ft high (900 mm), and 3 ft deep (900 mm).
    B. 3 ft (900 mm) of clear space in all directions from the transformer.
    C. 30 in. wide (750 mm), 4 ft high (1.2 m), and 3 ft (900 mm) clearance in front.
    D. 24 in. (600 mm) of clear space in all directions from the transformer.
    E. 12 in. wide (300 mm) and 3 ft high (900 mm) and completely open in front.

    Code reference ___________________

11. A manufactured wiring system is installed in the ceiling of an industrial building to supply high-intensity discharge (HID) luminaires (lighting fixtures). Type SO flexible cord with size 12 AWG conductors, completely visible for the entire length, is part of a listed factory-made assembly for connecting the luminaires (lighting fixtures) to the branch-circuit as shown in Figure 13.21. The maximum length of the manufactured wiring system is:
    A. 24 in. (600 mm).
    B. 3 ft (900 mm).
    C. $4^{1}/_{2}$ ft (1.4 m).
    D. 6 ft (1.8 m).
    E. not specified.

    Code reference ___________________

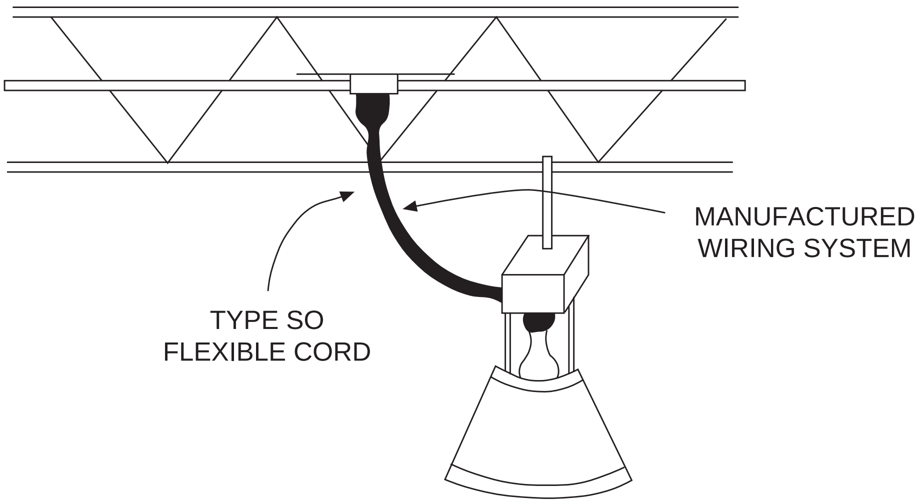


Figure 13.21 Determine the maximum length of flexible cord when a high-intensity discharge fixture is connected to a manufactured wiring system using Type SO flexible cord.

12. A required 125-volt, 15- or 20-ampere branch-circuit serves the lights and receptacles in an elevator machine room. The lights in the room are required to be:
    A. connected to the supply side of the ground-fault circuit interrupter.
    B. arc-fault protected.
    C. incandescent with at least two luminaires (lighting fixtures).
    D. ground-fault circuit-interrupter protected.
    E. grounded with an insulated equipment grounding conductor.

    Code reference ___________________

13. In the wellway of an escalator, trade size $^{3}/_{8}$ (12) Liquidtight Flexible Metal Conduit is used to protect wires supplying control equipment. The length of Liquidtight Flexible Metal Conduit is not permitted to exceed:
    A. 2 ft (600 mm). C. $4^{1}/_{2}$ ft (1.4 m). E. 10 ft (3 m).
    B. 3 ft (900 mm). D. 6 ft (1.8 m).

    Code reference ___________________

14. A computer room has a raised floor as shown in Figure 13.22. A circuit is run through the raised floor space to supply field-installed equipment and receptacles. A wiring method not permitted to be installed in the raised floor space is:
    A. Type UF Cable.
    B. Electrical Nonmetallic Tubing (ENT).
    C. Type AC Cable.
    D. Flexible Metal Conduit (FMC).
    E. Rigid Nonmetallic Conduit (RNC).

    Code reference ___________________

15. In an area of a commercial building where sensitive electronic equipment is used, and electrical noise is a major concern, a technical power system is installed. The sensitive electronic equipment is supplied power from receptacles of the technical power system which has two ungrounded conductors operating at 120 volts. A 125-volt, 15- or 20-ampere rated receptacle from the premises wiring system, with a grounded neutral conductor, is required to be installed in the same area with the technical power receptacles (Figure 13.23), and located a distance from any technical power receptacle not more than:
    A. 3 ft (900 mm). D. 10 ft (3 m).
    B. $4^{1}/_{2}$ ft (1.4 m). E. 15 ft (4.5 m).
    C. 6 ft (1.8 m).

    Code reference ___________________

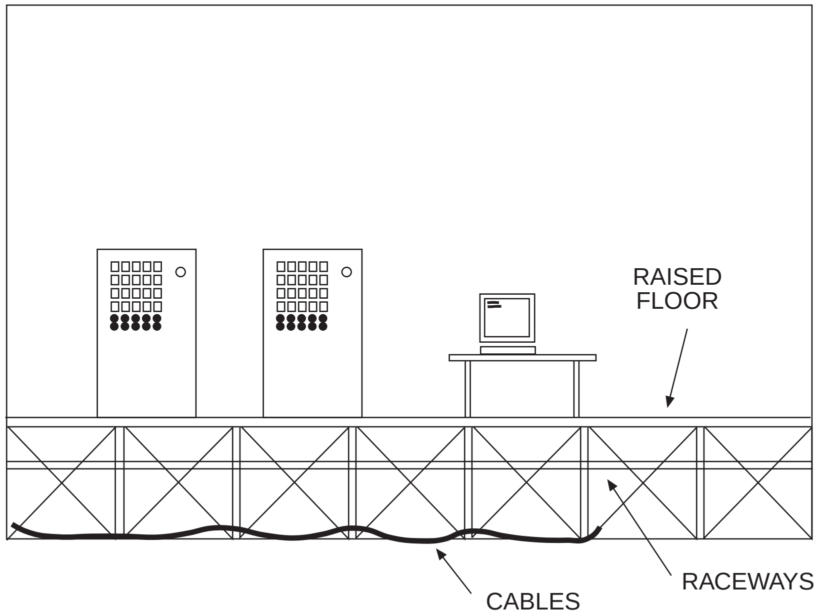


Figure 13.22 What are the wiring methods permitted for a power circuit supplying receptacles for information technology equipment and installed through the raised underfloor space of a computer room?

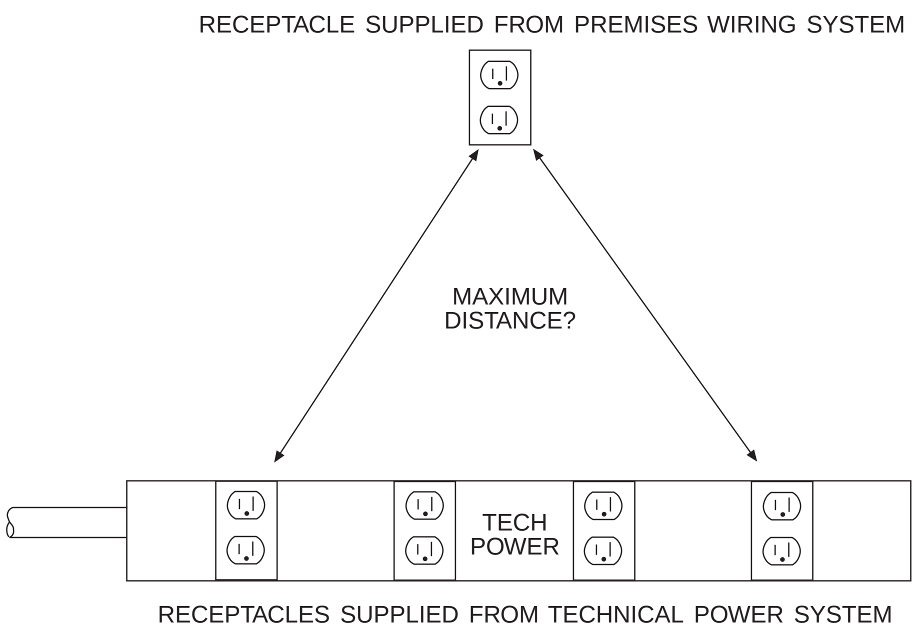


Figure 13.23 A 15- or 20-ampere, 125-volt receptacle supplied from the premises wiring system with a neutral circuit conductor is required to be installed within a maximum of what distance from all receptacles of the technical power system?

WORKSHEET NO. 13—ADVANCED COMMERCIAL WIRING APPLICATIONS

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A flat cable assembly consists of a Type FC Cable installed in strut that is attached to a ceiling. Taps are made for the installation of luminaires (lighting fixtures) by using terminal blocks that are installed into the strut and pierce the flat conductor cable as shown in Figure 13.1. If a protective cover is not installed to prevent access to the conductors, the minimum mounting height of the flat conductor assembly above the floor is:
   A. 7 ft (2.1 m).
   B. $7^1/_2$ ft (2.3 m).
   C. 8 ft (2.5 m).
   D. 10 ft (3 m).
   E. 12 ft (3.7 m).

   Code reference ___________________

2. An insert is installed into a cellular concrete floor raceway for a receptacle outlet at a workstation. An equipment grounding conductor shall be installed and shall:
   A. be bare.
   B. be bonded to the equipment grounding conductor in the header for the cell.
   C. be insulated.
   D. be bonded directly to the equipment grounding conductor in the adjacent cell.
   E. not exceed 100 ft (30 m) in length.

   Code reference ___________________

3. A receptacle outlet is removed at an insert in cellular metal floor raceway and the outlet is abandoned. The conductors that were connected to the receptacle are:
   A. permitted to be insulated with tape and placed into the raceway.
   B. required to be removed.
   C. permitted to remain in the raceway and reinsulated if the conductor is continuous without any nicks or breaks.
   D. permitted to remain if the reinsulation is listed for underground use and is watertight.
   E. required to be labeled as abandoned if reinsulated and left in the raceway.

   Code reference ___________________

4. A strut-type channel raceway, trade size $1^5/_8$ by 1, is installed across the ceiling of a commercial storage area to support wiring and luminaires (lighting fixtures). Internal joiners are used to connect the strut channel sections. The conductors installed in the strut channel are size 12 AWG copper, Type THWN with 75°C terminations, as shown in Figure 13.24. The maximum number of conductors permitted to be installed in the strut channel is:
   A. 9.
   B. 16.
   C. 21.
   D. 30.
   E. 34.

   Code reference ___________________

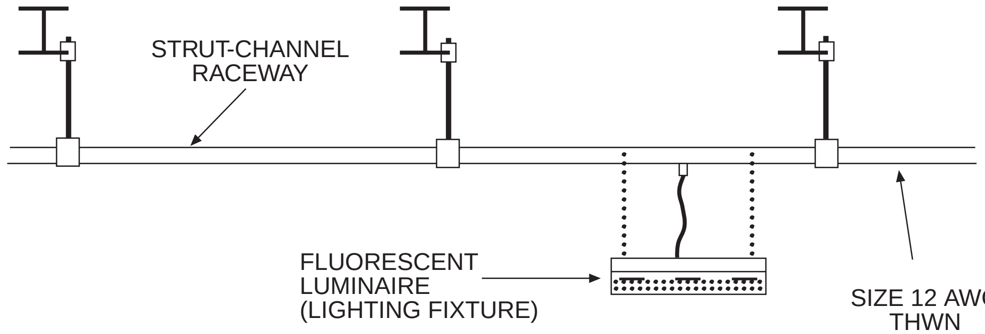


Figure 13.24 Determine the maximum number of size 12 AWG Type THWN conductors permitted to be installed in trade size 1⅝ by 1 strut-channel raceway.

5. The suspended ceiling of a restaurant classified as a place of assembly has a 15-minute finish fire rating, as shown in Figure 13.25. The space above the ceiling is not used as a plenum for environmental air. A wiring method not permitted to be used in the space above the suspended ceiling is:
   A. all are permitted.
   B. Electrical Nonmetallic Tubing (ENT).
   C. Flexible Metal Conduit.
   D. Type AC Cable not containing an insulated equipment grounding wire.
   E. Electrical Metallic Tubing (EMT).

   Code reference ___________________

6. In an exhibition hall ruled as an assembly occupancy, a cable tray is installed for the purpose of placing cords used for temporary wiring for the floor displays, as shown in Figure 13.26. Only qualified personnel will service and maintain the installation. The cords placed in the cable tray and used for the temporary wiring and shall be rated for:
   A. hard or extra-hard usage and must be installed with a space not less than one cord diameter between each cord.
   B. extra-hard usage and placed in a single layer.
   C. extra-hard usage and limited to 100 ft (30 m) lengths.
   D. hard or extra-hard usage and must be placed in a single layer.
   E. hard usage.

   Code reference ___________________

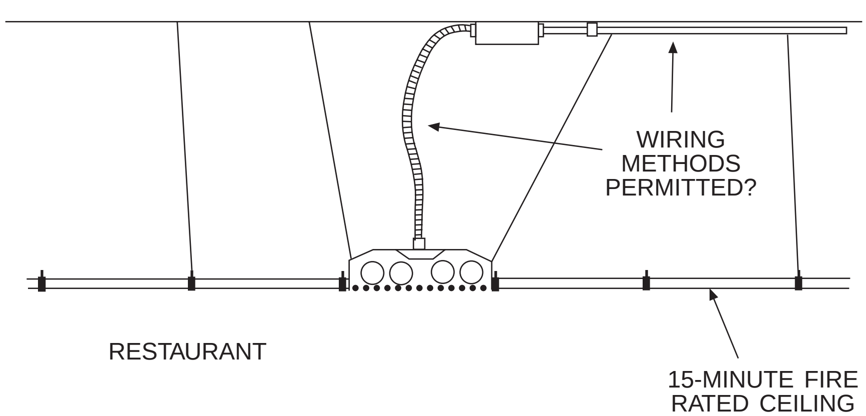


Figure 13.25 What wiring methods are permitted to be installed in a suspended ceiling of a restaurant that has a 15-minute finish rating.

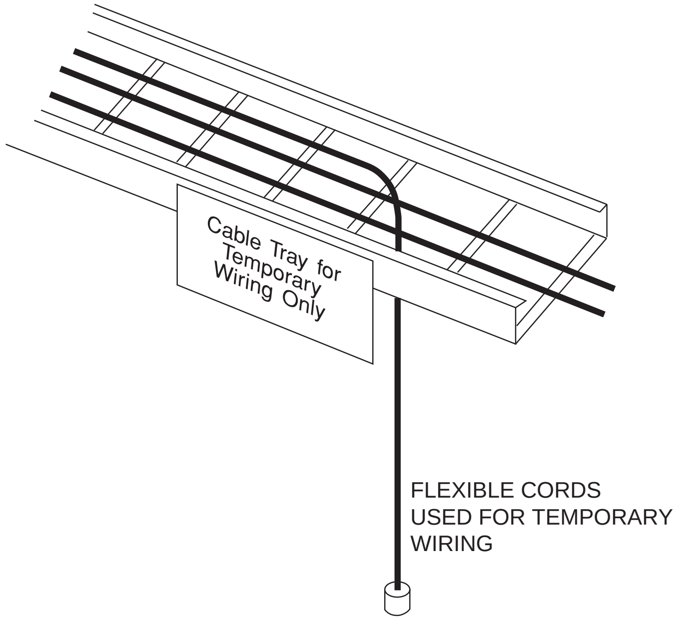


Figure 13.26 Cable tray is installed in an exhibition area for temporary wiring to exhibition booths has flexible cable provided to exhibit spates using what rating of flexible cord?

7. A commercial building with grade level access to pedestrians has only one entrance intended for the general public. This building is required to provide for the purpose of supplying an electric sign:
   A. one outlet located near the entrance on a 30-ampere circuit that serves no other loads.
   B. two outlets located near the entrance each on a separate 20-ampere branch-circuit.
   C. one outlet locate near the entrance on a 20-ampere branch-circuit and permitted to serve other general use receptacle loads.
   D. one outlet located near the entrance on a branch-circuit rated not less than 15 amperes.
   E. one outlet located near the entrance on a 20-ampere circuit that serves no other loads.

Code reference ___________________

8. A sign for a commercial building is supplied by a single branch-circuit and is operated by an electronic controller that is located separate from the sign. The disconnecting means:
   A. is required to be located within sight of the sign and capable of being locked in the open position if not in line of sight of any energized part of the sign.
   B. is required to be within the controller, disconnects all power to the controller, and capable of being locked in the open position.
   C. is required to be within sight of the controller but not necessarily within sight of the sign.
   D. for the sign is required to be located on the sign, which then requires an additional disconnecting means for the controller.
   E. is permitted to be a switch or circuit breaker, capable of being locked in the open position, and located within sight of the controller.

Code reference ___________________

9. A receptacle is situated so that it may be used to supply power to a free standing office furnishing partition having electrical wiring and supplied power with a size 12 AWG extra-hard usage flexible cord. The cord is plugged into a receptacle that serves no other load. The maximum permitted distance from the partition to the receptacle is:
   A. 12 in. (300 mm).
   B. 24 in. (600 mm).
   C. 36 in. (900 mm).
   D. $4\frac{1}{2}$ ft (1.4 m).
   E. 6 ft (1.8 m).

   Code reference ___________________

10. A single 125-volt, 20-ampere receptacle is installed in the hoistway pit of an elevator to supply a permanently installed sump pump. This receptacle:
    A. shall not require ground-fault circuit-interrupter protection.
    B. shall be arc-fault interrupter protected.
    C. is required to be of the ground-fault circuit-interrupter type.
    D. is required to be ground-fault circuit-interrupter protected.
    E. is not permitted to be located in an elevator hoistway pit for this purpose.

    Code reference ___________________

11. The minimum number of duplex receptacles required to be installed in an elevator machine room or space is:
    A. none because a single receptacle is permitted.
    B. as many as desired, because no minimum requirement is established.
    C. one.
    D. two.
    E. three.

    Code reference ___________________

12. Eight passenger elevators are powered with motor-generator sets with generator field control and rated 30-horsepower, 3-phase, 460-volt continuous duty. In addition to this load, the motion-operation controller for each elevator has a continuous load of 9 amperes. The feeder conductors for the elevators are THWN copper conductors with 75°C terminations. The minimum size feeder conductors required to supply this elevator load is:
    A. 600 kcmil.
    B. 700 kcmil.
    C. 750 kcmil.
    D. 800 kcmil.
    E. 900 kcmil.

    Code reference ___________________

13. The control for the disconnecting means for the computer room dedicated air-handling equipment that is used to ventilate the area under the raised floor of an information technology equipment room is required to be located:
    A. at the door considered to be the principal exit for the information technology equipment room.
    B. at a centrally located location within the information technology equipment room.
    C. within sight of the information technology equipment room.
    D. located on the air-handling equipment.
    E. located within 6 ft (1.8 m) of each exit.

    Code reference ___________________

14. Sensitive electronic equipment in a room is supplied 120-volt, single-phase power with a technical power system. The equipment is connected to receptacle outlets supplied by 15-ampere rated circuits. The voltage drop on the feeder from the supply transformer to the technical power panel is less than 1% when all equipment is operating. The distance from the technical power panel to the receptacles in the electronics room is 75 ft (22.86 m). The actual load on the circuits is not known. The minimum size copper conductors with 75°C insulation and terminations permitted for these technical power receptacle circuits is: (assume K = 12 (0.02))

A. 16 AWG. C. 12 AWG. E. 8 AWG.
B. 14 AWG. D. 10 AWG.

Code reference ___________________

15. A 15-kVA single-phase insulating transformer supplies 120-volt technical power to a single-phase panel with a 100-ampere main circuit breaker, as shown in Figure 13.27. The conductors from the transformer to the panelboard are size 1/0 copper. This separately derived electrical system is grounded to the structural steel of the building near the location of the panelboard. The minimum size grounding electrode conductor permitted for this technical power system is:

A. 10 AWG. C. 6 AWG. E. 3 AWG.
B. 8 AWG. D. 4 AWG.

Code reference ___________________

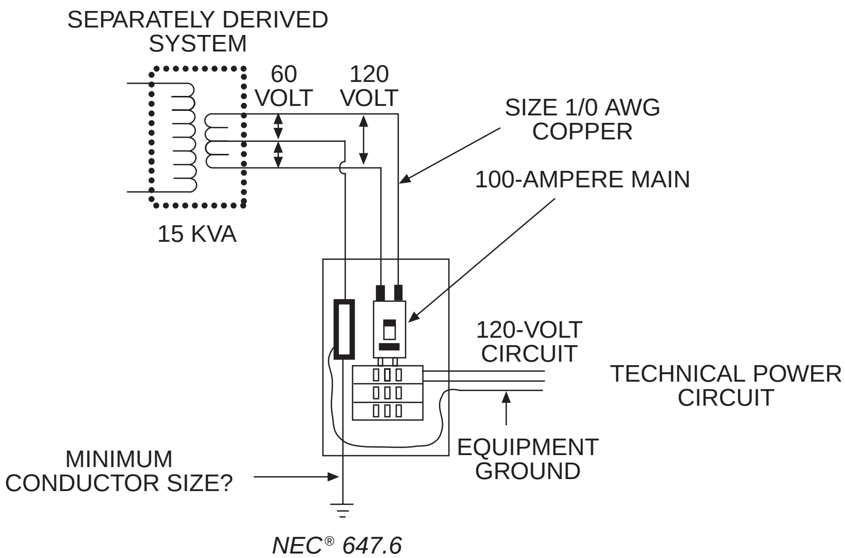


Figure 13.27 Determine the minimum size grounding electrode conductor for a technical power system where the conductors supplying the panel are size 1/0 AWG copper and the main in the panel is rated 100 amperes.

