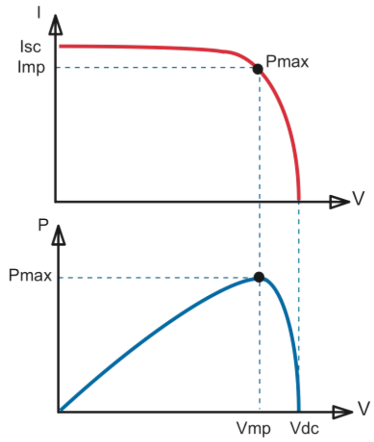
BlueSolar and SmartSolar MPPT Charge Controllers
Overview



Maximum Power Point Tracking (MPPT)

Upper curve:
Output current (I) of a solar panel as function of output voltage (V).
The Maximum Power Point (MPP) is the point Pmax along the curve where the product I x V reaches its peak.

Lower curve:
Output power P = I x V as function of output voltage.
When using a PWM (not MPPT) controller the output voltage of the solar panel will be nearly equal to the voltage of the battery, and will be lower than Vmp.

MPPT Control

SmartSolar Control

VictronConnect Application

Feature highlights common to all models

- Ultra-fast Maximum Power Point Tracking (MPPT).
- Advanced Maximum Power Point Detection in case of partial shading conditions.
- Outstanding conversion efficiency.
- Natural convection cooling.
- Automatic battery voltage recognition.
- Flexible charge algorithm.
- Over temperature protection and power derating when temperature is high.

Sizing options:

- Suitable for a variety of battery voltages. Most models connect to 12, 24, and 48V batteries, some only connect to 12 and 24V batteries, or only to 48V batteries.
- Charge currents rating from 10A all the way up to 100A.
- Maximum PV array Voc voltages ranging from 75V up to 250V.
- Multiple chargers can be used in parallel, for large systems we recommend to use the models with a VE.Can communication port.

PV terminal options:

- TR - one positive and one negative screw terminal.
- MC4 - 3 pairs of paralleled MC4 connectors.

Bluetooth options:

- SmartSolar models have Bluetooth.
- BlueSolar models do not have Bluetooth. They can be retrofitted to have Bluetooth by connecting the VE.Direct Bluetooth Smart dongle. Advantage: the product is not Bluetooth accessible when the dongle is not connected. Note that on the SmartSolar models, Bluetooth can be disabled.

Display options:

- VictronConnect Application. Connects via Bluetooth or via the VE.Direct - USB interface
- MPPT Control. Connects to all models via a VE.Direct cable
- SmartSolar Control Display. Plugs directly into the housing of the larger models
- GX device
- VRM website (GX monitoring device needed)

Communication ports:

- VE.Direct - all models
- VE.Direct and VE.Can - limited models. VE.Can is especially suitable for systems with multiple solar chargers. All units are simply “daisy chained” to each other with a single RJ45 cable between each unit and also between the las unit in the chain and the a GX monitoring device.

Temperature sensor options:

- Internally (all models).
- Externally via the Smart Battery Sense (only SmartSolar models).

Load output options:

- Physical output - On the 10, 15 and 20A models.
- Virtual output - via VE.Direct TX digital output cable and the BatteryProtect or a solid-state relay.

Remotely enabling and disabling the charger:

- All larger units feature the Victron standard remote on/off terminals. All models that don’t feature an onboard Remote on/off terminal can be remotely controlled by using the VE.Direct non inverting remote on/off cable – ASS030550310. Note that this prohibits using the VE.Direct port for anything else.

Firmware update options:

- Local updates via the VictronConnect Application (via Bluetooth or USB-VE.Direct interface)
- Remote updates via VRM website and a GX device

Optional accessories:

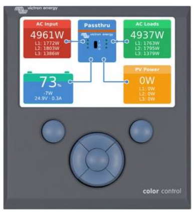
- VictronConnect Application (free download)
- Wire boxes, to cover and protect the terminals. See table on page 2 for wire box types
- Control and display panels: MPPT control or SmartSolar control)
- GX monitoring device (CCGX Venus GX or Octo GX)
- Data cables: VE.Direct cable, RJ45 Cable (CanBus models only) USB-VE.Direct interface
- External control cables: TX cable, non-inverting cable
- Bluetooth dongle (for non-smart models)

More information:

- To access the above-mentioned documents or information: press the search button on our website and enter the appropriate search word.

BlueSolar Charge Controller	Load output	Battery voltage	Optional display	Bluetooth	Com. port	Remote on-off	Programmable relay	Wire Box
75/10	15A	12/24	MPPT control	Optional dongle	VE.Direct	No	No	S 75-10/15
75/15	15A	12/24	MPPT control	Optional dongle	VE.Direct	No	No	S 75-10/15
100/15	15A	12/24	MPPT control	Optional dongle	VE.Direct	No	No	S 100-15
100/30	No	12/24	MPPT control	Optional dongle	VE.Direct	No	No	M
100/50	No	12/24	MPPT control	Optional dongle	VE.Direct	No	No	M
150/35	No	12/24/36/48	MPPT control	Optional dongle	VE.Direct	No	No	M
150/45-Tr	No	12/24/36/48	MPPT control	Optional dongle	VE.Direct	No	No	L
150/45-MC4	No	12/24/36/48	MPPT control	Optional dongle	VE.Direct	No	No	L
150/60-Tr	No	12/24/36/48	MPPT control	Optional dongle	VE.Direct	No	No	L
150/60-MC4	No	12/24/36/48	MPPT control	Optional dongle	VE.Direct	No	No	L
150/70-Tr	No	12/24/36/48	MPPT control	Optional dongle	VE.Direct	No	No	L
150/70-MC4	No	12/24/36/48	MPPT control	Optional dongle	VE.Direct	No	No	L