UNIT 14

Special Applications Wiring

OBJECTIVES

After completion of this unit, the student should be able to:

- state the wiring methods permitted for a theater or similar location.
- explain the location of the controls and overcurrent protection for stage lighting outlets and receptacles.
- explain the special requirements for switching lighting and receptacles in a theater dressing room.
- explain the wiring methods permitted to be used in a motion picture or television studio.
- state the minimum size of wire permitted to supply an arc or xenon projector in a motion picture projection room.
- define an equipotential plane, as related to agricultural building wiring.
- explain the grounding requirements for water pump on a farm.
- describe which article of the Code applies to the various types of communications circuits that can be installed within a building.
- describe the separation requirements of various types of communications wires in relation to circuit wires for normal light and power.
- explain the grounding of various types of communications circuits and equipment.
- answer wiring installation questions relating to *Articles 520, 522, 525, 530, 540, 547, 553, 555, 625, 626, 640, 650, 682, 800, 810, 820*, and *830.*
- state at least five significant changes that occurred from the 2005 to the 2008 Code for *Articles 520, 522, 525, 547, 555, 625, 626, 640, 682, 800, 810, 820*, or *830.*

CODE DISCUSSION

This unit deals with special applications where conditions exist resulting in special requirements for wiring installations. Generally, the requirements of the Code apply except for specific requirements of these articles.

Article 520 covers wiring installations in buildings or portions of buildings used as theaters for dramatic and musical presentations and musical and dramatic presentations both indoors and outdoors. This article also applies to portions of motion picture and television studios used as assembly areas. *Parts I, III* and *VI* apply to the fixed wiring in the auditorium stage, dressing rooms, and main corridors leading to the auditorium. The fixed wiring for lighting and power shall be in metal raceway, nonmetallic raceway encased in at least 2 in. (50 mm) of concrete, or Type MI Cable, Type MC Cable, or Type AC Cable with an insulated equipment grounding conductor. Many runs of wires are required for control of lighting. Many wires will be subjected to continuous load at times, but not all wires will be subjected to continuous load at the same time. For this reason, the derating factors of *310.15(B)(2)* do not apply when there are more than 30 wires in metal wireway or auxiliary gutter, as stated in *520.6.*

Dressing rooms of theaters and studios are areas where portable equipment is used, and there are usually high lighting levels. The potential for fire is great; therefore, special precautions are taken to minimize the chances of fire. Permanently attached open-ended guards are required to be installed around all incandescent lamps that are located less than 8 ft (2.5 m) above the floor, as indicated in *520.72.* According to *520.73,* all receptacles located adjacent to a mirror or serving a dressing table countertop are required to be controlled by a switch located in the dressing room. In addition, a pilot light must be installed outside of the

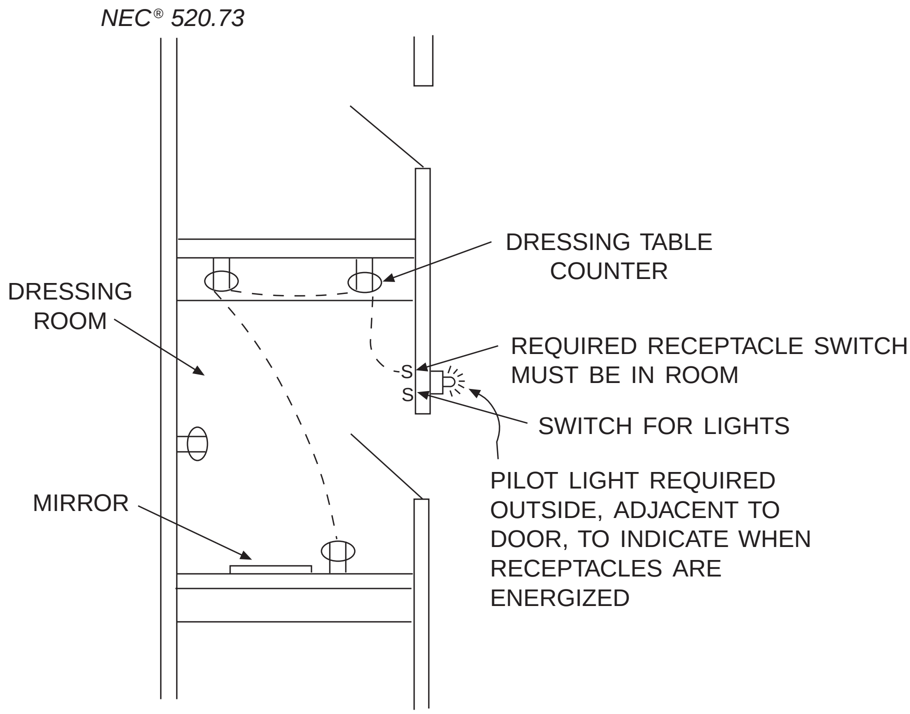


Figure 14.1 Only the receptacles serving the dressing table counter top and the receptacles located adjacent to the mirror are required to be controlled by a switch and the pilot light to indicate when the receptacles are energized is located outside the dressing room adjacent to the door.

dressing room adjacent to the door indicating when the dressing room receptacles are energized. These requirements are shown in Figure 14.1. Other receptacle outlets installed in the dressing room, not adjacent to a mirror or not serving a dressing table countertop, are not required to be controlled by a switch.

Part II applies to fixed stage switchboards and the feeders for switchboards. The requirements for portable switchboards are covered in *Part IV. NEC® 520.23* requires that receptacles intended to supply cord-and-plug stage lighting equipment, whether the receptacles are on the stage or located elsewhere, shall have their circuit overcurrent protection at the stage lighting switchboard location. *Part V* applies to portable stage equipment, but the receptacles for portable equipment are considered to be a fixed part of the building wiring and are covered in *520.45*. Any receptacle on a branch-circuit serving performance area may be required to carry current at the full rating of the circuit, therefore *520.9* requires all receptacles to have an ampere rating not less than the rating of the branch-circuit. The receptacle current limitation of *Table 210.21(B)(2)* does not apply to the receptacles serving performance areas. Conductors supplying receptacles shall be sized and protected for overcurrent in accordance with the provisions of *310.15* and *400.5*. The receptacles for connection of equipment shall supply continuous loads not in excess of 80% of the ampere rating of the receptacles since the receptacle has the same rating as the circuit overcurrent device. A receptacle outlet is permitted to supply a noncontinuous load rated at 100% of the receptacle ampere rating.

The definition of performance area in *520.2* makes it clear that temporary stage productions, both indoors and outdoors, are covered by the rules in *Article 520*. The rules in *Article 525* do not apply because they do not consider the unique nature of much of the equipment used for performances. An example of a portable performance stage and the equipment commonly used is shown in Figure 14.2. These temporary installations, according to *520.10*, are required to be supervised and operated by qualified personnel.

The power supply for temporary performance equipment is covered in *520.53(H)* and frequently consists of color-coded individual single-conductor flexible cables with pin-and-sleeve connectors. Portable utilization equipment generally requires a 120-volt nominal supply. Power supply feeders are generally 3-phase, 208Y/120-volt, 4-wire plus an equipment grounding cable. Good grounding is necessary for safety and proper operation of electronic equipment. The power supply may also be 208/120-volt, 3-wire plus and equipment grounding cable supplied from a 208Y/120-volt source. In this case, it is important to note that neutral current can be significant according to *310.15(B)(4)(b)*. Feeders can also be connected to a single-phase source and supplied 120/240-volt, 3-wire plus an equipment grounding cable.

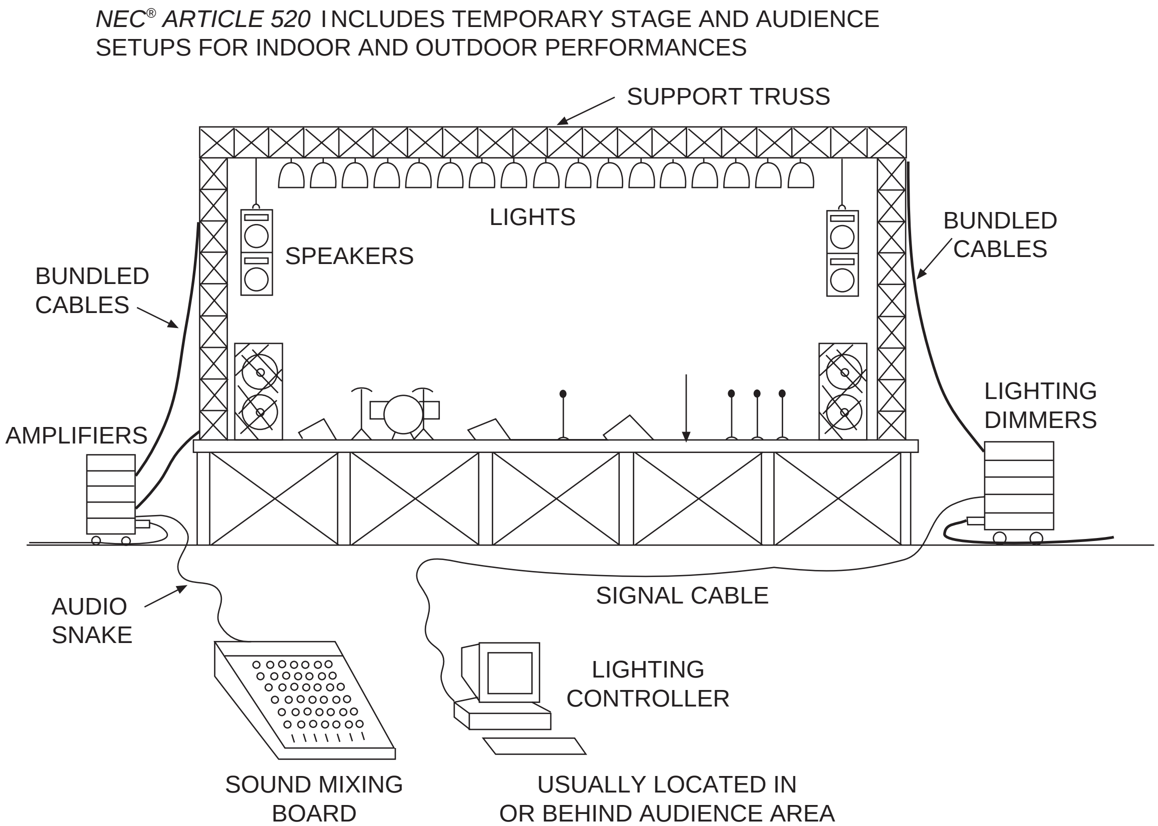


Figure 14.2 A temporary performance stage is generally supplied power with single-conductor feeder cables with the main power run to amplifiers and lighting dimmers where the main power-carrying conductors are confined to the stage area.

Article 522 provides rules for the installation of control systems for permanently installed amusement attractions such as would be found at a theme park. In the past, this control wiring was treated as Class 1, Class 2, or Class 3 wiring using the rules of *Article 725*, which did not always fit the application. One of the issues is that often the source for the control circuit has a higher power requirement than is permitted by *Article 725*. Overcurrent protection for these circuits is covered in *522.10* where non-interchangeable fuses are required for most applications. Another issue is wire size. Depending upon the application, wire sizes are permitted to be as small as 30 AWG copper. Metals other than copper are permitted for applications such as sensors, *522.20*. The maximum permitted ampere rating of these conductors is given in *Table 522.22*. Conductors are required to be insulated and may be solid copper or stranded. No minimum insulation voltage rating is specified because of the wide range of voltages utilized, but the insulation voltage rating would need to be adequate for the application. Maximum voltage as stated in *522.5* is 150 volts ac to ground and 300 volts dc to ground. Multiple control circuits, whether ac or dc, are permitted to share the same raceway, cable, cable tray, or enclosure, *522.24(A)*.

Article 525 deals with wiring of a temporary nature, installed in adverse conditions, where the public is exposed to the temporary wiring and equipment supplied. This article deals with electrical power for equipment at carnivals, circuses, fairs, and similar events. *Article 590* does not adequately cover the conditions that exist at these events. *NEC® 525.5(B)* specifies the clearances of overhead wires from amusement rides and attractions. For example, a horizontal clearance of not less than 15 ft (4.5 m) must be maintained from amusement rides or attractions to overhead conductors as illustrated in Figure 14.3. *NEC® 525.21(A)* requires a disconnecting means for the power to all rides to be located within sight and not more than 6 ft (1.8 m) from the operator's location. Flexible cords and cables shall be listed for extra-hard usage, wet locations, and be sunlight-resistant, *525.20(A)*. Where accessible to the public, flexible cords and cables shall be covered by approved nonmetallic mats. Receptacles shall have overcurrent protection that does not exceed the rating of the receptacle, *525.22(C)*. Receptacles rated 15 or 20 ampere, 125 volts and used by personnel shall have ground-fault circuit-interrupter protection. Grounding and bonding are covered in *Part IV*, which essentially complies with *Article 250*. It is pointed out that the grounded-circuit conductor and the equipment

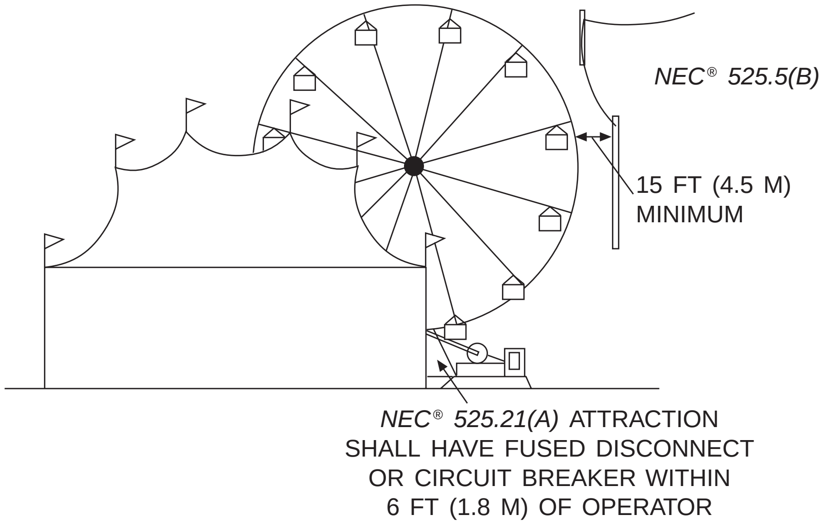


Figure 14.3 Overhead conductors are required to be kept at least 15 ft (4.5 m) horizontally from rides and attractions and a disconnect is to be located within sight and not more than 6 ft (1.8 m) from the operator's location.

grounding conductor are to be maintained separate on the load side of the service disconnecting means or the separately derived system, *525.31.* In *Article 590,* 90 days is generally defined as the maximum length of time permitted for temporary wiring. There is no time limit for wiring to equipment at carnivals, circuses, fairs, and similar events.

Article 530 applies to buildings or portions of buildings used as studios, using motion picture film or electronic tape more than 7/8 in. (22 mm) in width. This article also applies to areas where film and tape are handled, or where personnel are working with the film or tape for various purposes. An area for an audience is not present in the facilities covered by this article. The same requirements as for a theater, as covered in *Article 520,* should be applied. This article contains special requirements for areas where quantities of highly flammable materials, such as motion picture film and electronic recording tape, are present. The permanent wiring in stage and set areas shall be Type MC Cable, Type MI Cable, Type AC Cable with an insulated equipment grounding conductor, or approved raceway. The authority having jurisdiction will decide what wiring methods are approved. Generally, metal raceway wiring is the approved method for raceway wiring.

Article 540 deals with the wiring for motion picture projector rooms. NFPA standard, number 40 provides additional information about the storage and handling of cellulose nitrate motion picture film. This material is highly flammable; therefore, special requirements are placed on the wiring of projection rooms. Local building codes will provide additional information as to which areas are considered part of the projection room. For example, a film rewinding room would be considered part of the projection room because it opens directly into the projection room.

Article 547 covers the wiring of agricultural buildings where excessive dust, dust with water, or corrosive atmospheres are present. Buildings in agricultural areas in which these conditions are not present are permitted to have the wiring installed according to the requirements elsewhere in the Code. Conditions on farms are extreme. Wiring is generally exposed to a wide variation in temperature which causes expansion and contraction as well as temperature differences that can lead to condensation. The wiring may be exposed to severe physical abuse from impact, rubbing, and chewing. The conditions are often corrosive. High humidity is common, and frequently portions of the wiring is exposed to standing water and animal waste. *NEC® 547.5(A)* covers the wiring methods permitted in an agricultural building that preferably are Rigid Nonmetallic Conduit or Type UF Cable. Other materials frequently used are Liquidtight Flexible Nonmetallic Conduit, copper SE Cable, and jacketed Type MC Cable. Equipment grounding in damp and wet locations that often exist on farms requires effective equipment grounding. *NEC® 547.5(F)* requires a separate copper equipment grounding conductor run with the circuit conductors to all noncurrent-carrying metal parts of equipment, raceways, and other enclosures requiring grounding. Whenever this copper equipment grounding conductor is run underground, it is required to be insulated or covered.

Boxes and enclosures installed in areas where there is excessive dust or damp and wet conditions or corrosive conditions are required to be corrosion resistant, weatherproof, and designed to prevent the entrance of dust as stated in *547.5(C).* Nonmetallic boxes are generally ideal for these applications such as

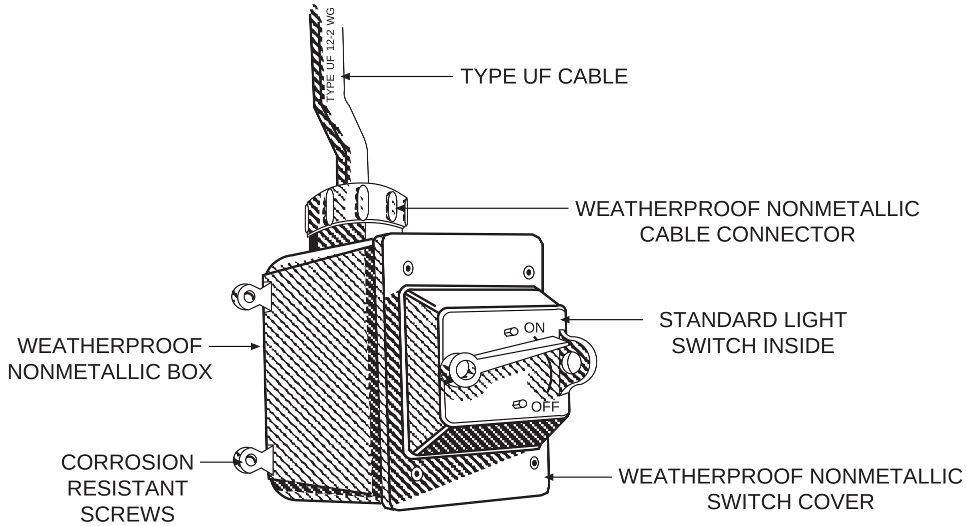


Figure 14.4 Nonmetallic weatherproof boxes with watertight connectors and Type UF Nonmetallic Cable will help to prevent corrosion of the wiring and moisture from entering the wiring. Courtesy of Consumers Energy, Jackson, MI.

the weatherproof switchbox shown in Figure 14.4. The connector is of a type that is made for Type UF Cable and is watertight and dusttight. *NEC® 547.5(C)(1)* requires boxes to be mounted in such a manner that holes are not drilled in the back of the box. The box in Figure 14.4 is constructed for external mounting. Motors used in these areas shall be totally enclosed or designed to minimize the entrance of dust particles and moisture. Luminaires (lighting fixtures) in agricultural buildings shall be a type that minimizes the entrance of dust, moisture, and other foreign material.

Receptacles installed in agricultural areas that are rated 15- or 20-ampere, 125-volts and intended for general use are required to be ground-fault circuit-interrupter protected. This rule applies to all buildings and areas that have equipotential planes, all outside locations, damp or wet locations, and dirt confinement areas for livestock.

Farms consist of a group of buildings frequently including one or more dwellings. The typical manner for distributing power to a farm is to a centrally located distribution point, which is defined in *547.2.* From the distribution point, power is extended to the various buildings either overhead or underground, or a combination of both. Minimum requirements for the distribution point equipment are explained in *547.9(A).* A means of disconnecting all ungrounded conductors to the buildings is required and called the site-isolation device. The grounded service conductor is required to be connected to a grounding electrode at the distribution point site-isolation device in accordance with the rules in *Article 250.* The site-isolation device can be provided by the serving utility or the property owner. Overcurrent protection at the distribution point is optional, unless supply to the buildings is underground.

Overcurrent protection at the distribution point site-isolation device is not always required. There can also be one large disconnect with a single overcurrent device sized to the entire farm load. The site-isolation device may be a double-throw standby generator transfer switch with an off position and sized for the total farm load. The conductors to the individual buildings are permitted to be run as outside feeders according to *240.21(B)(5)* ending at an overcurrent device sized not more than the ampere rating of the feeder. Only overhead feeder conductors to the individual buildings are permitted to be installed in this manner according to *547.9.* Using this procedure, the rules of installation are found in *547.9(B).* It is only permitted to ground the neutral conductor at each building disconnect for cases where the feeder supplies existing buildings, *250.32(B) Exception.* For new buildings, it is required to run a separate equipment grounding conductor with the feeder to the building, in which case the neutral is not grounded at the building disconnect This procedure is explained in *250.32(B),* described in *Unit 5,* and illustrated in Figure 5.5 and Figure 14.6.

The conductors from the central distribution point may have individual disconnecting means and overcurrent protection, in which case the conductors to the buildings are treated as feeders and installed according to *Part II* of *Article 225* and grounded in accordance with *250.32(B).* If the conductors to the buildings are run underground, then *547.9* requires an individual disconnect with overcurrent protection at the supply end of the feeder. When the conductors are run overhead, as shown in Figure 14.5, only a site-isolation device

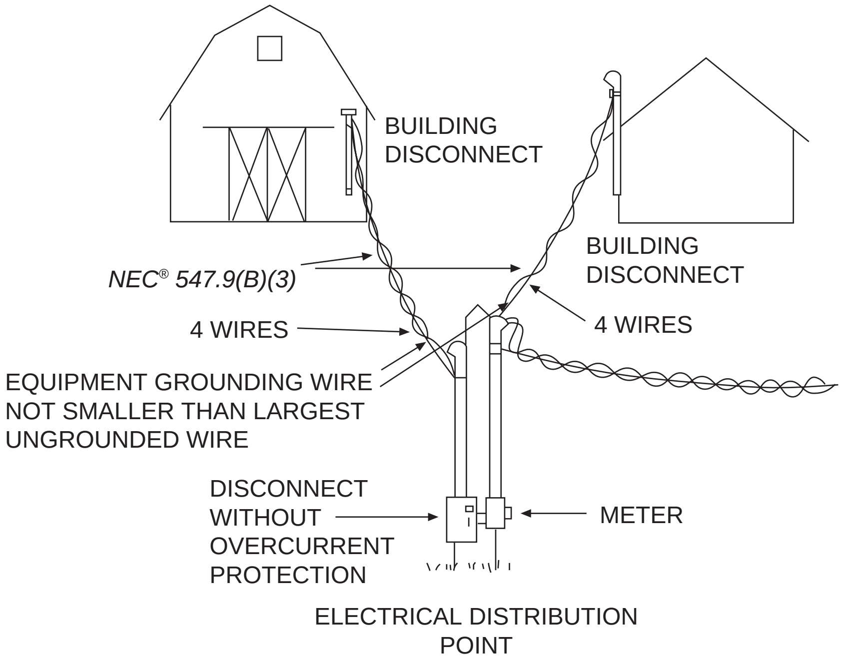


Figure 14.5 Disconnecting means must be provided at the electrical distribution point on a farm.

is required at the central distribution point, and overcurrent protection is provided at the individual buildings. The procedures of *547.9(B)* are required, which in paragraph (3) directs the installer to size the equipment grounding conductor not smaller than the largest ungrounded conductor.

The neutral conductor of a grounded electrical system carrying electrical current will usually have a measurable voltage from the neutral conductor to a ground rod driven into the earth in an isolated location. This is called neutral-to-earth voltage. The term **stray voltage** describes the condition where a neutral-to-earth voltage can be measured between points with which livestock may make contact, such as from a watering device in the barn to the concrete floor. A source of this stray voltage is the neutral wire of the feeder to a farm building. This article of the Code requires that the neutral of the feeder to a new building be run separate from and insulated from, the equipment grounding conductor to the building. This procedure will prevent the neutral-to-earth voltage from the feeder neutral from getting to the areas where an animal may make contact. This is accomplished by running four wires to a farm building in the case of a single-phase, 120/240-volt feeder. An equipment grounding terminal is installed at the building service panel, which is separate from the neutral terminal, as shown in Figure 14.6.

It is extremely important to note that when the neutral conductors and the equipment grounding conductors are separated in a building, an equipment grounding conductor must be run from that building back to the source of power. That source of power may be another building or it may be a center distribution pole. Simply grounding the equipment grounding bus to the earth and not running the equipment grounding bus back to the main source of power is a violation of *250.4(A)(5)*. The earth is not permitted to be the only equipment grounding conductor.

Electrical wiring in agricultural buildings often is subject to physical damage and corrosive conditions. *NEC® 547.5(F)* requires that a copper equipment grounding conductor be run for all circuits even when run in metal conduit. This is to ensure that noncurrent-carrying parts of equipment will remain grounded even in the harsh environments found in agricultural areas. *NEC® 250.112(L)* and *(M)* require that a water pump installed on a farm be grounded. There is an additional requirement that in the case of a submersible water pump, as shown in Figure 14.7, a metal well casing shall be bonded to the pump equipment grounding conductor.

Another requirement of some agricultural buildings is that an equipotential plane shall be installed. Rules for installing an equipotential plane are covered in *547.10*. This equipotential plane shall be bonded to the grounding electrode system of the building. By bonding all metal objects in an animal confinement area together and then bonding the metal to the service grounding electrode system, an animal is not exposed to stray voltage in that confinement area. This article requires that an equipotential plane shall be bonded to the building grounding electrode system. An equipotential plane in a milking parlor is illustrated in Figure 14.8.

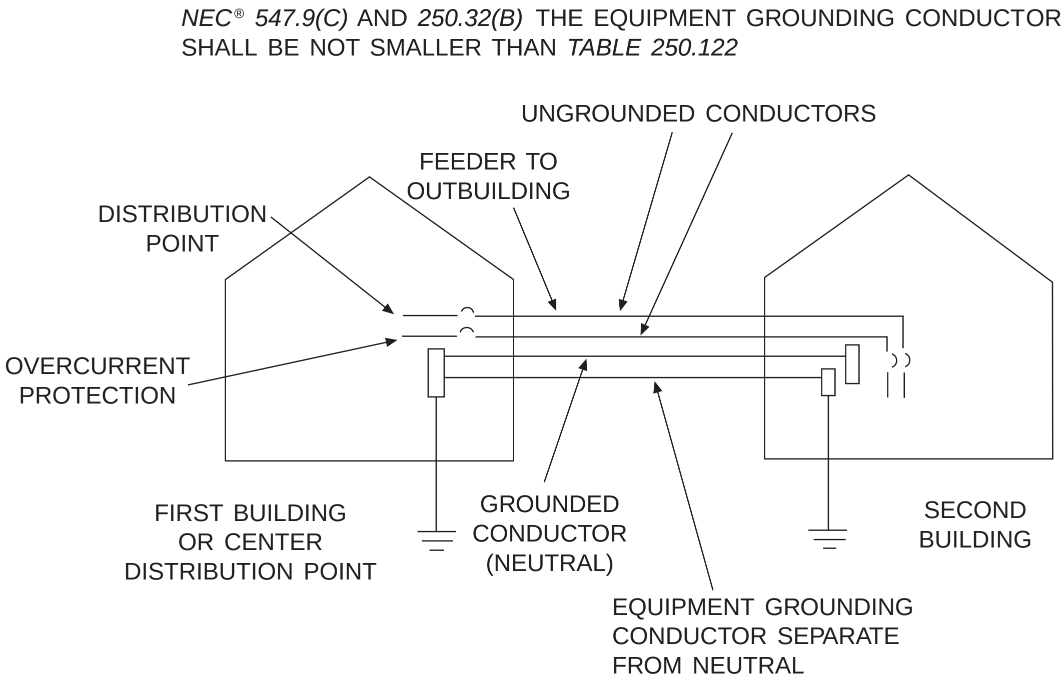


Figure 14.6 The equipment grounding conductor for a feeder on a farm is permitted to be run separated from the grounded circuit conductor and is required when there is a metal connection between buildings such as a water pipe.

Article 553 covers the wiring of an electrical service to floating buildings. A floating building is a structure moored in a permanent location, provided with electrical wiring, and permanently connected to an electrical system not associated with the floating building. The service equipment is not permitted to be located on or in the floating building. It shall be located adjacent to the building location. The equipment grounding conductor shall be run separate from the insulated neutral conductor. The equipment grounding conductor and the neutral conductors shall be maintained separate throughout the wiring system and equipment of the floating building. This is similar to the separation of neutral and equipment grounding conductor illustrated in Figure 14.6.

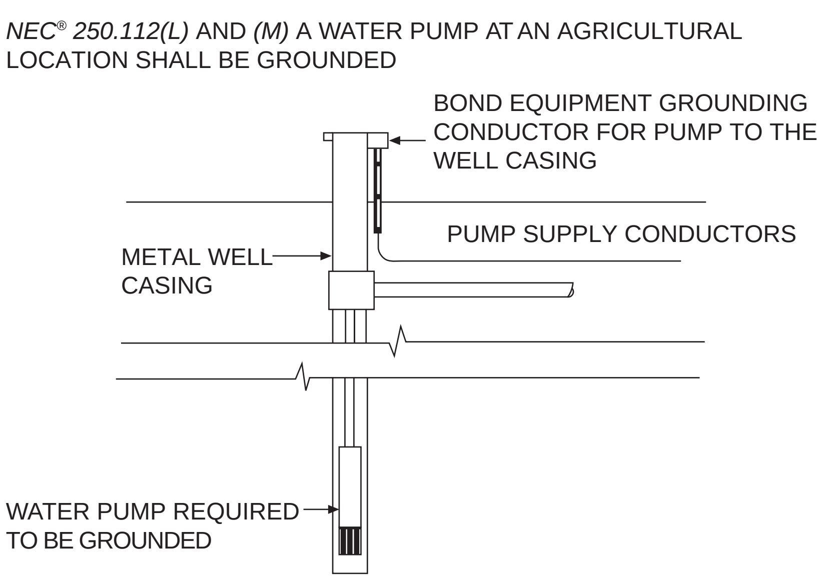


Figure 14.7 A water pump on a farm is required to be grounded and a metal well casing is required to be bonded to the equipment grounding conductor for a submersible pump.

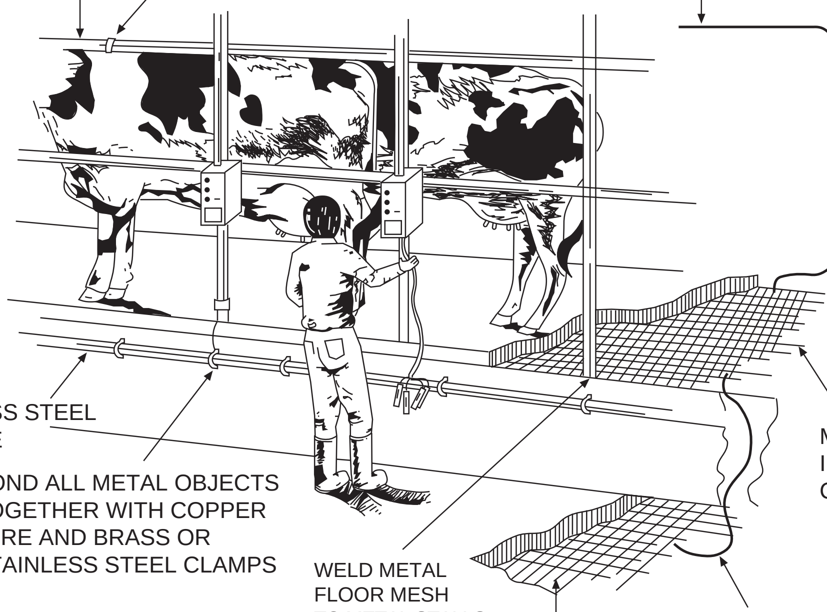


Figure 14.8 The installation of metal mesh in the floor connected to all exposed metal forms an equipotential plane that helps prevent animals from being exposed to stray voltage. Courtesy of Consumers Energy, Jackson, MI.

Article 555 covers the wiring of marinas and boatyards where electrical power is used on fixed or floating piers, wharfs, and docks, and where power from these structures supplies shore power to boats and floating buildings. A receptacle outlet intended to supply shore power to a boat shall be of the grounding and locking type. A receptacle outlet with a minimum rating of 30 amperes shall be provided for boats. If a receptacle rated at 15 or 20 amperes supplies 120-volt power for general use on the pier, ground-fault circuit-interrupter protection shall be provided. Wiring methods and grounding are covered. Extra-hard usage cord is permitted to be used as a feeder along the pier provided it is listed for use in wet locations and is marked as sunlight-resistant. Extra-hard usage cord also can be used as a feeder to floating docks and similar structures. But the electrical service is not permitted to be located on the floating dock. The limits of the classified hazardous location near gasoline dispensers are found in *555.21*. The wiring within these classified areas shall be as required in *Articles 501* and *514*.

It is important to determine the electrical datum plane in order to locate receptacles and other electrical enclosures and to make connections. The electrical datum plane is defined in *555.2*. For a shore area on a body of water where there are tides, the electrical datum plane is a horizontal plane that is 2 ft (600 mm) higher than the normal high tide for the area. If the body of water is not subject to tides, then the electrical datum plane is a horizontal plane that is 2 ft (600 mm) higher than the normal water level. In the case of a floating dock or pier, the electrical datum plane of the dock or pier is 30 in. (750 mm) above the water level as illustrated in Figure 14.9.

Article 625 deals with the wiring and equipment external to a vehicle used for charging of electric vehicles. *NEC® 625.5* specifies that all materials and equipment shall be listed for the purpose. Specifications for the connection to the electric vehicle are covered in *Part II*. Electric vehicle charging loads are to be consid-

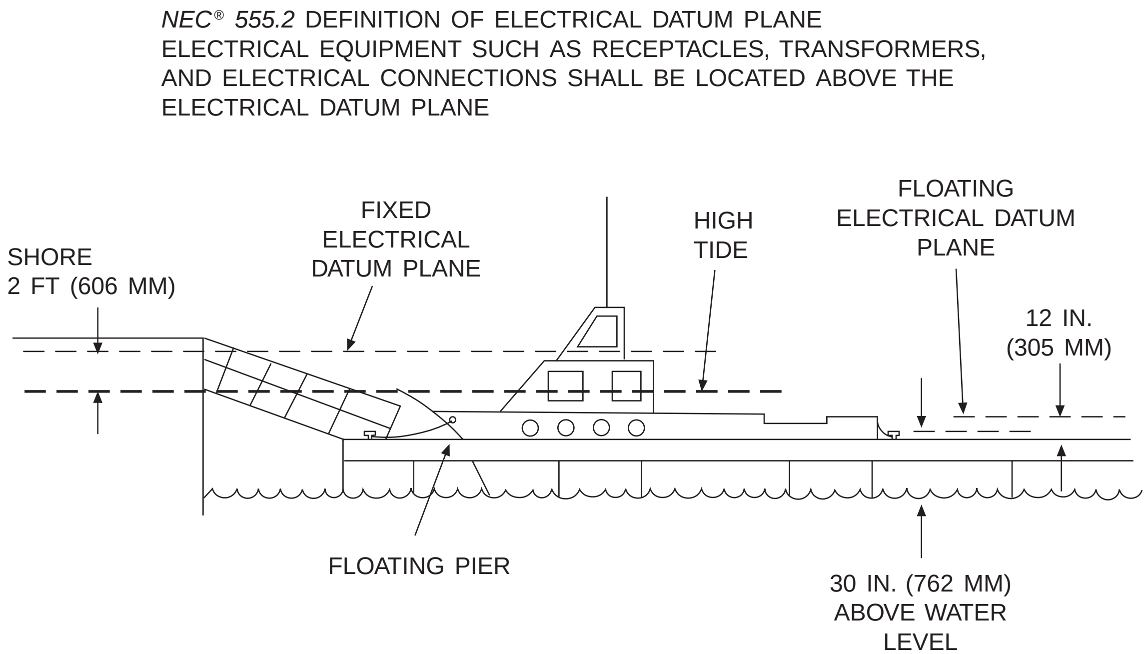


Figure 14.9 The datum plane must be established for a marina before the location of receptacles and other equipment can be determined.

ered continuous loads, *625.14*. Electric vehicle supply cable shall be a type with the letters EV as stated in *625.17* or a type listed as being suitable for the purpose. Basically this is a cable suitable for hard-usage and wet locations. The electric supply equipment for the vehicle shall have a listed shock protection system for personnel. It shall also have a ground-fault protection system that will disconnect power to the equipment at a level less than required to operate the circuit or feeder overcurrent device, *625.22*. A minimum ground-fault level is not specified. *NEC® 625.23* requires a disconnecting means capable of being locked in the open position when the equipment is rated more than 60 amperes or more than 150 volts to ground.

Attached and detached residential garages are included in the rules for supply to electric vehicle charging equipment. *NEC® 625.29(C)* provides specifications for ventilation. The batteries will give off vapors during charging that can create a hazard if not vented. Ventilation is not required where nonvented storage batteries are utilized. When vented batteries are used, such as deep discharge lead-acid batteries, ventilation is required when charging is in a closed garage. *NEC® 625.29(D)(2)* gives a formula for determining the required ventilation rate. The gas expelled from the batteries during charging is hydrogen, which will rise to the ceiling. A ventilation system for an electric vehicle garage with a charging system is illustrated in Figure 14.10. Systems for charging electric vehicles shall have provisions to disconnect power in the event of loss of normal power as stated in *625.25*.

Article 626 provides installation requirements for electrified truck parking spaces. In the interest of curbing sources of air pollution and atmospheric carbon emissions that contribute to global warming, changes are occurring with the long-haul trucking industry. Laws mandate minimum rest time for truck operators, and those rest periods are generally spent in the truck cab or sleeper unit. Power is needed for heating, air-conditioning, and lighting as a minimum, and power for computers and some appliances is also desirable. Generally, power for these services is provided by idling the truck engine. It is not uncommon to consume 10 gallons of fuel or more per rest period. About 10% of truck trailers transport perishable products that require refrigeration. Transport refrigerated units (TRUs) are usually powered with a compression-ignition engine, which also must operate during a rest period. Truck stop electrification (TSE) equipment is rapidly becoming available to provide electrical power for these tasks so that on-board engines are not needed during the resting periods. Long-haul trucks are being produced and retrofitted for connection to electrical power supply units at truck stops. This *Article* provides the basic requirements for the installation of electrical power supply for the truck and transport refrigerated units. This *Article* has been coordinated with manufacturers of truck stop electrification equipment to bring about conformity of equipment across the United States, Canada, and Mexico.

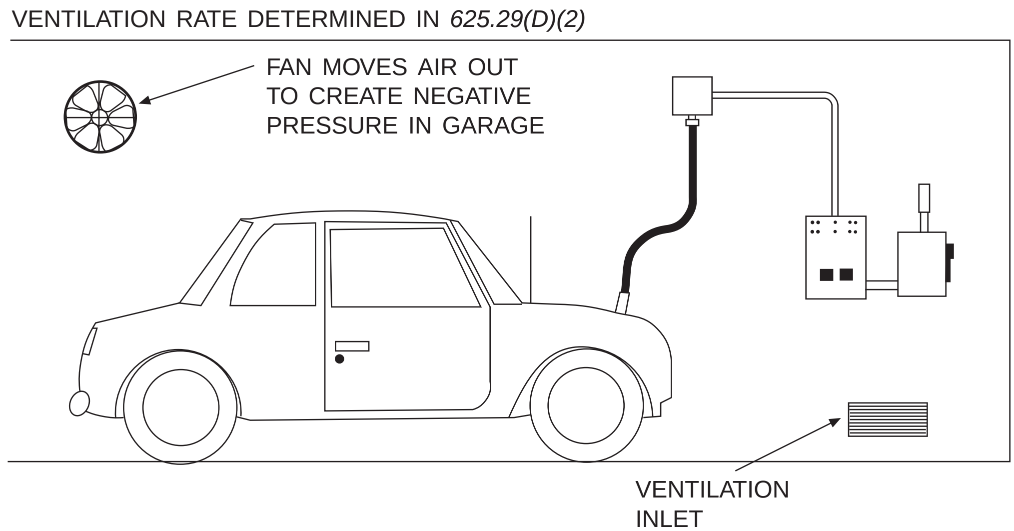


Figure 14.10 Vented batteries in electric vehicles require ventilation when charging occurs in a closed garage.

Electrical systems for supply to the truck are found in *626.10.* Single-phase, 3-wire power is provided to the truck, but it is permitted to originate from a 120/240-volt single-phase system or from a 208/120-volt 3-phase system. Demand information for determining the size of feeders to the individual parking sites is found in *626.11.* Receptacle configurations and ratings along with wiring requirements are provided in *Part III.* Typical service to the truck is from a ground-level pedestal or from an overhead gantry. The overhead gantry system is used with heating, and air-conditioning is provided by a unit at the parking site rather than using the on-board heating and air-conditioning equipment, which requires engine power for operation. Requirements for supplying power to a trailer refrigeration unit are provided in *Part IV.* The refrigeration unit may have dual power sources (engine and electric motor), or it may have an electric motor that is either powered by an on-board engine-generator set or off-board power supply at the parking site.

Article 640 applies to the wiring of sound recording and sound reproduction systems, such as public address systems, and it even applies to sound reproduction systems of electronic organs. The power wiring to the components of a system follow the rules of the Code that apply to the particular type of wiring or type of conditions. The wiring of the amplifier output and similar wiring shall follow the requirements of *Article 725* for Class 2 or Class 3 wiring, whichever applies. When not more than 30 wires are installed in wireways or auxiliary gutters, ampacity derating factors do not apply, and the cross-sectional area of the wires is permitted to fill up to 20% of the cross-sectional area of the wireway or auxiliary gutter.

Audio distribution cables are required to be secured to the structure of the building in such a manner that they will not obstruct normal building operations. These cables are required to be installed according to *300.4* and *300.11.* They are not permitted to be placed on a suspended ceiling. These cables are permitted to be supported by ceiling tie wires that have been installed in addition to the ceiling grid support wires. Accessible portions of abandoned audio distribution cables, according to *640.3(A),* are required to be removed.

Article 650 applies to the circuit wiring for the keyboard of an electrically operated pipe organ and to the controls of the sounding devices. The wiring of electronic organs is to be done following the requirements of *Article 640.* The energy source for electrically operated pipe organs is not permitted to exceed 30 volts and shall originate from a self-excited generator, a rectifier supplied from a two-winding transformer, or a battery. When a motor-generator set is used, the bonding is important to prevent the 120- or 240-volt supply voltage from getting onto the generator output circuit wires which are limited to not more than 30 volts. Either the generator shall be effectively insulated from the motor or they shall be bonded together. The conductor size, insulation, overcurrent protection, and installation of the wiring operating not over 30 volts are specified in this article.

Article 682 provides rules for the safe installation of electrical wiring and equipment in or associated with natural and artificially made bodies of water. Other than electrical equipment installed in lakes, ponds, rivers, and streams, this article includes electrical equipment installed in such artificially made bodies of water as aeration ponds, fish farm ponds, storm retention basins, treatment ponds, and irrigation channels. Key factors are location of equipment and connections above a level where water may enter enclosures. The datum plane must be determined in order to locate equipment. The rules for establishing the datum plane are obvious in many situations, and not so obvious for other bodies of water. The rules for establishing the datum plane are the same as used in *Article 555* for marinas. The disconnect required for the equipment in or on the water is required to be not closer than 5 ft (1.5 m) from the shore or edge of the water. Equipment and connections not rated to be submersible are required to be located not less than 12 in. (300 mm) above the datum plane.

Another aspect of electrical installations associated with electrical equipment in bodies of water is the potential for a person experiencing voltage differences between grounded equipment and the earth. This equipment ground-to-earth voltage is experienced by personnel in the form of step and touch voltages. A person standing on the wet earth and touching metal equipment can experience a touch voltage high enough to receive a mild shock. If the equipment is damaged and is faulting to the earth or water, a serious shock hazard can result. Ground-fault circuit interrupter protection is required in *682.33(B)* for single-phase equipment operating at 120 volts, 208 volts, or 240 volts and protected by a circuit rated not over 60 amperes. For other circuits, GFCI protection is not required. To protect personnel from potentially dangerous step and touch voltages, an equipotential plane is required to be installed at exposed metal equipment such as the disconnect as shown in Figure 14.11. Specifications are not given in the Code for the illustration of the equipotential plane. The equipotential plane can be bare copper wires forming a grid beneath the ground surface, or concrete reinforcing steel mesh can also be used. Covering the area with crushed stone helps keep the standing surface dry. The equipotential plane is required to extend 3 ft (900 mm) beyond the normal standing area of personnel operating or maintaining the equipment shown in Figure 14.12. The equipotential plane is required by *680.33(C)* to be connected to the equipment grounding conductor of the equipment using a copper wire not smaller than size 8 AWG. The connection to the equipotential plane is required to be by means of exothermic welding or a listed pressure connector.

Article 800 deals with the installation of communication circuits, such as telephone wiring within a building. *NEC® 800.1* provides a description of the types of communications circuits covered by this article. Some important terms are described in the FPN to *800.90(A). Part III* of the article deals with the requirements for the installation of a primary protector on the communications circuit at or near the point of entry to a building or structure. Point of entry is defined in *800.2.* The minimum grounding requirements at the primary protector are covered in *800.100.* In the case of a mobile home, the primary protector is permitted to be grounded at the grounding electrode of the mobile home service or disconnecting means, which may be up to 30 ft (9 m) from the mobile home. The grounding requirements at the primary protector when a grounding means is not available are illustrated in Figure 14.13.

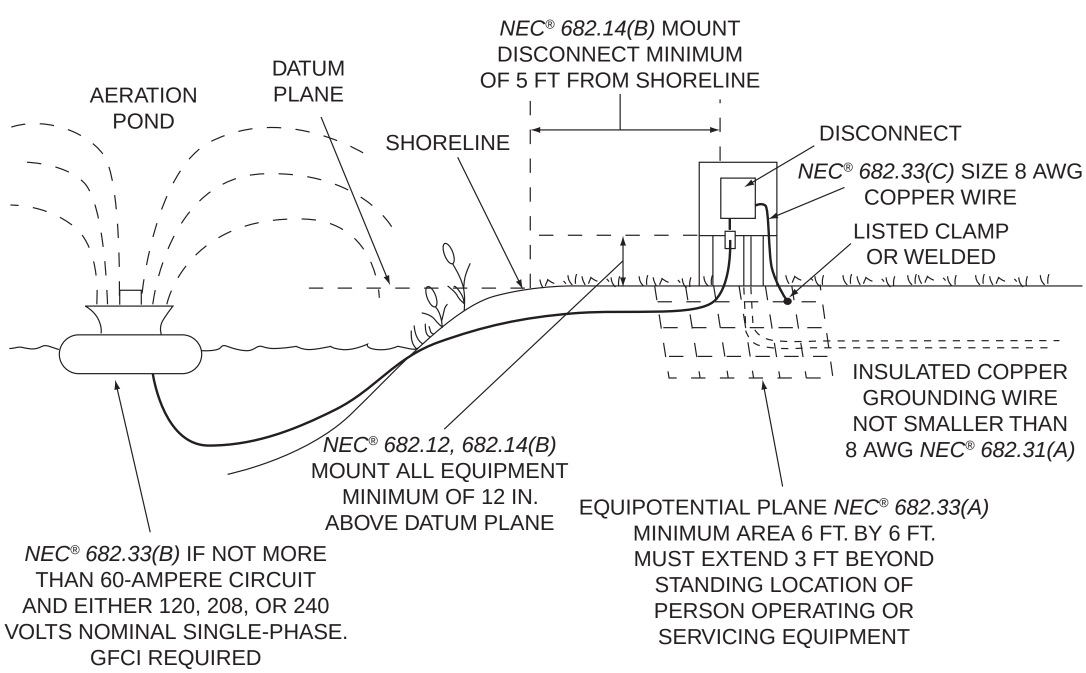


Figure 14.11 A disconnect is required for equipment located on or in a body of water with an equipotential plane installed in the earth around the disconnect to protect personnel from touch and step voltages.

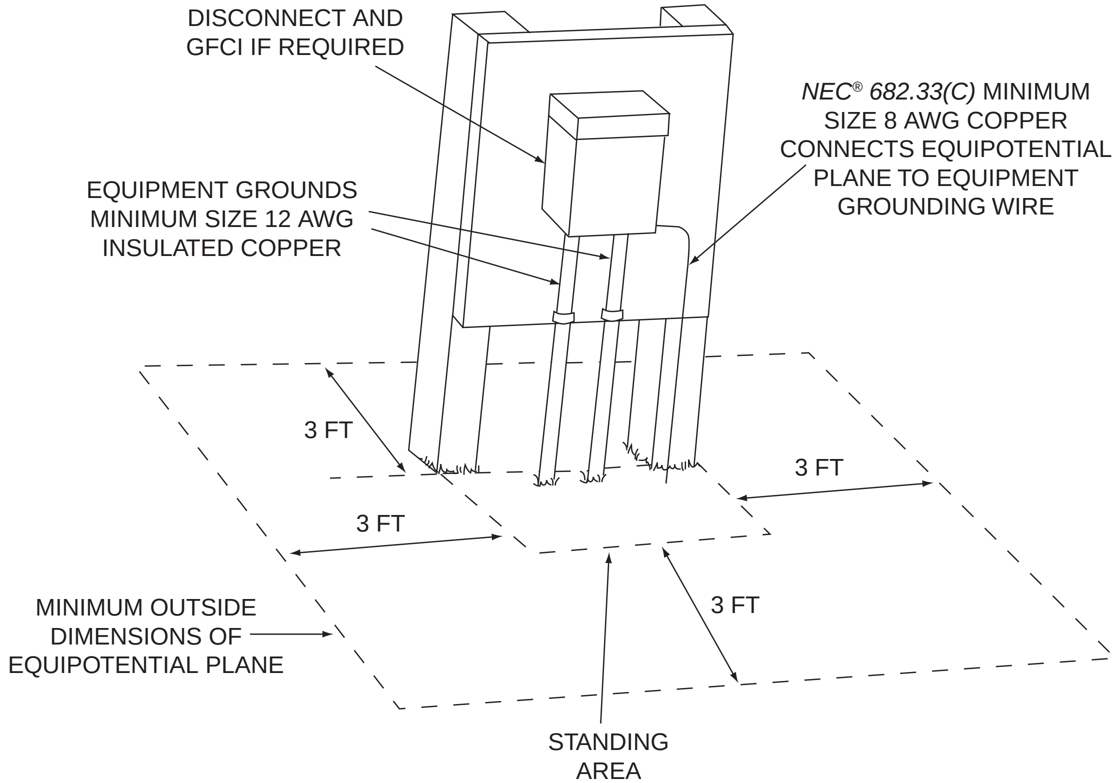


Figure 14.12 An equipotential plane is required to be provided around a disconnect or service supplying power to equipment installed on or in a body of water of a natural or artificially made body of water.

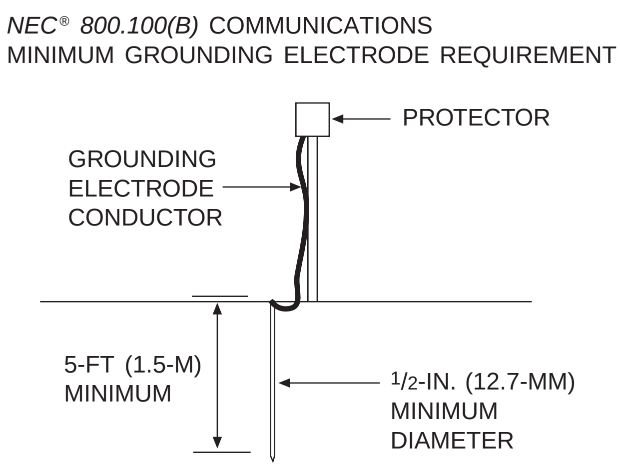


Figure 14.13 The grounding electrode for communication equipment is permitted to be a rod or pipe not less than 1/2 in. (12.7 mm) in diameter and a minimum of 5 ft (1.5 m) in length where there is no grounding means in the building.

Part V provides the requirements for the installation of communications cables on the inside of buildings. It should be noted the requirements of *300.22* are followed when these cables pass through areas where environmental air is contained. The installation of communication conductors outside and entering buildings is covered in *Part II.* A local jurisdiction may have special rules different from the Code. Communications cables used for wiring in buildings are required to be marked as communications cable or a substitute listed in *800.154(E)* or *Figure 800.154(E).* The listings and markings of cables for inside installation are covered in *800.179.* The grounding of the communication equipment, communication cable sheath, and the protector is covered in *Part IV.* There is a provision in *500.24* that requires that communications systems be installed in a neat and workmanlike manner. Also, raceway is not permitted to be used as means of support for communications cables because the conduit is not considered part of the building structure. This is illustrated in Figure 14.14.

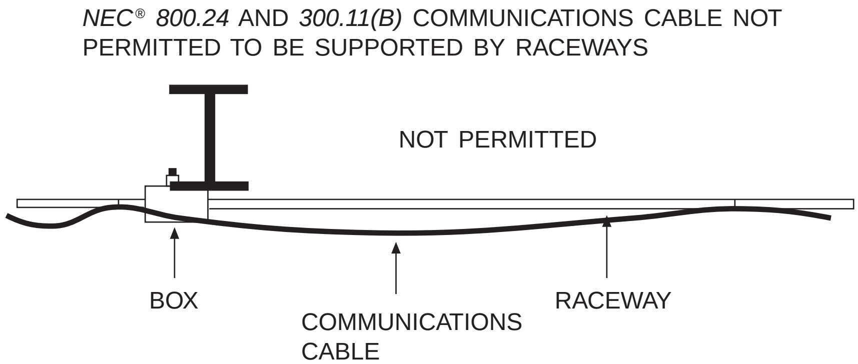


Figure 14.14 Communication cables are not permitted to use raceways as means of support.

Article 810 deals with radio and television receiving equipment and receiving and transmitting equipment used in amateur radio. A point of emphasis is the avoidance of contact between the normal electric circuits for light and power and the antenna and wiring of the radio or television lead-in circuits. The normal power circuits for equipment shall follow the provisions of the appropriate portions of the Code. Specific clearances are given in the article for inside and outside installations. These requirements must be studied carefully before making an installation.

Article 820 covers the installation of coaxial cable for community antenna distribution systems for radio and television. Cables used for these purposes shall be listed for use as community antenna television cable, Type CATV. *NEC® 820.154* lists the specific cable markings required for particular installations. The requirements for installation of the various cable types are covered in *820.113* and *820.179*. The clearances of outside conductors are given in *Part II*. The grounding of the cable, protector, and equipment shall be done following the provisions of *Part IV*.

Article 830 covers wiring requirements for network-powered broadband communications systems. The FPN to *830.1* provides some insight into these systems. Broadband data communication uses a modem to introduce carrier signals onto the transmission system. The carrier signals are modulated by a digital signal. Broadband systems can be subdivided into multiple carrier signals, each carrying a different digitized signal. Broadband operates at the high end of the radio range with frequencies generally between 10 megahertz and 400 megahertz. Multiple carrier signals each transporting a digital signal can operate simultaneously, thus allowing large quantities of digital data to be transported. Teleconferencing including audio, video, and data communication is made possible with a broadband communication system.

MAJOR CHANGES TO THE 2008 CODE

These are the changes to the 2008 *NEC®* that correspond to the Code sections studied in this unit. The following analysis explains the significance of the changes from the 2005 to the 2008 Code only and this analysis is not intended to be used in place of the Code. Refer to the actual section of the 2008 Code for the exact wording and meaning of each section discussed. Changes are indicated in the Code with a vertical line in the margin. If material was deleted or moved to another location in the Code, the location of the deletion is indicated with a dark dot in the margin.

Article 520 Theaters, Audience Areas of Motion Picture and Television Studios, Performance Areas, and Similar Locations

520.2: Solid-state phase-control dimmer is a new definition, but existing equipment is used generally for the control of stage and room lighting. The current is considered a non-linear load with respect to the voltage. This equipment is frequently supplied from a 3-phase, 4-wire, 208/120-volt feeder, and the neutral is required to be considered a current-carrying conductor because even when phase loads are balanced there will be a significant current on the neutral.

520.2: Solid-state sine-wave dimmer is a new definition of a fairly new lighting control device. With this equipment, the output current is considered to be linear with respect to the input voltage, and the phase currents do combine on a common feeder neutral to result in very little neutral current. The result is that feeders supplying these devices are not required to consider the neutral a current-carrying conductor.

520.27(B): The previous edition of the Code considered feeder neutral conductors supplying 3-phase, 4-wire solid-state dimmers to be a current-carrying conductor. Now, if a feeder is installed to supply a solid-state dimmer that is of the 3-phase, 4-wire, 208/120-volt sine-wave type, the feeder neutral is not required to be considered to be a current-carrying conductor. If the dimmer is of the phase-control type or if the dimmer type is not known, then the 3-phase, 4-wire neutral is to be considered to be a current-carrying conductor.

520.51: This section specifies the wiring to the portable switchboards and power distribution equipment that is likely to supply solid-state dimmers. The previous edition of the Code required the neutral of a 3-phase, 4-wire feeder to be considered a current-carrying conductor. Now, the rules of *520.27(B)* apply, which means in some cases the feeder neutral may not be required to be considered a current-carrying conductor. See also the discussion of the change to *518.5* in *Unit 13*.

520.53(O)(2): This section provides rules for feeders to supply equipment on performing stages and the construction of the switchboard equipment itself. The change is with respect to the sizing of the feeder neutral conductor. The previous edition of the Code required the neutral to be a current-carrying conductor in all cases where a solid-state dimmer was to be supplied. If a feeder supplies a solid-state sine-wave dimmer, the neutral conductor of a 3-phase, 4-wire, 208/120-volt feeder is not required to be considered a current-carrying conductor for the purposes of ampere rating adjustment.

Portable stage equipment with solid-state dimmers are often supplied with feeders consisting of single conductor cables. For a 208/120-volt, 3-phase, 4-wire feeder, it takes five single cables, three phase conductors, a neutral, and an equipment grounding cable. These are large-size, multi-stranded flexible cables with pin-and-sleeve connectors for this application. Run as separate cables in the open across a flat surface exposed to free air movement, these cables generally are not subject to overheating, and ampere rating adjustment is not a factor, except in the case of the neutral, which usually carries significant current because it is supplying only phase to neutral loads when feeding a solid-state dimmer and harmonic currents are usually present. This is why the neutral is required to have an ampere rating of 130% of the phase-conductor ampere rating when single-conductor cables supply a solid-state dimmer. When installed in raceway, all of the conductors are subject to an ampere rating adjustment. The change in this section is that in the case where the neutral is run as a single conductor and is supplying a solid-state sine-wave dimmer, the ampere rating of the neutral is permitted to be the same (100%) as the phase conductor ampere rating.

Article 522 Control Systems for Permanent Amusement Attractions

522.1: This is a new *Article* dealing with power sources and control circuit wiring for permanently installed amusement attractions. There are some unique applications that are not covered in the Code, which in the past generally used *Article 725* as the standard for this control wiring. This *Article* sets some basic limits for the wiring of these control systems.

522.5: Voltages on control circuits for permanent amusement attractions is limited to 150 volts to ground ac and 300 volts to ground dc.

522.7: These control systems are accessible only to qualified personnel.

522.10(A): The rated output of a power-limited source is not permitted to exceed 1000 volt-amperes with a maximum of 30 volts. For a Class 2 circuit, the limit is 100 volt-amperes.

522.10(A)(2): For a power-limited source other than a transformer, overcurrent protection is required to be provided. The overcurrent protection is not to exceed 167% of the power source current rating determined by dividing the power-source volt-ampere rating by the rated output voltage. Type S non-interchangeable fuses shall be used to protect the output of these power sources.

522.10(B): Non–power-limited sources do not have a maximum volt-ampere limitation, but they do have a maximum limitation of 300 volts. This section does not specify whether the 300 volts is line-to-line or line-to-ground.

522.10(B)(2): All non–power-limited sources are to be protected from overcurrent with devices that have a rating not exceeding 125% of the volt-ampere rating of the source divided by the maximum output voltage of the source. These overcurrent devices are to be Type S non-interchangeable. There is no exception to permit rounding up to the next standard size.

522.20: Control conductors are to be stranded or solid copper and insulated. Exceptions are busbars, slip rings, and special purpose devices such as thermocouples that measure temperature, and resistive thermal devices (RTDs) that also measure temperature.

522.21: Control conductors are permitted to be sizes 30 AWG and larger with the maximum permitted ampere rating of the conductors listed in *Table 522.22*. Conductor sizes smaller than 26 AWG are only permitted within enclosures and control stations. If a part of a listed cable assembly is run outside enclosures, the conductors are not permitted to be smaller than 26 AWG. If run outside enclosures as individual conductors, the minimum size is 18 AWG.

522.23: Conductors are required to be provided with overcurrent protection not exceeding their ampere rating, as given in *Table 522.22* or *Table 310.16*.

522.24(A): Multiple control circuits are permitted to share the same raceway, cable tray, cable, or enclosure whether ac or dc.

522.24(B): Control circuits are permitted to share the same cable, raceway, cable tray, or enclosure with power wires that are functionally associated.

Article 525 Carnivals, Circuses, Fairs, and Similar Events

525.2: A definition of portable structure was added that includes amusement rides, attractions, tents, trailers, and even trucks. The previous edition of the Code made reference to amusement rides and attractions, which was a narrower category than portable structures.

525.5(B): This section specifies minimum clearances for overhead conductors. The previous edition of the Code only mentioned amusement rides and attractions, and the term portable structures includes a much broader range of equipment for which minimum overhead clearances must be maintained.

525.11: The previous edition of the Code stated that for portable structures supplied from separate electrical supplies and located less than 12 ft (3.7 m) apart, the electrical systems were required to be bonded to the same grounding electrode system. Now, the requirement is that the separate equipment grounding conductors are to be bonded together at the portable structures as shown in Figure 14.15. Further, the bonding conductor is to be copper and sized using *Table 250.122* based upon the highest rated overcurrent device serving the portable structures. The minimum size in any case is 6 AWG.

Article 547 Agricultural Buildings

547.5(G): The previous edition of the Code requires every general-purpose receptacle supplied by a 15- or 20-ampere, 125-volt branch circuit to be provided with GFCI protection. If such a receptacle is provided at a location for specific-purpose equipment, it was not to be considered a general-purpose receptacle. The change is that now a receptacle supplied from a 15- or 20-ampere, 125-volt circuit that is accessible and provided for a specific load is permitted to have GFCI protection omitted only if there is a GFCI protected receptacle located within 3 ft (900 mm).

547.9: A new sentence was added to make it clear that the electrical distribution point that supplies power to agricultural buildings is also permitted to supply power to other buildings on the same premises that are not considered to be agricultural buildings, as described in *547.1*. Examples would be a dwelling, shop, or machine storage building.

547.9(A)(10): A site-isolating device is located at a central electrical distribution point and consists of a disconnect switch or a transfer switch that serves both as a disconnect and as a connection to an optional

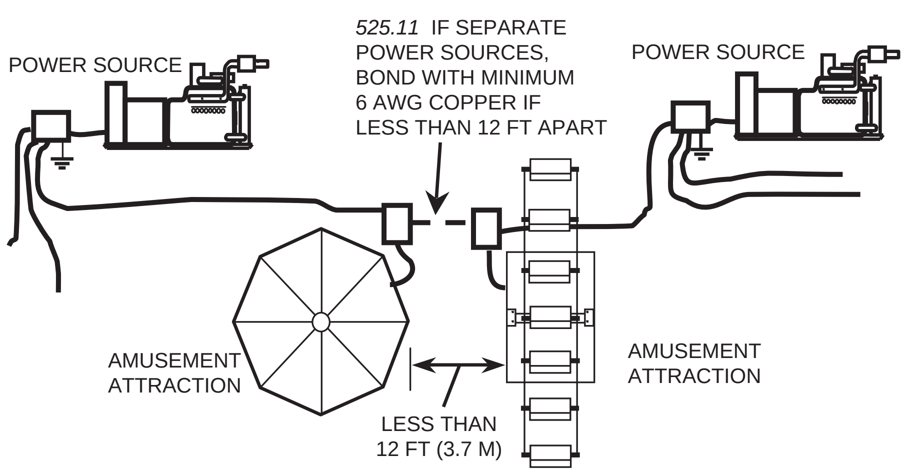


Figure 14.15 When two portable structures such as amusement rides are supplied from separate power sources and located less than 12 ft (3.7 m) from each other, a bonding jumper is required to be run between the equipment grounding conductors supplying each portable structure and sized not smaller than 6 AWG copper.

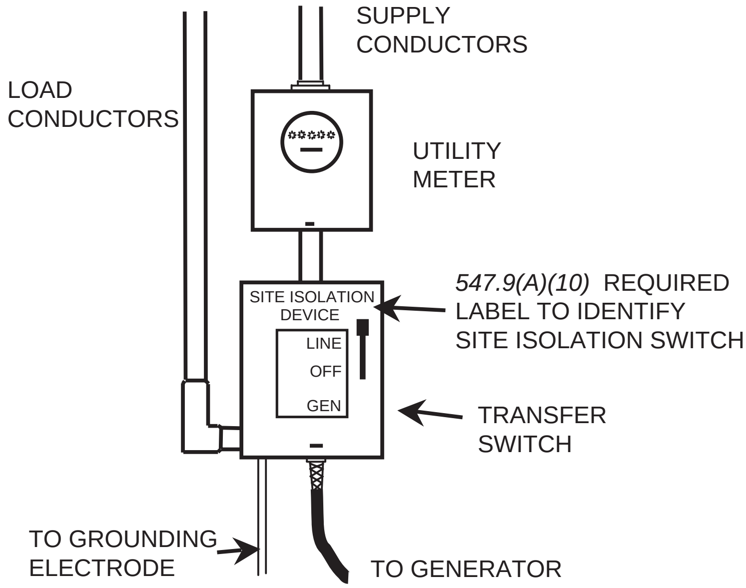


Figure 14.16 The disconnecting means at the central distribution point serving agricultural buildings is known as the site-isolating device, and it is now required to be labeled on the front of the enclosure as the site-isolating device.

standby power system. Overcurrent protection is not required to be part of or located adjacent to the site-isolating device. The change is that this site-isolating device is now required to be marked to identify it as the site-isolating device, such as shown in Figure 14.16. This can be in the form of a label on the front of the enclosure that will withstand the elements.

547.9(B)(3): Supplying electrical power to buildings from a central distribution point with a site-isolating device is considered similar to supplying power from one building to another on the same premises. The rules for installing those feeders is found in *250.32*, is described in detail in *Unit 5*, and is illustrated in Figure 5.5. The previous edition of the Code permitted feeder neutral to also serve as the equipment-grounding conductor and in such a case was required to be bonded to the building disconnect enclosure and to a grounding electrode at the second building. According to *250.32*, that procedure is no longer permitted, except for existing buildings. This change means that feeders to new buildings require a separate neutral conductor and equipment-grounding conductor. The neutral conductor is not permitted to be bonded to the second building disconnect enclosure and not permitted to be connected to a grounding electrode, as illustrated in Figure 14.6. The equipment-grounding conductor is required to be connected to a grounding electrode. The feeder neutral is permitted to serve as the equipment-grounding conductor only for existing buildings.

547.9(E): In the case where the site is served with more than one type of electrical service and those services are located not more than 500 ft (150 m) apart, a directory is required to be provided at each service to indicate the location of any other service disconnecting means. An example may be a farm served with 120/240-volt, single-phase power from a central distribution point, and also a separate 3-phase service to one or more buildings.

Article 555 Marinas and Boatyards

555.9: Conductor splices in conductors are now permitted below the datum plane and above the water line where made in approved junction boxes using sealed wire connector systems identified for submersion.

555.21(B): Previous editions of the Code did not provide specific dimensions for the classification of hazardous areas near fuel dispensers. Reference was made to *Article 514* and *NFPA* document *303*. Now, there are specific dimensions that describe the classified areas. One case is a dock, pier, or wharf that is solid to the waterline with no open space underneath between the dock, pier, or wharf and the waterline. In this case, the Class I, Division 2 area is that area within 18 in. (450 mm) horizontally of the edge of the dispenser and the area up to 18 in. (450 mm) above the surface of the dock, pier, or wharf extending out from the dispenser a distance of 20 ft (6 m). The other case is where there is open space between the bottom of the dock, pier, or wharf and the waterline. In that case, the Class I, Division 2 area is measured to a height of 18 in. (450 mm) above the surface of the dock, pier, or wharf and extending out from the dispenser a distance of 20 ft (6 m). If the 20 ft (6 m) distance extends out over the water, then the Class I, Division 2 area extends down to the waterline. Any depression, pit, or chase located in the dock, pier, or wharf within the Class I, Division 2 area where flammable vapors may accumulate is considered to be a Class I, Division I area. There are some exceptions that apply to dock, pier, and wharf sections that may join these areas in such a manner that flammable vapors will not accumulate, and thus they are considered unclassified areas.

Article 625 Electric Vehicle Charging System

625.23: In the case of an electric vehicle charging system rated more than 60 amperes or more than 150 volts to ground, the disconnecting means is required to be in a readily accessible location and capable of being locked in the open position. The change is that the locking means shall be of a type that will remain in position with the lock removed. Portable means of locking the switch or circuit breaker in the open position is no longer permitted.

Article 626 Electrified Truck Parking Spaces

626.1: This *Article* provides standardized rules for the installation of electrical equipment at truck parking spaces to supply power for heating, air-conditioning, lighting, appliances, and communications, and for power to refrigerated trailers known as transport refrigerated units or TRUs. A sample installation with a truck supplied from a pedestal is shown in Figure 14.17.

626.4(B): Nominal ac electrical systems that may be available at a truck parking space are 120-volt, single-phase, 2-wire, 120/240-volt, single-phase, 3-wire, 208/120-volt, single-phase, 3-wire from a 4-wire 3-phase system, 240-volt, 3-phase, 3-wire, and 480/277-volt, 3-phase, 4-wire.

626.10: Power to the truck is to be single-phase, 3-wire derived from a 3-phase 208/120-volt, 4-wire system or from a single-phase 120/240-volt, 3-wire system. Single-phase, 2-wire, 120-volt service is only permitted for existing electrified truck parking spaces.

626.11(A): For the purpose of determining the size of the service and feeders to supply truck parking spaces, a minimum demand load of 11 kVA is required for each parking space.

626.11(B): A demand factor is permitted to be applied to the truck parking space load, depending upon the geographic location. The demand factors are given in *Table 626.11(B);* however, it is necessary to determine the climatic temperature zone for the area where the truck parking facility is to be located. To find this climatic temperature zone, it is necessary to look at the climatic temperature zone map published by the *UDSA*. This map can be found on the internet. For example, St. Louis is zone 6a. From *Table 626.11(B)*, the demand factor is 39%. If a feeder were to supply 10 electrified truck parking spaces, the minimum feeder demand load would be 179 amperes (11,000 VA $\times$ 10 sites $\times$ 0.39 divided by 240 volts = 179 amperes).

626.22(A): An electrified truck parking space is permitted to be supplied by means of equipment mounted to a pedestal, a raised concrete pad, or by means of an overhead gantry.

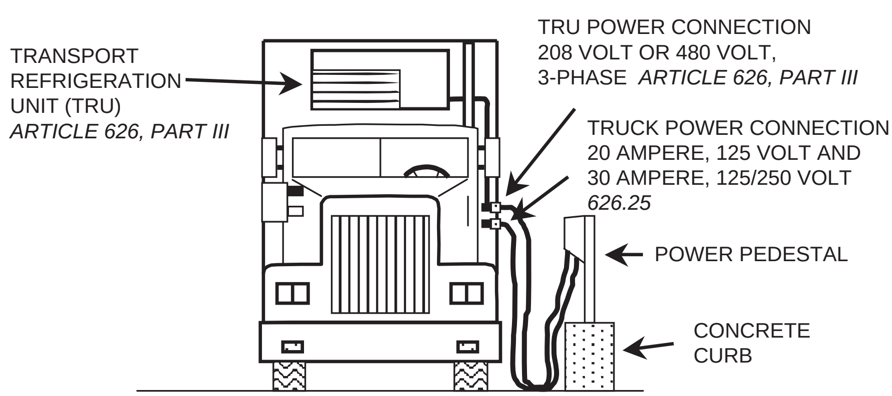


Figure 14.17 Electrified truck parking spaces are permitted to be supplied with power for heating, air-conditioning, lighting, and appliances in the cab and sleeper, and also power for operation of a refrigerated trailer unit.

626.23(B): When a supply cable originates from an overhead gantry, a means of strain relief is required that will disconnect power to the cable if sufficient strain is detected that could cause damage.

626.24(B): All electrified truck parking space equipment shall provide a minimum of two receptacles rated 20-ampere, 125-volts and connected to an individual branch circuit. If the space does not provide air-conditioning without electrical connection to the truck, then a 30-ampere, single-phase, 125/250-volt, 4-pole grounding receptacle shall be provided. The receptacle is permitted to be supplied from a 120/240-volt, 3-wire, single-phase feeder, or from a 208/120-volt feeder.

626.24(C): Means of disconnecting power to the electrified truck parking site receptacles by means of a circuit breaker or switch. This disconnecting means is required to be capable of being locked, and it must be in a readily accessible location.

626.24(D): Electrified truck parking space receptacles are required to be provided with ground-fault circuit-interrupter protection.

626.25: Required listed power supply cable assemblies for connection of power from the site receptacles to the truck are described in this section. There are 20-ampere, 125-volt, 2-wire with equipment grounding wire cord assemblies, and 30-ampere, 125/250-volt, 3-wire, with equipment grounding wire cord assemblies.

Part IV: Rules for supplying power to a transport refrigerated unit (TRU) are provided. Power supply, receptacles, and cable assemblies to operate refrigeration units are either 30-ampere, 480-volt, 3-phase, 3-pole, 4-wire, or 60-ampere, 208-volt, 3-phase, 3-pole, 4-wire. In either case, the electrical supply is to be grounded.

Article 640 Audio Signal Processing, Amplification, and Reproduction Equipment

640.6(B): Cable ties are now specifically listed as an acceptable means of supporting and securing audio distribution cables.

640.6(D): Audio distribution cables intended for future use are to be durably marked with the date of marking, date of intended use, and the intended use.

Article 682 Natural and Artificially Made Bodies of Water

682.13: The rules are more specific as to the types of wiring methods permitted to be installed for supply to electrical equipment associated with natural and artificially made bodies of water. Flexible wiring methods Liquidtight Flexible Metal Conduit and Liquidtight Flexible Nonmetallic Conduit with approved fittings are the only types permitted for feeders and services. Where flexibility is required for feeders and branch circuits, extra-hard usage portable power cable, as described in *Table 400.4*, is the only type of flexible cable permitted. The cable must be listed for wet locations and be sunlight resistant. Types listed in *Table 400.4* that meet these requirements are Type W, Type PPE, Type G, and Type G-GC. Other non-flexible wiring methods suitable for the conditions as described in *Chapter 3* are permitted. It is made clear that temporary wiring methods described in *590.4* are only permitted for temporary installations.

Article 800 Communications Circuits

800.24: Cable ties are now included in the list of acceptable means of supporting communications cable to the structure of the building.

800.25: Cables that are taken out of service and intended for future use, or cables that are installed for future use, are now required to be durably labeled as cables for future use.

800.26: Communications cables and raceways that penetrate a fire-resistant–rated wall, partition, floor, or ceiling are required to be firestopped using approved materials.

800.48: Unlisted communications cables are permitted to enter buildings; however, they must be terminated within 50 ft (15 m) of the point of entry to the building.

800.83(B): This is a new paragraph that permits communications cables with a metallic sheath and terminated on the outside of a building to either have the sheath connected to a grounding electrode or fitted with an insulating joint. The previous edition of the Code did not cover the situation where the cable was terminated on the outside of the building.

800.100(B)(1): If the electrical service installation for the building has an intersystem bonding terminal, then the communications system grounding conductor is required to be connected to the intersystem grounding terminal.

800.156: For new construction of a dwelling, a minimum of one communications outlet is required to be installed and cabled to the point where the communications cable will enter the building from the service provider.

800.179: Communications wires and cables are now required to have an insulation rating of not less than 300 volts; however, the voltage is not to be marked on the cable unless the cable is dual rated where one of the applications requires the voltage to be printed on the cable.

Article 810 Radio and Television Equipment

810.21(F)(1): If the electrical service installation for the building has an intersystem bonding terminal, then the antenna system grounding conductor is required to be connected to the intersystem grounding terminal.

Article 820 Community Antenna Television and Radio Distribution Systems

820.24: Cable ties are now included in the list of acceptable means of supporting coaxial cables to the structure of the building.

820.25: Cables that are taken out of service and intended for future use, or cables that are installed for future use, are now required to be durably labeled as cables for future use.

820.26: Coaxial cables and raceways that penetrate a fire-resistant–rated wall, partition, floor, or ceiling are required to be firestopped using approved materials.

820.48: Unlisted coaxial and CATV cables are permitted to enter buildings; however, they must be terminated within 50 ft (15 m) of the point of entry to the building.

Article 830 Network-Powered Broadband Communications Systems

830.24: Cable ties are now included in the list of acceptable means of supporting network-powered broadband cables to the structure of the building.

830.25: Cables that are taken out of service and intended for future use, or cables that are installed for future use, are now required to be durably labeled as cables for future use.

830.26: Network-powered broadband cables and raceways that penetrate a fire-resistant–rated wall, partition, floor, or ceiling are required to be firestopped using approved materials.

830.100(B)(1): If the electrical service installation for the building has an intersystem bonding terminal, then the network-powered broadband system grounding conductor is required to be connected to the intersystem grounding terminal.

830.106: Special problems are created when network-powered broadband cables enter a mobile home where the service does not meet the requirements of *Article 550.* This new section provides procedures for providing grounding.

WORKSHEET NO. 14—BEGINNING SPECIAL APPLICATIONS WIRING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. The minimum copper conductor size permitted to supply an outlet for an arc or xenon projector in the projection room of a theater is:
   A. 14 AWG.
   B. 12 AWG.
   C. 10 AWG.
   D. 8 AWG.
   E. not specified in the Code.

   Code reference ___________________

2. A 30-ampere, locking-type grounding receptacle outlet is used to supply shore power to a boat at a marina. A disconnecting means shall be readily accessible and located so that the distance from the disconnect to the receptacle it controls is not more than:
   A. 6 ft (1.8 m).
   B. 10 ft (3 m).
   C. 24 in. (600 mm).
   D. 30 in. (762 mm).
   E. 50 ft (15 m).

   Code reference ___________________

3. A dimmer is to be installed for a bank of lights for a theater stage. The circuit originates from a fixed stage switchboard. Unless listed for a higher voltage, a solid-state dimmer shall not be permitted to be used on a circuit where:
   A. the voltage between conductors exceeds 150 volts.
   B. the voltage to ground exceeds 150 volts.
   C. the voltage between conductors exceeds 300 volts.
   D. the voltage to ground exceeds 300 volts.
   E. higher than 200 watt lamps are to be dimmed.

   Code reference ___________________

4. The permanent power wiring for a commercial television studio where there are no provisions for an audience may include all the wiring methods listed below except:
   A. Type MI Cable.
   B. Type AC Cable with insulated equipment ground.
   C. Type UF Cable.
   D. Type MC Cable.
   E. approved raceway.

   Code reference ___________________

5. A metal grid of welded steel rods is installed in the concrete floor of a barn where dairy cows are to be milked and the grid is welded to the metal support poles for the equipment in the barn. This metal grid in the concrete floor is required to be bonded to the building electrical grounding system with copper wire not smaller than size:
   A. 10 AWG.
   B. 8 AWG.
   C. 4 AWG.
   D. 2 AWG.
   E. 2/0 AWG.

   Code reference ___________________

6. In an area of an agricultural building having an equipotential plane installed, general use receptacles installed on 15- and 20-ampere, 125-volt circuits are required to be:

A. only grounding-type receptacles.
B. tamper-proof.
C. arc-fault protected.
D. listed for hazardous locations.
E. ground-fault circuit-interrupter protected for personnel.

Code reference ___________________

7. As shown in Figure 14.18, a 125-volt, 20-ampere, ground-fault circuit-interrupter receptacle is mounted on a floating pier. The purpose of this receptacle is for general use, not for shore power to boats. The minimum mounting height of the receptacle is:
   A. 30 in. (762 mm) above the high water level.
   B. 24 in. (600 mm) above the datum plane.
   C. 24 in. (600 mm) above the deck of the pier.
   D. 12 in. (305 mm) above the deck of the pier.
   E. 12 in. (305 mm) above the datum plane.

Code reference ___________________

8. Unless listed otherwise, the coupling means for an electrical vehicle supply equipment, installed indoors, shall be located at a height above the floor not to exceed:
   A. 24 in. (600 mm).
   B. 4 ft (1.2 m).
   C. 5 ft (1.5 m).
   D. 6 ft (1.8 m).
   E. 8 ft (2.5 m).

Code reference ___________________

9. Telephone cable is run from outlet to outlet in a one-story commercial building. The type of cable permitted for this application, but not permitted to be used as a riser or in air handling spaces without being run in raceway is Type:
   A. CM.
   B. CMX.
   C. CMP.
   D. CMR.
   E. CMP-50.

Code reference ___________________

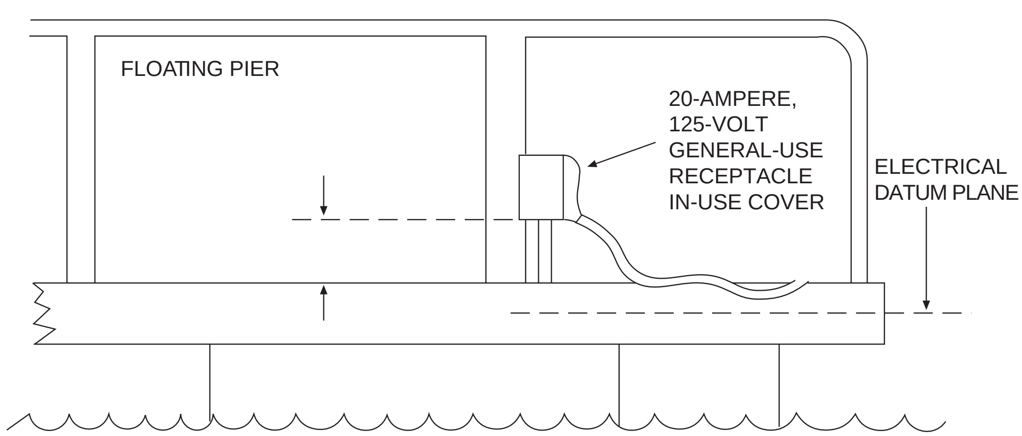


Figure 14.18 A general-use, 125-volt 20-ampere, ground-fault circuit-interrupter receptacle is mounted above a floating pier.

10. A television antenna is placed on a tower for a single-family dwelling. It is grounded to an 8 ft (2.5 m) ground rod placed at the base of the footings for the tower. A bonding jumper is required to connect the antenna's grounding electrode to the building's electrical grounding system as shown in Figure 14.19. This copper bonding jumper is not permitted to be smaller than size:
    A. 10 AWG.
    B. 8 AWG.
    C. 6 AWG.
    D. 4 AWG.
    E. the size based upon *Table 250.66.*

    Code reference ___________________

11. A minimum spacing between community antenna system coaxial cables and conductors used for lightning protection where practical shall not be less than:
    A. 10 ft (3 m).
    B. 6 ft (1.8 m).
    C. 5 ft (1.5 m).
    D. 12 in. (300 mm).
    E. 4 in. (100 m).

    Code reference ___________________

12. Direct buried network powered broadband cable is run underground from one building to another at a commercial site. The conductors are installed in a trench without raceway protection, nor is it protected with any concrete placed above the cable. If the cable does not pass under a driveway the minimum depth of burial is:
    A. 6 in. (150 mm).
    B. 12 in. (300 mm).
    C. 18 in. (450 mm).
    D. 24 in. (600 mm).
    E. not specified in the Code.

    Code reference ___________________

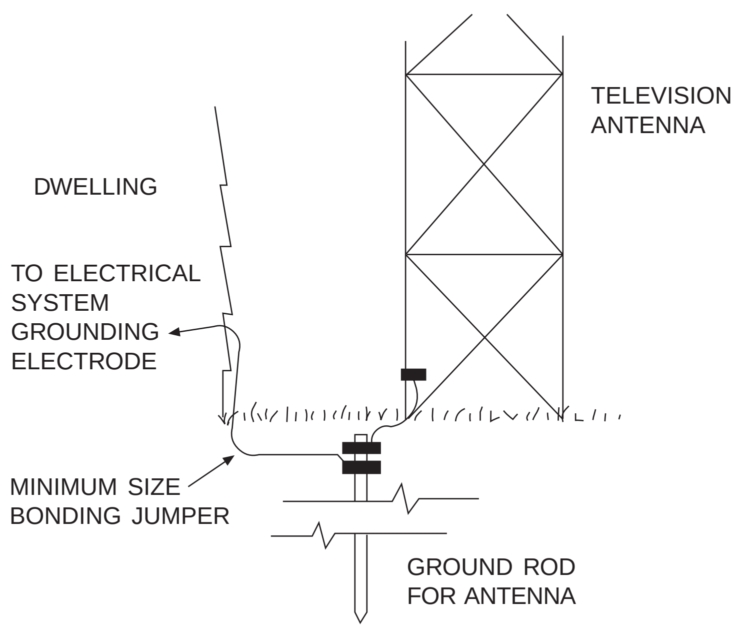


Figure 14.19 Bonding a television antenna grounding electrode to the electrical system grounding electrode at a dwelling.

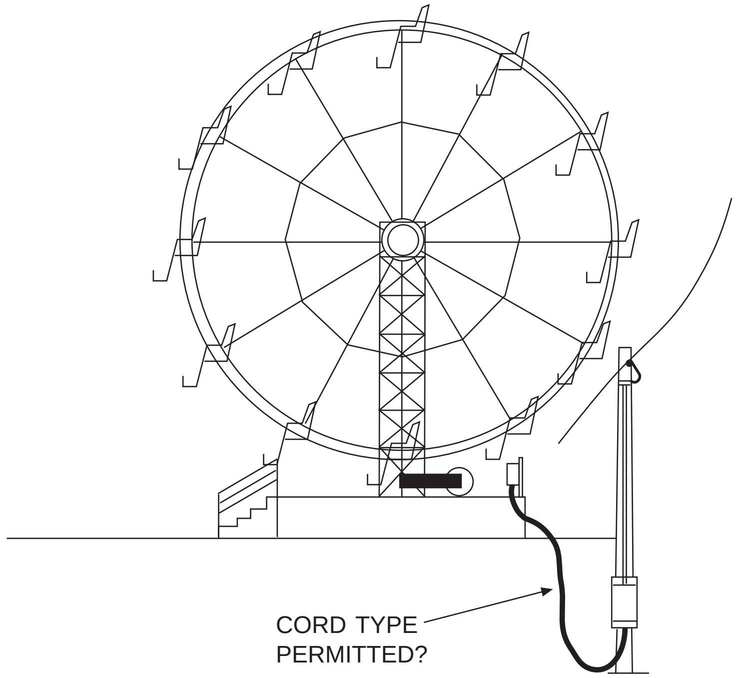


Figure 14.20 An amusement park ride is supplied with a flexible cord for temporary power.

13. An amusement park ride is temporarily placed on a site for a week during a carnival. From the disconnecting means to the ride a flexible cord is installed, as shown in Figure 14.20. This flexible cord that supplies temporary power to the ride shall be sunlight-resistant, listed for wet locations, and be:
    A. listed for the purpose and may only be used as permanent wiring on the ride.
    B. extra-hard usage, unless arc-fault circuit-interrupter protected, then hard-usage cords are permitted.
    C. hard-usage and must be sunlight-resistant.
    D. extra-hard usage, unless ground-fault circuit-interrupter protected, then hard-usage cords are permitted.
    E. extra-hard usage, unless located in an area not subjected to physical damage, then hard-usage cords are permitted.

    Code reference ___________________

14. A group of control wires to electric pipe organ electromagnetic sounding devices mounted on a common frame is permitted to have a common copper return conductor not smaller than size:
    A. 14 AWG.
    B. 18 AWG.
    C. 20 AWG.
    D. 26 AWG.
    E. 28 AWG.

    Code reference ___________________

15. When installed in an agricultural building that houses livestock, the wiring material that is not permitted be installed is:
    A. jacketed Type MC Cable.
    B. Rigid Nonmetallic Conduit.
    C. Liquidtight Flexible Nonmetallic Conduit.
    D. Type UF Cable.
    E. Type AC Cable with an insulated equipment ground.

    Code reference ___________________

WORKSHEET NO. 14—ADVANCED SPECIAL APPLICATIONS WIRING

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A metal auxiliary gutter contains only Class 3 wires of a public address system for a building and no power supply wires, and it is permitted to be grounded to a common ground for the public address system with a copper wire not required to be larger than size:
   A. 14 AWG.
   B. 12 AWG.
   C. 10 AWG.
   D. 8 AWG.
   E. not specified in the Code.

   Code reference__________________

2. A group of control wires to electric pipe organ sounding devices mounted on a common frame are permitted to have a common copper return conductor that:
   A. shall have an overcurrent device that is rated not more than 6 amperes.
   B. shall be ground-fault circuit-interrupter protected.
   C. shall have an overcurrent device that is rated not more than 2 amperes.
   D. requires raceway protection.
   E. is not required to have overcurrent protection.

   Code reference__________________

3. Egress lighting at a carnival shall:
   A. not be ground-fault circuit-interrupter protected.
   B. have a disconnecting means within 6 ft (1.8 m) of each lighting source.
   C. be ground-fault circuit-interrupter protected.
   D. be connected to two sources of power, emergency and normal, through the use of a transfer switch.
   E. be arc-fault circuit-interrupter protected, when accessible.

   Code reference__________________

4. At an outdoor location, a temporary stage is assembled for a concert. The wiring methods for this performance area shall be according to the requirements of:
   A. *Article 527.*
   B. *Article 525.*
   C. *Article 520.*
   D. *Article 518.*
   E. *Article 590.*

   Code reference__________________

5. Cables used to supply stage set lighting for a television studio shall be protected with an overcurrent device set at no higher than the ampacity of the conductors taken at:
   A. 100%.
   B. 125%.
   C. 175%.
   D. 200%.
   E. 400%.

   Code reference__________________

6. A motion picture projector that is installed in a permanently constructed projection room shall have a working clearance on the sides and rear of the projector of not less than:
   A. 12 in. (300 mm).
   B. 18 in. (450 mm).
   C. 24 in. (600 mm).
   D. 30 in. (750 mm).
   E. 36 in. (900 mm).

   Code reference__________________

7. An agricultural building is supplied single-phase, 120/240-volt power from a 400-ampere rated pole-top disconnect that does not contain overcurrent protection. The conductors to the building are overhead aluminum with 75°C insulation and terminations, as shown in Figure 14.21. The conductors supply a panelboard that contains a 200-ampere main circuit breaker. The overhead ungrounded conductors are size 3/0 AWG aluminum. The overhead conductors consist of two ungrounded conductors, an insulated neutral, and a bare equipment grounding conductor. The neutral is not grounded at the agricultural building. The minimum aluminum size overhead equipment grounding conductor permitted is:
   A. 6 AWG.
   B. 3 AWG.
   C. 2 AWG.
   D. 3/0 AWG.
   E. not specified in the Code.

   Code reference ___________________

8. A disconnecting means that is capable of being locked in the open position is required for an electric vehicle charging system with a rating of more than 150 volts-to-ground or rated at more than:
   A. 30 amperes.
   B. 50 amperes.
   C. 60 amperes.
   D. 70 amperes.
   E. 100 amperes.

   Code reference ___________________

9. An equipotential plane:
   A. is required to have a voltage transition ramp where animals enter and exit from the plane.
   B. is required in all concrete floors in livestock confinement areas where metal electrical equipment is accessible to the livestock.
   C. requires the bonding of slats for a slatted flooring system.
   D. must be installed in wash rooms where milking equipment is washed.
   E. is required in all areas where the surface the livestock are confined on is dirt.

   Code reference ___________________

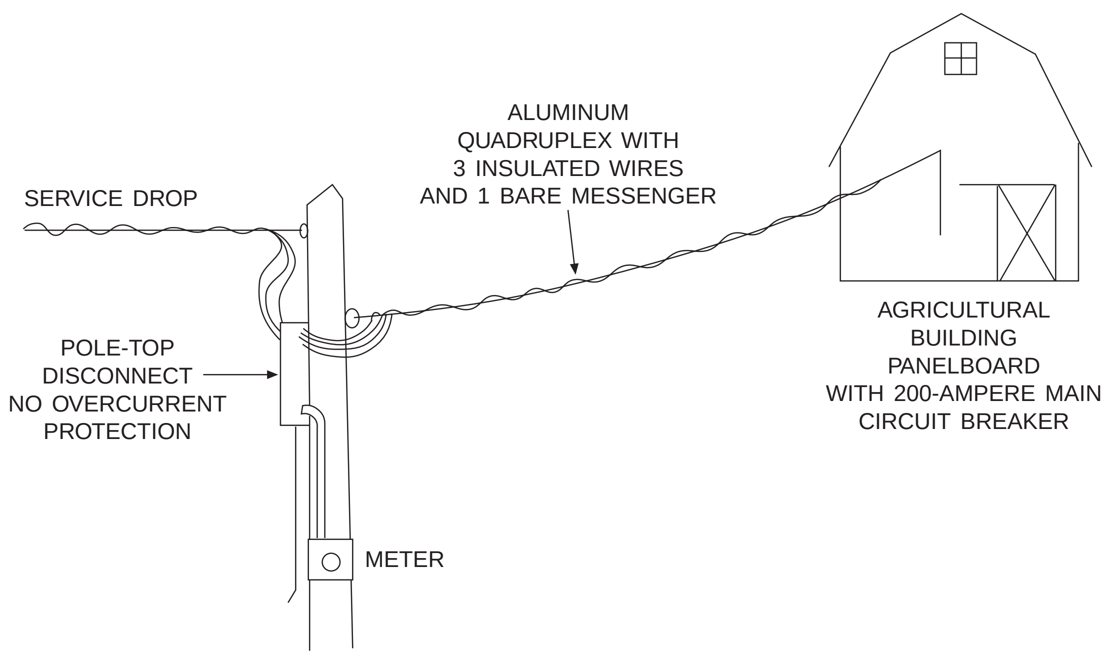


Figure 14.21 Aluminum quadruplex supplies an agricultural building from a pole-top disconnect that contains no overcurrent protection.

10. The receptacles installed adjacent to the mirror and above the dressing tables of a dressing room of a theater are required to be:
    A. arc-fault interrupter protected.
    B. ground-fault circuit-interrupter protected.
    C. controlled by a wall switch located in the dressing room.
    D. controlled by a wall switch located outside and adjacent to the door.
    E. provided with a pilot light at each receptacle.

Code reference ___________________

11. A wiring method not permitted to be used for power circuits in a movie theater, which is run as surface wiring and in wall and ceiling cavities, is:
    A. Type AC Cable with an insulated equipment grounding conductor.
    B. Type UF Cable with an insulated equipment grounding conductor.
    C. Electrical Metallic Tubing.
    D. Rigid Nonmetallic Conduit encased in 2 in. (50 mm) of concrete.
    E. Type MC Cable.

Code reference ___________________

12. A mast or metal supporting structure for a television antenna or a satellite receiving dish is required to be grounded to limit the damaging effects of high voltage surges. When grounding this equipment it is:
    A. not required to protect the grounding conductors when exposed to physical damage.
    B. permitted to ground this equipment by connecting onto the grounding electrode conductor for the service to the building.
    C. only permitted to install the grounding electrode conductor outdoors.
    D. required to use either insulated or covered conductors.
    E. necessary to install an individual grounding electrode, such as a ground rod, for this equipment.

Code reference ___________________

13. CATV Cable from a community antenna system is installed underground to a single-family dwelling. An additional grounding electrode is required to be installed when the grounding electrode conductor connecting the shield of the cable to the electrical system grounding electrode is longer than:
    A. 6 ft (1.8 m).
    B. 10 ft (3 m).
    C. 20 ft (6 m).
    D. 25 ft (7.5 m).
    E. 50 ft (15 m).

Code reference ___________________

14. Rigid Nonmetallic Conduit is used to supply a motor in an agricultural building as shown in Figure 14.22. The raceway is not installed in the earth. The equipment grounding conductor for the motor:
    A. is permitted to be aluminum.
    B. is required to be covered or insulated.
    C. is not required because the Code permits the motor to be grounded to a ground rod at the motor.
    D. shall be copper.
    E. is required to be the same size as the branch-circuit conductors serving the motor.

Code reference ___________________

15. A network-powered broadband communications medium-power cable that is permitted to be installed underground without additional protection is:
    A. CLU.
    B. BL.
    C. BLX.
    D. UBM.
    E. BMU.

Code reference ___________________

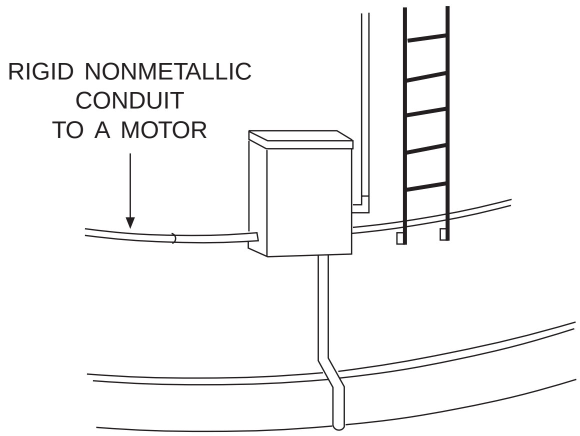


Figure 14.22 Rigid Nonmetallic Conduit is installed above ground and used to supply a motor in an agricultural building where physical strength is needed.

UNIT 15

Review

OBJECTIVES

After completion of this unit, the student should be able to:

- evaluate ability to solve basic electrical fundamentals calculations.
- evaluate ability to find answers to questions from the Code.
- evaluate ability to make electrical wiring calculations.
- determine which articles of the Code require further work to increase the student's level of understanding.

EVALUATION PROCESS

This review is designed to serve as a self-evaluation. Mark only the answer on the answer sheet. It is best to do this evaluation in a specified period of time. A suggested time interval is two hours. If the review test is taken in a two-hour time limit, it will generally not be possible to look up the answer to every question in the Code. Usually, the answer can be narrowed to two possible answers by elimination. The following example of an electrical fundamentals problem will illustrate how the possible answers can be reduced to only two by using basic understanding of the concept.

Example 15.1 Three resistors with the values 4 ohms, 6 ohms, and 12 ohms are connected in parallel. The total resistance of the circuit is:

A. 1 ohm.
B. 2 ohms.
C. 6 ohms.
D. 22 ohms.

Answer: The circuit resistance is less than the smallest resistor in the group; therefore, the answer must be either response A or B. Working out the answer shows that the answer is response B.

$$\frac{1}{R_T} = \frac{1}{4} + \frac{1}{6} + \frac{1}{12} = \frac{3}{12} + \frac{2}{12} + \frac{1}{12} = \frac{6}{12}$$

$$R_T = \frac{12}{6} = 2 \text{ ohms}$$

WORKSHEET NO. 15—BEGINNING REVIEW

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A 260 ft (79.25 m) length of size 4 AWG uncoated copper wire operating at a temperature of 75°C has a resistance of:
   A. 0.0801 ohm. C. 0.308 ohm. E. 1.010 ohm.
   B. 0.0792 ohm. D. 0.524 ohm.
   Code reference NA

2. An extension cord with size 16 copper conductors operating at 50°C has a length of 150 ft (45.72 m) and is supplying a 120-volt load that is drawing 8 amperes. If the total resistance for the neutral and ungrounded wire is 1.375 ohms, the voltage drop caused by the resistance of the cord is:
   A. 5.2 volts. C. 11.0 volts. E. 18.3 volts.
   B. 7.6 volts. D. 14.0 volts.
   Code reference NA

3. A chandelier has eight 60-watt incandescent lamps and operates at 120-volts. The total current drawn by the chandelier is:
   A. 0.5 amperes. C. 2.5 amperes. E. 8.0 amperes.
   B. 2.0 amperes. D. 4.0 amperes.
   Code reference NA

4. A circuit has three resistors connected in parallel. One resistor is 4 ohms, the next is 6 ohms, and the last is 12 ohms. The total resistance of the circuit is:
   A. 1.5 ohms. C. 4 ohms. E. 22 ohms.
   B. 2 ohms. D. 11 ohms.
   Code reference NA

5. A circuit has two resistors connected in series—one with 3 ohms and the other with 21 ohms. The two resistors are connected to a 120-volt ac electrical supply. The voltage across the 21-ohm resistor will be:
   A. 15 volts. C. 60 volts. E. 120 volts.
   B. 45 volts. D. 105 volts.
   Code reference NA

6. A feeder supplies 76 amperes of continuous load and 45 amperes of noncontinuous load. The feeder consists of three Type THHN copper current-carrying conductors in raceway. The minimum rating overcurrent device permitted for this feeder is:
   A. 100 amperes. D. 140 amperes.
   B. 110 amperes. E. 175 amperes.
   C. 125 amperes.
   Code reference ____________

7. A raceway contains six size 2/0 AWG copper current-carrying conductors with THHN insulation. The maximum allowable ampacity of these conductors in this raceway is:
   A. 116 amperes.
   B. 123 amperes.
   C. 136 amperes.
   D. 140 amperes.
   E. 156 amperes.

   Code reference ___________________

8. A feeder consisting of three current-carrying conductors supplies a continuous load of 94 amperes and is protected with a 125-ampere circuit breaker. All conductor terminations in the circuit are rated at 75°C. If the circuit conductors are THWN copper, the minimum size permitted for the circuit is:
   A. 6 AWG.
   B. 4 AWG.
   C. 3 AWG.
   D. 2 AWG.
   E. 1 AWG.

   Code reference ___________________

9. A 20-ampere, 120-volt circuit for lighting in the yard of a dwelling is not protected with a ground-fault circuit interrupter, although there is one GFCI type receptacle installed on the circuit. The circuit is run as Direct Burial Type UF Cable that passes under the dwelling drive that is not paved, and is not subject to other than light vehicle traffic. The minimum depth of burial permitted for the cable is:
   A. 6 in. (150 mm).
   B. 12 in. (300 mm).
   C. 18 in. (450 mm).
   D. 24 in. (600 mm).
   E. 30 in. (750 mm).

   Code reference ___________________

10. Type NM-B Cable is used in a dwelling as a switch loop from a ceiling box at a luminaire (lighting fixture) to a single-pole switch on the wall. A 120-volt black insulated conductor and a white insulated neutral conductor are run using Type NM-B Cable to the ceiling box. The white insulated conductor from the ceiling box to the switch box:
    A. is only permitted to be the 120-volt feed to the switch and must be marked to identify it as an ungrounded conductor.
    B. is only permitted to be the return to the light and must be marked to identify it as an ungrounded conductor.
    C. is permitted to be either the 120-volt supply to the switch or the return to the light.
    D. if marked with black tape is permitted to be the return to the light.
    E. is only permitted to be the return to the light.

    Code reference ___________________

11. Type NM-B Cable enters a metal device box and is secured by a cable clamp at the bottom of the box. The cable is installed so the cable jacket is flush with the cable clamp so free conductors begin at the cable clamp. If the device box has a depth of $2^{3}/_{4}$ in. (70 mm), the minimum length of free conductor permitted in this box is required to be not less than:
    A. 3 in. (75 mm).
    B. 6 in. (150 mm).
    C. $6^{1}/_{2}$ in. (163 mm).
    D. 8 in. (200 mm).
    E. 12 in. (300 mm).

    Code reference ___________________

12. Four Type THWN size 500 kcmil copper conductors are run in Electrical Metallic Tubing (EMT). The minimum trade diameter EMT for this run is:
    A. trade size 2 (53).
    B. trade size $2^{1}/_{2}$ (63).
    C. trade size 3 (78).
    D. trade size $3^{1}/_{2}$ (91).
    E. trade size 4 (103).

    Code reference ___________________

13. A trade size 4 (103) Intermediate Metal Conduit (IMC) enters one side of a pull box and two trade size 3 (78) Rigid Metal Conduits enter the adjacent side. If the conductors running from the trade size 4 (103) conduit to either of the trade size 3 (78) conduits is larger than size 4 AWG, the minimum distance permitted between the conduit entries inside the box is:
A. not specified.
B. 8 in. (200 mm).
C. 12 in. (300 mm).
D. 18 in. (450 mm).
E. 24 in. (618 mm).

Code reference ___________________

14. Wiring in a dwelling uses single-gang nonmetallic boxes without cable clamps. A 20-ampere circuit is wired with Type NM-B Cable size 12 copper. A box on the wall has a three-way switch and a Type NM-B Cable with three insulated conductors and an equipment ground entering one end of the box. It also has a Type NM-B Cable with two insulated conductors and an equipment ground entering the other end of the box. The internal volume of the box is:
A. 15 $in.^3$ (246 cm^3).
B. 16.25 $in.^3$ (266 cm^3).
C. 18 $in.^3$ (295 cm^3).
D. 20 $in.^3$ (328 cm^3).
E. 22.5 $in.^3$ (369 cm^3).

Code reference ___________________

15. Fluorescent lay-in luminaires (lighting fixtures) are mounted in a suspended ceiling and supplied from 20-ampere branch-circuits. Flexible Metal Conduit supported only by a listed connector at a solidly mounted junction box and at the luminaire is permitted to be installed to supply a luminaire in lengths not to exceed:
A. 18 in. (450 mm).
B. 24 in. (600 mm).
C. 3 ft (900 mm).
D. 4 ft (1.2 m).
E. 6 ft (1.8 m).

Code reference ___________________

16. Trade size 1 (27) PVC type Rigid Nonmetallic Conduit is run as exposed surface wiring in a building and securely fastened within a distance of not more than 3 ft (900 mm) of each box and cabinet. The maximum distance between supports in a run of this RNC is not permitted to be greater than:
A. 3 ft (900 mm).
B. 5 ft (1.5 m).
C. 6 ft (1.8 m).
D. 8 ft (2.5 m).
E. 10 ft (3 m).

Code reference ___________________

17. The minimum branch-circuit rating permitted for a 12-kW, 120/240-volt electric range in a dwelling is:
A. 30 amperes.
B. 35 amperes.
C. 40 amperes.
D. 50 amperes.
E. 60 amperes.

Code reference ___________________

18. An unbroken length of kitchen counter along a wall in a dwelling is 10 ft (3.05 m) long. The counter extends from the edge of the sink for 4 ft (1.22 m), then makes a corner and continues for 6 ft (1.83 m) to the end of the counter at the refrigerator. The minimum number of receptacle outlets required on this length of wall space is:
A. not specified and the number is up to the owner of the dwelling.
B. one.
C. two.
D. three.
E. four.

Code reference ___________________

19. A single-family dwelling has three bathrooms. The minimum number of 20-ampere, 125-volt branch-circuits required for the dwelling is:
    A. three.
    B. four.
    C. five.
    D. six.
    E. not specified in the Code.

    Code reference ___________________

20. A single-family dwelling has two wall-mounted ovens and one counter-mounted cooking unit supplied by a single branch-circuit. The total rating of the two ovens and the cooking unit is 22 kW. The minimum permitted demand rating for this range branch-circuit is:
    A. 8 kVA.
    B. 8.4 kVA.
    C. 9.2 kVA.
    D. 11 kVA.
    E. 12 kVA.

    Code reference ___________________

21. A service entrance in a single-family dwelling has a 150-ampere main circuit breaker. The service-entrance conductor is aluminum with 75°C insulation and terminations. The calculated demand load for the dwelling is 115 amperes. The minimum size ungrounded conductors for this service is:
    A. 1 AWG.
    B. 1/0 AWG.
    C. 2/0 AWG.
    D. 3/0 AWG.
    E. 4/0 AWG.

    Code reference ___________________

22. Service-Entrance Cable Type SE style U is installed on the outside of a building for a service entrance. The weather head is fastened to the side of the building and the cable is supported within 12 in. (300 mm) of the weather head. The maximum distance permitted between supports for the cable is:
    A. 8 in. (200 mm).
    B. 12 in. (300 mm).
    C. 18 in. (450 mm).
    D. 24 in. (600 mm).
    E. 30 in. (750 mm).

    Code reference ___________________

23. The service drop to a building is required to meet minimum clearance requirements depending upon the use of the area beneath the service drop. In no case is the point of attachment of the service drop permitted to be less than:
    A. the minimum required to prevent personal contact.
    B. 10 ft (3 m).
    C. 12 ft (3.7 m).
    D. 15 ft (4.5 m).
    E. 18 ft (5.5 m).

    Code reference ___________________

24. A short section of Liquidtight Flexible Nonmetallic Conduit connects the circuit conductors to a machine. The conductors are size 1 AWG copper protected by 125-ampere time-delay fuses. The copper equipment grounding conductor required for this circuit is not permitted to be smaller than size:
    A. 6 AWG.
    B. 4 AWG.
    C. 3 AWG.
    D. 2 AWG.
    E. 1 AWG.

    Code reference ___________________

25. A metal underground water-piping system is used as a grounding electrode for a service of a dwelling and it is supplemented with an additional grounding electrode consisting of a ground rod driven 8 ft (2.44 m) into the earth. If the supplemental ground rod is not 25 ohms or less to ground:
    A. a second ground rod driven 6 ft (1.8 m) away and bonded to the first ground rod meets the service grounding requirement.
    B. nothing additional is required because the underground water pipe acts as the additional grounding electrode.
    C. more ground rods are required to be driven until a resistance of less than 25 ohms is achieved.
    D. soil treatment is required to lower the resistance to less than 25 ohms.
    E. a bare copper wire at least 20 ft (6 m) in length and not smaller than size 2 AWG is required to be used in place of the ground rod.

Code reference ___________________

26. The service-entrance conductors in a commercial building are size 250 kcmil copper and the main circuit breaker is rated 225 amperes. The grounding electrode for the service is the structural steel of the building that is effectively grounded by bonding to reinforcement steel in the building footings. The minimum size copper grounding electrode conductor from the service panel to the structural steel is not permitted to be smaller than:
    A. 8 AWG.
    B. 6 AWG.
    C. 4 AWG.
    D. 2 AWG.
    E. 1/0 AWG.

Code reference ___________________

27. The equipotential bonding for a permanent swimming pool is formed by connecting together all metal parts associated with the pool such as reinforcing steel in the pool wall and deck, metallic parts of the pool structure, forming shells and mounting brackets of lighting fixtures, metal ladders and other metal fixtures attached to the pool, metal equipment associated with the water circulating system, pool covers and similar metal parts. The conductor used for this bonding is:
    A. permitted to be solid aluminum if insulated and not smaller than size 8 AWG.
    B. required to be insulated copper, stranded, and not smaller than size 8 AWG.
    C. permitted to be bare, insulated, or covered copper if not smaller than size 6 AWG.
    D. required to be copper not smaller than size 2 AWG.
    E. required to be solid copper not smaller than size 8 AWG.

Code reference ___________________

28. A standard rating of an overcurrent device as recognized by the Code is:
    A. 55 amperes.
    B. 110 amperes.
    C. 130 amperes.
    D. 750 amperes.
    E. 1500 amperes.

Code reference ___________________

29. When terminating neutral conductors and equipment grounding conductors to the neutral terminal bus in a service panelboard:
    A. only a single neutral conductor is permitted to be connected to a terminal.
    B. only one neutral and one equipment grounding conductor of the same circuit are permitted to be connected to a terminal.
    C. any number of neutral and equipment grounding conductors are permitted to be connected to a terminal if they will fit the space available.
    D. not more than two neutral conductors are permitted to be connected to a terminal.
    E. there is no limit to the number of conductors for any terminal provided a minimum torque is applied to the terminal.

Code reference ___________________

30. A mobile home served with 120/240-volt, 3-wire service that has a calculated load greater than 50 amperes is required to be supplied power using a permanent wiring method from the adjacent power supply pole to the mobile home. The power supply feeder is required to consist of:
    A. three insulated conductors and an equipment ground permitted to be bare.
    B. three insulated conductors and an equipment grounding conductor with the insulated conductors permitted to be identified with colored tape.
    C. only three insulated conductors if the mobile home panel is grounded to the earth.
    D. two insulated and color coded ungrounded conductors with the neutral permitted to be bare.
    E. four insulated and color coded conductors—one of which is an equipment grounding conductor.

Code reference ___________________

31. According to *430.102(B)* in the Code, a disconnecting means is required to be located "in sight from" a motor and driven machinery location. In addition to being directly in the line of sight, the term "in sight from" means the disconnect is not permitted to be located from the motor and driven machine a distance greater than:
    A. 20 ft (6 m).
    B. 25 ft (7.5 m).
    C. 30 ft (9 m).
    D. 50 ft (15 m).
    E. 75 ft (22.5 m).

Code reference ___________________

32. A 10-horsepower single-phase, 240-volt induction motor has a nameplate current of 46 amperes and a service factor of 1.0. If the motor is protected from overload by a current-sensing device in the supply conductors, the maximum current setting of the overload device is:
    A. 46 amperes.
    B. 50 amperes.
    C. 53 amperes.
    D. 58 amperes.
    E. 63 amperes.

Code reference ___________________

33. A 3-phase, 20 horsepower, 460-volt, design B induction motor is supplied with copper conductors with 75°C rated insulation and terminations. The minimum size branch-circuit conductors permitted for this circuit is:
    A. 10 AWG.
    B. 8 AWG.
    C. 6 AWG.
    D. 4 AWG.
    E. 3 AWG.

Code reference ___________________

34. A 3-phase, 25-horsepower, 460-volt, design B induction motor with a service factor of 1.15 is supplied with copper conductors with 75°C insulation and terminations. The motor is powering an easy starting load. The maximum rating inverse time circuit breaker permitted on the circuit to provide branch-circuit, short-circuit and ground-fault protection is:
    A. 50 amperes.
    B. 60 amperes.
    C. 70 amperes.
    D. 80 amperes.
    E. 90 amperes.

Code reference ___________________

35. A 3-phase transformer is rated 37.5 kVA and supplies a panelboard with a 100-ampere main circuit breaker with 208/120-volt power from a 480/277-volt supply. The conductors from the transformer to the panelboard are size 3 AWG copper and the input conductors to the transformer are size 8 AWG copper. The maximum standard rating overcurrent device permitted on the primary side of the transformer is:
    A. 35 amperes.
    B. 40 amperes.
    C. 50 amperes.
    D. 110 amperes.
    E. 125 amperes

Code reference ___________________

36. A transformer is installed in a building and is considered to be a separately derived system. There is a metal underground water-piping system entering the building but no metal water pipe in the area of the transformer. The structural steel of the building is effectively grounded. The required grounding electrode for the transformer secondary electrical system is the:
    A. metal underground water-piping system connected within 5 ft (1.5 m) of the point where it enters the building.
    B. metal underground water-piping system connected within 5 ft (1.5 m) of the point where it enters the building and supplemented with one additional electrode.
    C. ground rod driven next to the transformer.
    D. structural steel of the building with a connection as close to the transformer as possible.
    E. bare copper wire not smaller than size 2 AWG buried under the floor near the transformer.

Code reference ___________________

37. A duplex receptacle is installed on a masonry wall in the service area of a commercial garage to provide power for portable tools. The commercial garage is used only for the repair of gasoline and diesel powered vehicles. The receptacle is installed in a surface-mount masonry box and supplied with EMT using set screw connectors. This installation is permitted provided the distance from the service area floor to the bottom of the box is not less than:
    A. 12 in. (300 mm).
    B. 18 in. (450 mm).
    C. 24 in. (600 mm).
    D. 3 ft (900 mm).
    E. 5 ft (1.5 m).

Code reference ___________________

38. Wiring using field-threaded and installed Rigid Metal Conduit in a Class I, Division 1 hazardous location is required to be made up with the conduit having a minimum number of threads fully engaged of:
    A. not less than 5 threads.
    B. not less than 6 threads.
    C. not less than 8 threads.
    D. not less than 4 and sealed with a sealing compound.
    E. any number as long as the connection is tight.

Code reference ___________________

39. The extent of the Class I, Division 2 classified hazardous location at a gasoline dispenser is measured up from the surface 18 in. (450 mm) and out from the edge of the dispenser a minimum of:
    A. 10 ft (3 m).
    B. 15 ft (4.5 m).
    C. 20 ft (6 m).
    D. 25 ft (7.5 m).
    E. 50 ft (15 m).

Code reference ___________________

40. Even though circuit wiring is run in metal raceway of a hospital, an insulated copper equipment grounding conductor is required to be run in the raceway and connected to the grounding terminal of:
    A. all equipment, receptacles, and lighting fixtures in the hospital.
    B. all receptacles in patient care areas.
    C. receptacles installed in basements and other below grade areas.
    D. every circuit protected with a ground-fault circuit interrupter.
    E. ceiling lighting fixtures in patient care areas.

Code reference ___________________

41. Receptacles rated 20 amperes at 125 volts in an operating room of a hospital are supplied from an isolated power system. The orange conductor of the isolated power system is to be:
    A. connected to the equipment grounding terminal of the receptacles.
    B. connected only to the silver-colored screw terminal of the receptacles.
    C. run without splices and looped at each receptacle terminal connection.
    D. connected only to the brass-colored screw terminal of the receptacles.
    E. connected to either the silver- or brass-colored terminal of the receptacles.

Code reference ___________________

42. A receptacle in the unfinished portion of the basement of a dwelling that is installed to provide power to a non-power-limited fire alarm system is:
    A. not permitted and the installation is required to be supplied by a circuit near an exit door on the first level.
    B. required to be ground-fault circuit-interrupter protected.
    C. not permitted to be ground-fault circuit-interrupter protected.
    D. required to be protected by an arc-fault circuit interrupter.
    E. required to be controlled by a switch.

Code reference ___________________

43. The circuit conductors from an emergency panelboard to exit signs in a building are:
    A. permitted to be run in the same raceway with normal power conductors provided all conductors have 600-volt insulation.
    B. required to be run in Rigid Metal Conduit.
    C. required to be run only in Type MI, MC, or AC Cable, or metallic raceway.
    D. required to be run in separate raceways even when two separate emergency circuits originate from the same panelboard.
    E. not permitted to be run in the same raceway with other power or lighting circuit conductors.

Code reference ___________________

44. A fire pump installation consists of only one motor that is rated 60-horsepower, 3-phase, 460-volt, design B. Conductors are copper with 75°C rated terminations. The minimum size copper Type THWN conductors permitted to be run from the controller to the fire pump motor is:
    A. 8 AWG.
    B. 6 AWG.
    C. 4 AWG.
    D. 3 AWG.
    E. 2 AWG.

Code reference ___________________

45. In an existing building, optical fiber cable is to be installed where the most convenient way of running the necessary cables is across the upper side of a permanent suspended ceiling in a hallway. There are no other cables run across the suspended ceiling. The maximum number of optical fiber cables permitted to be installed by running them across the suspended ceiling from one end of the hallway to the other is:
    A. two.
    B. three.
    C. zero, because this practice is not permitted.
    D. only one.
    E. as many as desired.

Code reference ___________________

46. Ventilated-trough cable tray contains only single-conductor cables installed in a single layer with an air space maintained between and secured to the cable tray so they will not move. The width of the air space is equal to the cable diameter. There are eleven Type XHHW size 500 kcmil copper single-conductor cables. The minimum width cable tray required for this installation is:
    A. 9 in. (225 mm).
    B. 12 in. (300 mm).
    C. 18 in. (450 mm).
    D. 24 in. (600 mm).
    E. 30 in. (750 mm).

    Code reference ___________________

47. A required 125-volt, 15- or 20-ampere branch-circuit serves the lights and receptacles in an elevator machine room. The lights in the room are required to be:
    A. connected to the supply side of any ground-fault circuit interrupter.
    B. arc-fault protected
    C. incandescent with at least two luminaires (lighting fixtures).
    D. grounded with an insulated equipment grounding conductor.
    E. ground-fault circuit-interrupter protected.

    Code reference ___________________

48. Strut-type channel raceway is surface mounted to a ceiling and used to support luminaires (lighting fixtures) as well as serve as the raceway for the conductors. The sections of strut channel are secured within 3 ft (900 mm) of ends and terminations, and shall be secured at intervals not to exceed:
    A. 3 ft (900 mm).
    B. 4.5 ft (1.4 m).
    C. 5 ft (1.5 m).
    D. 8 ft (2.5 m).
    E. 10 ft (3 m).

    Code reference ___________________

49. A restaurant is classified as a place of assembly when the seating capacity of the building is:
    A. 50 or more persons.
    B. 75 or more persons.
    C. 100 or more persons.
    D. 150 or more persons.
    E. 200 or more persons.

    Code reference ___________________

50. A wiring method not permitted to be used for light and power circuits in a movie theater and run as surface wiring, and in wall and ceiling cavities is:
    A. Type AC Cable with an insulated equipment grounding conductor.
    B. Type UF Cable with an insulated equipment grounding conductor.
    C. Electrical Metallic Tubing.
    D. Rigid Nonmetallic Conduit encased in 2 in. (50 mm) of concrete.
    E. Type MC Cable.

    Code reference ___________________

WORKSHEET NO. 15—ADVANCED REVIEW

Mark the single answer that most accurately completes the statement based upon the 2008 Code. Also provide, where indicated, the Code reference that gives the answer or indicates where the answer is found, as well as the Code reference where the answer is found.

1. A fluorescent luminaire (lighting fixture) has a ballast that operates two 40-watt lamps and draws 1.32 amperes at 120 volts with a power factor of 0.58. The power drawn by the luminaire (lighting fixture) is approximately:
   A. 80 watts.
   B. 92 watts.
   C. 115 watts.
   D. 158 watts.
   E. 273 watts.

   Code reference NA

2. A 3-phase resistance-type electric heater has a rating of 15 kW at 240 volts. The current drawn by the electric heater is approximately:
   A. 20.8 amperes.
   B. 28.9 amperes.
   C. 36.1 amperes.
   D. 45.1 amperes.
   E. 62.5 amperes.

   Code reference NA

3. A circuit has three resistors connected in parallel. One resistor is 4 ohms, the next is 14 ohms, and the last is 28 ohms. The total resistance of the circuit is:
   A. 1.5 ohms.
   B. 2.8 ohms.
   C. 4 ohms.
   D. 23.0 ohms.
   E. 46 ohms.

   Code reference NA

4. A circuit supplying twelve 150-watt, 120-volt incandescent lamps is not turned off for a week. If the average cost of electrical power for the building is 10.2 cents per kilowatt-hour, the approximate cost of operating the lamps for one week is:
   A. $12.38.
   B. $18.22.
   C. $23.64.
   D. $26.47.
   E. $30.84.

   Code reference NA

5. A 3-phase electric motor running at full-load and developing exactly 10 horsepower draws 28 amperes at 230 volts with a power factor of 71.2%. The efficiency of the motor is approximately:
   A. 62%.
   B. 66%.
   C. 71%.
   D. 82%.
   E. 94%.

   Code reference NA

6. A 3-phase, 208/120-volt feeder consists of three ungrounded conductors and a neutral, and all four conductors count as current-carrying conductors because of the type of load being supplied. The conductors are copper with THHN insulation. The only terminations are rated 75°C and they are at panelboards on each end of the feeder. The

feeder passes through an area of the building where the ambient temperature is typically 125°F (51.7°C). If the conductors are size 300 kcmil, the allowable ampacity of these conductors for this feeder is:

A. 195 amperes.
B. 204 amperes.
C. 320 amperes.
D. 335 amperes.
E. 526 amperes.

Code reference __________________

7. A feeder consisting of three current-carrying conductors supplies a continuous load of 90 amperes, and is protected with a 125-ampere circuit breaker. All conductor terminations in the circuit are rated at 75°C. If the circuit conductors are THWN copper, the minimum size permitted for the circuit is:

A. 6 AWG.
B. 4 AWG.
C. 3 AWG.
D. 2 AWG.
E. 1 AWG.

Code reference __________________

8. Two sets of 3-phase feeders are run in the same raceway for a total of six current-carrying conductors. Each circuit supplies a 42-ampere continuous load. The circuit conductors are copper with THHN insulation and all circuit conductor terminations are rated 75°C. A portion of the raceway run goes through a room that is 30 ft wide and runs typically at a temperature of 130°F (54.4°C). The minimum size conductors permitted for these feeders is:

A. 6 AWG.
B. 4 AWG.
C. 3 AWG.
D. 2 AWG.
E. 1 AWG.

Code reference __________________

9. An 480/277-volt electrical panelboard is mounted to the surface of a poured concrete wall and extends out from the wall surface 10 in. (250 mm). The minimum clearance in front of the panelboard from the front to the opposite concrete block wall is not permitted to be less than:

A. 24 in. (600 mm).
B. 30 in. (750 mm).
C. 3 ft (900 mm).
D. $3^1/2$ ft (1 m).
E. 4 ft (1.2 m).

Code reference __________________

10. Receptacles, rated 125 volts, 20 amperes, are installed on a construction site for the purpose of supplying power for portable equipment. These receptacles are not permitted to be:

A. of the grounding type.
B. supplied with Type NM-B Cable if the building is more than three floors in height.
C. installed on branch-circuits that also supply temporary lighting.
D. supplied with Type NM-B Nonmetallic-Sheathed Cable except for dwellings.
E. ground-fault circuit-interrupter protected.

Code reference __________________

11. Type SE-R Service-Entrance Cable with three insulated conductors and a bare equipment grounding conductor contained within the outer nonmetallic sheath is used as a feeder to provide power from the service panel to a panelboard located in another part of the building. The cable run along the flat surface of structural materials is required to be supported at intervals not to exceed:

A. 1 ft (300 mm).
B. 2 ft (600 mm).
C. 3 ft (900 mm).
D. $4^1/2$ ft (1.4 m).
E. 6 ft (1.8 m).

Code reference __________________

12. Electrical Nonmetallic Tubing (ENT) is permitted to be installed:
    A. as concealed wiring in buildings of more than three floors where the walls, floors, and ceilings provide a thermal barrier that has at least a 15-minute finish fire rating.
    B. as concealed wiring in buildings of not more than three floors unless the walls, floors, and ceilings provide a thermal barrier that has at least a 1-hour finish fire rating.
    C. for exposed work in buildings of any height.
    D. as concealed wiring only if the walls, floors, and ceilings provide a thermal barrier that has at least a 15-minute finish fire rating.
    E. as concealed wiring in buildings of any height with no requirement the walls, floors, or ceiling have a fire rating.

Code reference ___________________

13. A run of Rigid Metal Conduit contains three size 3/0 AWG Type THWN conductors and six size 8 AWG Type THHN conductors. The minimum size RMC permitted for these circuits is:
    A. trade size $1^1/_4$ (35).
    B. trade size $1^1/_2$ (41).
    C. trade size 2 (53).
    D. trade size $2^1/_2$ (63).
    E. trade size 3 (78).

Code reference ___________________

14. A junction box has two Type NM-B cables size 12-3 AWG with ground and one Type NM-B Cable size 8-3 AWG with ground. The box has a blank cover. The minimum trade size box from the following list permitted for these conductors is:
    A. $4 \times 2^1/_8$ in. (100×54 mm) octagonal.
    B. $4 \times 2^1/_8$ in. (100×54 mm) round.
    C. $4 \times 1^1/_2$ in. (100×38 mm) square.
    D. $4^{11}/_{16} \times 1^1/_4$ in. (120×32 mm) square.
    E. $4^{11}/_{16} \times 2^1/_8$ in. (120×54 mm) square.

Code reference ___________________

15. Several runs of Electrical Metallic Tubing enter adjacent sides of a pull box. On one side of the box are trade size 4 (103) and two trade size 2 (53) runs of EMT, and from the adjacent size there are two trade size 4 (103) runs of EMT. All conductors are size 4 or larger. The pull box is required to have dimensions not less than:
    A. 24 in. × 24 in. (618 mm × 618 mm).
    B. 28 in. × 28 in. (724 mm × 724 mm).
    C. 24 in. × 32 in. (618 mm × 812 mm).
    D. 26 in. × 30 in. (660 mm × 762 mm).
    E. 24 in. × 36 in. (610 mm × 914 mm).

Code reference ___________________

16. An 80 ft (24.38 m) horizontal run of trade size 2 (53) schedule 40 Rigid Nonmetallic Conduit in a parking garage will experience a change in temperature of 110°F (61.1°C) throughout the year. The change in length of this run of Rigid Nonmetallic Conduit throughout a year is approximately:
    A. 1.50 in. (38.1 mm).
    B. 1.94 in. (49.3 mm).
    C. 2.43 in. (61.7 mm).
    D. 3.57 in. (90.6 mm).
    E. 4.46 in. (113.3 mm).

Code reference ___________________

17. A single-family dwelling has a living area of 3100 sq. ft (288.0 m^2). All circuits for general illumination, in addition to those for small appliance, laundry and the bathroom receptacles, are rated at 15 amperes. The minimum number of general illumination branch-circuits permitted for this dwelling is:
    A. two.
    B. three.
    C. four.
    D. five.
    E. six.

    Code reference ___________________

18. An electric range rated 18.4 kW is installed in a single-family dwelling. The minimum demand load permitted to be used to determine the rating of the circuit is:
    A. 8.0 kVA.
    B. 8.8 kVA.
    C. 10.4 kVA.
    D. 10.56 kVA.
    E. 18.4 kVA.

    Code reference ___________________

19. In a dwelling, the light for a stairway is required to be controlled from each level:
    A. if there are six risers or steps or more.
    B. if there is an exit to the outside of the dwelling from both levels.
    C. if there are more than four steps.
    D. if there is a change in elevation in a step and not a ramp.
    E. unless the light is controlled by a circuit breaker.

    Code reference ___________________

20. A 208/120-volt, 4-wire feeder supplies power from one building to a separate building on the same property. The feeder is protected by a 100-ampere overcurrent device in the first building. The property management does not have a qualified electrician on site at all times. The disconnecting means for the second building is:
    A. required to be located at the first building.
    B. permitted to be located on the outside of the second building.
    C. required to be located inside the second building at the nearest practical point where the conductors enter the building.
    D. permitted to be located inside the first building.
    E. required to be located on the outside of the second building near the point of entry of the conductors to the building.

    Code reference ___________________

21. A service has a calculated demand load of 405 amperes. The service-entrance conductors are copper with 75°C rated insulation and terminations. The service conductors terminate at six disconnecting means arranged in one location that add up to a combined rating of 600 amperes. The minimum size copper conductors permitted for this service is:
    A. 500 kcmil.
    B. 600 kcmil.
    C. 700 kcmil.
    D. 750 kcmil.
    E. 800 kcmil.

    Code reference ___________________

22. A single-family dwelling with a total living area of 2300 sq. ft (213.7 m^2) is served with a single-phase 120/240-volt electrical system. Appliances in the dwelling are a 12-kW electric range and a 5-kW electric clothes dryer operating at 120/240 volts, a 4.5-kW, 240-volt electric water heater, a 1.2-kW, 120-volt dishwasher, a $^1/_2$-horsepower, 120-volt garbage disposer, and a central air-conditioner with a nameplate rated load current of 17 amperes at 240 volts. The minimum service demand load for the dwelling using the optional method of *220.82* is:
    A. 101 amperes.
    B. 125 amperes.
    C. 130 amperes.
    D. 148 amperes.
    E. 160 amperes.

    Code reference ___________________

23. A multifamily dwelling has 18 living units all provided with an electric range. Six of the units have 14-kW electric ranges, eight have 10-kW electric ranges, and four units have 12-kW electric ranges. For the purpose of determining the demand load for the building, the average rating of electric range is:
   A. 11.8 kVA.
   B. 12.0 kVA.
   C. 12.7 kVA.
   D. 13.2 kVA.
   E. 14.0 kVA.

   Code reference ___________________

24. A 480/277-volt, 4-wire service to a building consists of two parallel sets of 600 kcmil copper conductors run underground from a transformer in separate Rigid Nonmetallic Conduit. A metal water pipe from underground serves the building and is used as a grounding electrode for the service. The minimum size grounding electrode conductor permitted from the main disconnect to the water pipe is:
   A. 4 AWG.
   B. 2 AWG.
   C. 2/0 AWG.
   D. 3/0 AWG.
   E. 4/0 AWG.

   Code reference ___________________

25. An existing building on the same property is supplied 120/240-volt single-phase power from another building. The second building is supplied from a 4-wire feeder with two ungrounded conductors, a neutral conductor, and an equipment grounding conductor. The neutral conductor at the second building is:
   A. not permitted to be connected to a grounding electrode at either building.
   B. required to be bonded to the equipment grounding conductor at the load end in the second building.
   C. required to be bonded to the disconnect enclosure in the second building and connected to a grounding electrode.
   D. only permitted to be connected to a grounding electrode at the second building.
   E. only permitted to be connected to a grounding electrode and bonded to the disconnect enclosure at the supply end of the feeder in the first building.

   Code reference ___________________

26. A feeder in an industrial building is protected with 800-ampere fuses and has the ungrounded conductors run as two parallel sets of copper conductors in individual Rigid Nonmetallic Conduits. The conductors in each conduit are size 500 kcmil. The minimum size copper equipment grounding conductor required to be run in parallel in each conduit is:
   A. 3 AWG.
   B. 2 AWG.
   C. 1 AWG.
   D. 1/0 AWG.
   E. 2/0 AWG.

   Code reference ___________________

27. A permanent swimming pool is installed in a large backyard at a dwelling and at least one general-purpose receptacle that is ground-fault circuit-interrupter protected for personnel is required to be installed not more than 20 ft (6 m) from the inside edge of the pool. This receptacle is not permitted to be installed closer from the inside edge of the pool than:
   A. 5 ft (1.5 m).
   B. 6 ft (1.83 m).
   C. 10 ft (3 m).
   D. 12 ft (3.7 m).
   E. 15 ft (4.5 m).

   Code reference ___________________

28. A tap is made to supply a load protected by a 50-ampere circuit breaker. The feeder conductors are size 250 kcmil copper and the feeder is rated 208/120-volts protected with a 250-ampere circuit breaker. All conductors are copper with insulation and terminations rated 75°C. The distance from the tap point on the feeder to the 50-ampere circuit breaker is 22 ft (6.7 m). The minimum tap conductor size permitted for this installation is:

A. 4 AWG.
B. 3 AWG.
C. 2 AWG.
D. 1 AWG.
E. 250 kcmil.

Code reference ___________________

29. The service equipment or a disconnecting means listed as suitable for use as service equipment is required to be installed adjacent to a mobile home and within sight of the mobile home and located from the exterior wall of the mobile home not more than:

A. 25 ft (7.5 m).
B. 30 ft (9 m).
C. 35 ft (11 m).
D. 40 ft (12 m).
E. 50 ft (15 m).

Code reference ___________________

30. A 200-ampere panelboard is supplied with a 120/240-volt, 3-wire electrical supply containing a neutral conductor. The 12-space panelboard contains only six two-pole circuit breakers, one rated at 100 amperes, three rated at 40 amperes, and two rated at 20 amperes. The neutral conductor is only used with the 100-ampere circuit breaker. This panelboard is rated as a:

A. lighting and appliance branch-circuit panelboard.
B. panelboard with no other classification.
C. sub-panel.
D. load center.
E. heavy-duty panelboard.

Code reference ___________________

31. A motor and driven machine are located within sight of the controller and a fusible switch capable of being locked in the open position is located within sight of the controller but not within sight of the motor or driven machine. This installation is permitted:

A. if there is an additional disconnect located between the controller and the motor and within sight of the motor and driven machine
B. in any type of occupancy.
C. only in a commercial occupancy where there are qualified personnel on duty to service the installation.
D. even if the disconnect cannot be locked in the open position as long as a warning label can be attached to the disconnect during servicing.
E. because the fuses can be removed from the disconnect during servicing.

Code reference ___________________

32. A 3-phase, design B, 50-horsepower induction motor is rated 60 amperes at 460 volts. Circuit conductors are copper with 75°C insulation and terminations. The minimum size copper conductors permitted to supply this motor is:

A. 8 AWG.
B. 6 AWG.
C. 4 AWG.
D. 3 AWG.
E. 2 AWG.

Code reference ___________________

33. A 3-phase, design B, 40-horsepower induction motor is rated 48 amperes at 460 volts. The circuit conductors are size 6 AWG copper. The motor is powering an easy starting load. The maximum standard rating time-delay fuse permitted to provide short-circuit and ground-fault protection for the circuit is:
A. 60 amperes.
B. 70 amperes.
C. 80 amperes.
D. 90 amperes.
E. 100 amperes.

Code reference ___________________

34. Three induction motors are supplied by a single feeder. There are two 40-horsepower, 3-phase, design B, 460-volt motors and one 50-horsepower, 3-phase, design B, 460-volt motor. The feeder conductor is copper with 75°C insulation and terminations. The minimum size conductor permitted as a feeder to supply these motors is:
A. 1 AWG.
B. 1/0 AWG.
C. 2/0 AWG.
D. 3/0 AWG.
E. 4/0 AWG.

Code reference ___________________

35. A 75-kVA 3-phase transformer is tapped to a 480/277-volt feeder to supply a 200-ampere 208/120 volt panelboard. The distance from the feeder tap point through the transformer to the panelboard is less than 25 ft (7.5 m). It is permitted to tap the transformer directly to feeder without an overcurrent device protecting the transformer primary provided the feeder overcurrent device is not rated higher than:
A. 200 amperes.
B. 225 amperes.
C. 250 amperes.
D. 300 amperes.
E. 400 amperes.

Code reference ___________________

36. A 50-kVA single-phase transformer supplies 120/240-volt, 3-wire power to a panelboard with a 200-ampere main circuit breaker. The secondary conductors from the transformer to the panelboard are size 3/0 AWG copper. The structural steel of the building is effectively grounded and is used as the grounding electrode for the separately derived system. The minimum size copper grounding electrode conductor permitted from the transformer secondary system to the structural steel is:
A. 6 AWG.
B. 4 AWG.
C. 3 AWG.
D. 2 AWG.
E. 1/0 AWG.

Code reference ___________________

37. A trade size 1 (27) Rigid Metal Conduit enters a NEMA 7 explosionproof motor starter installed in a Class I, Division 1 classified hazardous area. The seal placed in the conduit is not permitted to be located a distance from the motor starter enclosure more than:
A. 6 in. (150 mm).
B. 12 in. (300 mm).
C. 18 in. (450 mm).
D. 24 in. (600 mm).
E. 3 ft (900 mm).

Code reference ___________________

38. A gasoline dispenser at a service station is supplied with 120-volt power from a circuit breaker panelboard where the circuit breaker will act as the disconnecting means for the dispenser. The circuit breaker permitted to serve as the dispenser disconnect is:
A. a single-pole circuit breaker.
B. a single-pole, ground-fault circuit-interrupter circuit breaker.
C. a single-pole, arc-fault circuit interrupter.
D. an instantaneous trip circuit breaker.
E. a 2-pole switched neutral circuit breaker.

Code reference ___________________

39. An intrinsically safe circuit runs from a control panel containing electronic barriers located in a nonclassified area to control devices located in a Class I hazardous location. The intrinsically safe circuits are run in a cable and not in raceway through the nonclassified area. The minimum separation distance from the intrinsically safe circuit cable to other power circuit cable shall not be less than:
    A. $^1/_2$ in. (13 mm).
    B. $^3/_4$ in. (19 mm).
    C. 1 in. (25 mm).
    D. 2 in. (50 mm).
    E. 6 in. (150 mm).

    Code reference ___________________

40. A hospital has a demand load on the essential electrical system of more than 150 kVA. A single standby generator supplies the equipment system, the critical branch, and the life safety branch. Upon a loss of normal utility power to the hospital, the equipment system is:
    A. required to be energized in not more than 10 seconds.
    B. permitted to be completely or partially transferred to the generator manually.
    C. required to be started simultaneously along with the emergency system.
    D. permitted to be started simultaneously along with the emergency system.
    E. required to have power restored automatically with an appropriate time-lag.

    Code reference ___________________

41. For a critical care area in a hospital, each patient bed location is required to be provided with two branch-circuits:
    A. one of which shall originate from the emergency electrical system.
    B. both of which shall originate from the emergency electrical system.
    C. both of which shall originate from the normal electrical system.
    D. with not less than two receptacles connected to each branch-circuit.
    E. that are permitted to originate from any electrical system desired.

    Code reference ___________________

42. Fire alarm cables installed in a room with a non-fire-rated suspended ceiling grid of an existing building are not permitted to be supported by the ceiling grid:
    A. unless there are no more than three cables in any 10 ft by 10 ft (3 m by 3 m) area.
    B. except where there is a maintenance electrician.
    C. unless the cables have a diameter not more than $^1/_2$ in. (13 mm) and there are no more than three cables across any one ceiling tile.
    D. unless only one cable is across any one ceiling tile.
    E. in any type of building.

    Code reference ___________________

43. The authority having jurisdiction may rule in some situations that the electrical supply for an emergency panel is permitted to be:
    A. a tap to the normal service conductors entering the building provided the tap is made ahead of the main service disconnect.
    B. a circuit in the first panelboard of the normal power system.
    C. a tap to the normal service made at the main lugs of the disconnect.
    D. a separate and independent service to the building supplying only the emergency panelboard.
    E. any circuit from the normal power system in the building.

    Code reference ___________________

44. A 50-horsepower, 460-volt, 3-phase, design B fire pump motor in a building is supplied with copper conductors size 4 AWG with 75°C insulation and terminations. The fire pump circuit is protected with a fusible disconnect. The minimum rating fuse permitted for the circuit is:
A. 90 amperes.
B. 100 amperes.
C. 300 amperes.
D. 350 amperes.
E. 400 amperes.

Code reference ___________________

45. When installing optical fiber cables in raceway with no electrical conductors in the raceway:
A. only one cable is permitted for each raceway.
B. the fill requirements that apply to electrical conductors do not apply to optical fiber cables.
C. the cross-sectional area of the cables is not permitted to exceed 20% of the area of the raceway.
D. the cross-sectional area of the cables is not permitted to exceed 40% of the area of the raceway.
E. a maximum of three cables are permitted in a raceway.

Code reference ___________________

46. A ladder-type cable tray supports TC multiconductor power cables with Type XHHW copper conductors. There are four 3-conductor cables size 500 kcmil with a diameter of 2.26 in. (57.4 mm), five 4-conductor cables size 3/0 AWG with a diameter of 1.58 in. (40.0 mm) and a cross-sectional area of 1.96 sq. in. (1264 mm^2). There is no maintained air space between conductors. The 3-conductor cables are in a single layer and the 4-conductor cables are in a double layer. The minimum width of cable tray permitted for this installation is:
A. 9 in. (225 mm).
B. 12 in. (300 mm).
C. 18 in. (450 mm).
D. 24 in. (600 mm).
E. 30 in. (750 mm).

Code reference ___________________

47. The minimum number of duplex receptacles required to be installed in an elevator machine room or space is:
A. one.
B. two.
C. three.
D. as many as desired because no minimum requirement is established.
E. none because a single receptacle is permitted.

Code reference ___________________

48. A strut-type channel raceway, trade size $1\frac{5}{8}$ by 1, is installed across the ceiling of a commercial storage area to support wiring and luminaires (lighting fixtures). Internal joiners are used to connect the strut channel sections. The conductors installed in the strut channel are size 12 AWG copper Type THWN with 75°C terminations. The maximum number of conductors permitted to be installed in the strut channel is:
A. 11.
B. 19.
C. 21.
D. 28.
E. 34.

Code reference ___________________

49. The suspended ceiling of a restaurant classified as a place of assembly has a 15-minute finish fire rating. The space above the ceiling is not used as a plenum for environmental air. A wiring method not permitted to be used in the space above the suspended ceiling is:
    A. Type MC Cable.
    B. Electrical Nonmetallic Tubing (ENT).
    C. Flexible Metal Conduit.
    D. all are permitted.
    E. Electrical Metallic Tubing (EMT).

    Code reference ___________________

50. Conductors for border and pocket lighting in the stage area of an auditorium are run in metal wireway. The cross-sectional area of the conductors does not exceed 20% of the cross-sectional area of the wireway. Adjustments to the ampacity of conductors:
    A. shall be applied for more than 3 current-carrying conductors.
    B. shall be applied for more than 9 current-carrying conductors.
    C. shall be applied for more than 30 current-carrying conductors.
    D. is a fixed 0.8 whenever there are more than twelve conductors.
    E. do not apply in this application.

    Code reference ___________________

Annex A-1 Common English distances and the metric equivalent frequently used in the Code.

English Distance	Rounded Metric	Actual Metric	Difference
1/4 in.	6 mm	6 mm	
1/2 in.	13 mm	13 mm	
5/8 in.	16 mm	16 mm	
3/4 in.	19 mm	19 mm	
1 in.	25 mm	25 mm	
1 1/2 in.	38 mm	38 mm	
2 in.	50 mm	51 mm	
2 1/2 in.	65 mm	64 mm	
3 in.	75 mm	76 mm	
3 1/2 in.	90 mm	89 mm	
4 in.	100 mm	102 mm	–1/16 in.
6 in.	150 mm	152 mm	–1/16 in.
8 in.	200 mm	203 mm	–1/8 in.
12 in.	300 mm	305 mm	–3/16 in.
18 in.	450 mm	457 mm	–1/4 in.
20 in.	500 mm	508 mm	–5/16 in.
24 in.	600 mm	610 mm	–3/8 in.
30 in.	750 mm	762 mm	–7/16 in.
3 ft	900 mm	914 mm	–9/16 in.
3 1/2 ft	1 m	1.067 m	–2 5/8 in.
4 ft	1.2 m	1.219 m	–3/4 in.
4 1/2 ft	1.4 m	1.372 m	–1 1/16 in.
5 ft	1.5 m	1.524 m	–1 5/16 in.
6 ft	1.8 m	1.829 m	–1 1/8 in.
7 ft	2.1 m	2.134 m	–1 5/16 in.
8 ft	2.5 m	2.438 m	–2 7/16 in.
10 ft	3 m	3.048 m	–1 7/8 in.
12 ft	3.7 m	3.658 m	–1 5/8 in.
14 ft	4.3 m	4.267 m	–1 5/16 in.
15 ft	4.5 m	4.572 m	–2 13/16 in.
16 ft	4.9 m	4.877 m	7/8 in.
18 ft	5.5 m	5.486 m	9/16 in.
20 ft	6 m	6.096 m	–3 3/4 in.
25 ft	7.5 m	7.620 m	–4 11/16 in.
30 ft	9 m	9.144 m	–5 11/16 in.
35 ft	11 m	10.668 m	13 1/16 in.
40 ft	12 m	12.192 m	–7 9/16 in.
50 ft	15 m	15.240 m	–9 7/16 in.
75 ft	22.5 m	22.860 m	–14 3/16 in.
100 ft	30 m	30.480 m	–18 7/8 in.

Annex A-2 Metric unit and in.-pound unit conversions.

Length:

in. × 25.4 = millimeters (mm)	millimeters / 25.4 = inches (in.)
ft × 0.3048 = meters (m)	meters × 3.28 feet (ft)
miles × 0.62 = kilometers (km)	kilometers × 1.61 = miles (mi)

Area:

in.^{2} × 645 = mm^2	mm^2 / 645 = in.^{2}
mm^2 / 100 = cm^2	cm^2 × 100 = mm^2
ft^2 × 0.0929 = m^2	m^2 × 10.76 = ft^2
acre × 43,560 = ft^2	ft^2 / 43,560 = acres
hectares × 10,000 = m^2	m^2 / 10,000 = hectares
acres × 0.4047 = hectares	hectares × 2.471 = acres

Volume:

in.^{3} × 16.387 = cm^3	cm^3 / 16.387 = in.^{3}
gallons × 3.785 = liters	liters × 0.264 = gallons
gallons × 0.1336 = ft^3	ft^3 × 7.48 = gallons
liters × 0.001 = m^3	m^3 × 1000 = liters (l)
ft^3 × 28.32 = liters	liters × 0.0535 = ft^3
gallons × .003784 = m^3	m^3 × 264.2 = gallons (gal)

Weight:

pounds × 0.454 = kilograms (kg)	kilograms × 2.20 pounds (lb)

Force:

pounds × 4.448 = Newtons (N)	Newtons × 0.2248 = pounds

Torque:

pound-ft × 1.357 = Newton-meters (Nm)	Newton-meters × 0.737 = pound-ft
pound-in × 0.1130 = Newton-meters	Newton-meters × 8.850 = pound-in.

Pressure:

psi × 6.9 = kilopascals (kPa)	kilopascals × 0.145 = psi
in. of water × 249.3 = pascals (Pa)	Pascals × 0.00401 = in. of water
psi × 27.68 = in. of water	in. of water 3 0.0361 = psi

Air or Vapor Flow Rate:

cubic ft per minute × 0.0283 = m^3/minute	m^3/minute × 35.3 = cubic ft per minute (cfm)
ft^3 per hour × 28,339 = cm^3 per hour	cm^3 per hour × 0.0000353 = ft^3 per hour

Power:

horsepower × 746 = watts (W)	kilowatts (kW) × 1.34 = horsepower (hp)
horsepower × 33,000 = ft-pounds per minute	
kilowatts × 3,413 = Btu/hour	

Annex A-3 Conduit and tubing trade sizes and equivalent metric designators.

3/8 in.	12	2 1/2 in.	63
1/2 in.	16	3 in.	78
3/4 in.	21	3 1/2 in.	91
1 in.	27	4 in.	103
1 1/4 in.	35	5 in.	129
1 1/2 in.	41	6 in.	155
2 in.	53		

ANSWER SHEET

Name ______________________________

Unit No.______ Beginning or Advanced (circle one)

	Answer	Code reference
1.	A B C D E	____________________
2.	A B C D E	____________________
3.	A B C D E	____________________
4.	A B C D E	____________________
5.	A B C D E	____________________
6.	A B C D E	____________________
7.	A B C D E	____________________
8.	A B C D E	____________________
9.	A B C D E	____________________
10.	A B C D E	____________________
11.	A B C D E	____________________
12.	A B C D E	____________________
13.	A B C D E	____________________
14.	A B C D E	____________________
15.	A B C D E	____________________

ANSWER SHEET Name ______________________________

No. 15 REVIEW—Beginning or Advanced (circle one)

Answer	Code reference	Answer	Code reference
1. A B C D E	NA	26. A B C D E	
2. A B C D E	NA	27. A B C D E	
3. A B C D E	NA	28. A B C D E	
4. A B C D E	NA	29. A B C D E	
5. A B C D E	NA	30. A B C D E	
6. A B C D E		31. A B C D E	
7. A B C D E		32. A B C D E	
8. A B C D E		33. A B C D E	
9. A B C D E		34. A B C D E	
10. A B C D E		35. A B C D E	
11. A B C D E		36. A B C D E	
12. A B C D E		37. A B C D E	
13. A B C D E		38. A B C D E	
14. A B C D E		39. A B C D E	
15. A B C D E		40. A B C D E	
16. A B C D E		41. A B C D E	
17. A B C D E		42. A B C D E	
18. A B C D E		43. A B C D E	
19. A B C D E		44. A B C D E	
20. A B C D E		45. A B C D E	
21. A B C D E		46. A B C D E	
22. A B C D E		47. A B C D E	
23. A B C D E		48. A B C D E	
24. A B C D E		49. A B C D E	
25. A B C D E		50. A B C D E	

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