SmartSolar Charge Controller	Load output	Battery voltage	Optional display	Bluetooth	Com. port	Remote on-off	Programmable relay	Wire Box
75/10	15A	12/24	MPPT control	Built-in	VE.Direct	No	No	S 75-10/15
75/15	15A	12/24	MPPT control	Built-in	VE.Direct	No	No	S 75-10/15
100/15	15A	12/24	MPPT control	Built-in	VE.Direct	No	No	S 100-15
100/20	20A	12/24	MPPT control	Built-in	VE.Direct	No	No	S 100-20
100/20-48V	1A	48	MPPT control	Built-in	VE.Direct	No	No	S 100-20
100/30	No	12/24	MPPT control	Built-in	VE.Direct	No	No	M
100/50	No	12/24	MPPT control	Built-in	VE.Direct	No	No	M
150/35	No	12/24/36/48	MPPT control	Built-in	VE.Direct	No	No	M
150/45-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
150/45-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
150/60-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
150/60-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
150/70-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
150/70-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
150/70-Tr-CAN	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct & VE.Can	Yes	Yes	L
150/85-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL
150/85-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL
150/100-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL
150/100-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL
150/100-Tr-CAN	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct & VE.Can	Yes	Yes	XL
250/60-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
250/60-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
250/70-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
250/70-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	L
250/85-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL
250/85-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL
250/100-Tr	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL
250/100-MC4	No	12/24/36/48	MPPT ctrl & SmartSolar ctrl	Built-in	VE.Direct	Yes	Yes	XL


Color Control GX


Venus GX


Octo GX


Smart Battery Sense


VE.Direct Bluetooth Smart Dongle


VE.Direct to USB interface

victron energy
BLUE POWER

SmartSolar Charge Controllers with load output

MPPT 75/10, 75/15, 100/15, 100/20, 100/20-48V

SmartSolar Charge Controller
MPPT 75/15

Bluetooth sensing
Smart Battery Sense

Bluetooth sensing
BMV-712 Smart Battery Monitor

Bluetooth Smart built-in

The wireless solution to set-up, monitor, update and synchronise SmartSolar Charge Controllers.

VE.Direct

For a wired data connection to a Color Control GX, other GX products, PC or other devices

Ultra-fast Maximum Power Point Tracking (MPPT)

Especially in case of a clouded sky, when light intensity is changing continuously, an ultra-fast MPPT controller will improve energy harvest by up to 30% compared to PWM charge controllers and by up to 10% compared to slower MPPT controllers.

Load output

Over-discharge of the battery can be prevented by connecting all loads to the load output. The load output will disconnect the load when the battery has been discharged to a pre-set voltage (48V model: interface with a relay).
Alternatively, an intelligent battery management algorithm can be chosen: see Battery Life.
The load output is short circuit proof.

Battery Life: intelligent battery management

When a solar charge controller is not able to recharge the battery to its full capacity within one day, the result is often that the battery will continually be cycled between a 'partially charged' state and the 'end of discharge' state. This mode of operation (no regular full recharge) will destroy a lead-acid battery within weeks or months.
The Battery Life algorithm will monitor the state of charge of the battery and, if needed, day by day slightly increase the load disconnect level (i.e. disconnect the load earlier) until the harvested solar energy is sufficient to recharge the battery to nearly the full 100%. From that point onwards, the load disconnect level will be modulated so that a nearly 100% recharge is achieved about once every week.

Programmable battery charge algorithm

See the software section on our website for details

Day/night timing and light dimming option

See the software section on our website for details

Internal temperature sensor

Compensates absorption and float charge voltage for temperature.

Optional external battery voltage and temperature sensing via Bluetooth

A Smart Battery Sense or a BMV-712 Smart Battery Monitor can be used to communicate battery voltage and temperature to one or more SmartSolar Charge Controllers.

SmartSolar Charge Controller	MPPT 75/10	MPPT 75/15	MPPT 100/15	MPPT 100/20	MPPT100/20-48V
Battery voltage (auto select)	12/24V				12/24/48V
Rated charge current	10A	15A	15A	20A	20A
Nominal PV power, 12V 1a,b)	145W	220W	220W	290W	290W
Nominal PV power, 24V 1a,b)	290W	440W	440W	580W	580W
Nominal PV power, 48V 1a,b)	n. a.	n. a.	n. a.	n. a.	1160W
Max. PV short circuit current 2)	13A	15A	15A	20A	20A
Automatic load disconnect	Yes				
Max. PV open circuit voltage	75V		100V		
Peak efficiency	98%				
Self-consumption	12V: 25 mA 24V: 15 mA				25 / 15 / 10 mA
Charge voltage 'absorption'	14,4V / 28,8V (adjustable)				14,4V / 28,8V / 57,6V (adj.)
Charge voltage 'float'	13,8V / 27,6V (adjustable)				13,8V / 27,6V / 55,2V (adj.)
Charge algorithm	multi-stage adaptive				
Temperature compensation	-16 mV / °C resp. -32 mV / °C				
Max. continuous load current	15A			20A	20A / 20A / 1A
Low voltage load disconnect	11,1V / 22,2V / 44,4V or 11,8V / 23,6V / 47,2V or Battery Life algorithm				
Low voltage load reconnect	13,1V / 26,2V / 52,4V or 14V / 28V / 56V or Battery Life algorithm				
Protection	Output short circuit / Over temperature				
Operating temperature	-30 to +60°C (full rated output up to 40°C)				
Humidity	95%, non-condensing				
Data communication port	VE.Direct (see the data communication white paper on our website)				
ENCLOSURE					
Colour	Blue (RAL 5012)				
Power terminals	6 mm^2 / AWG10				
Protection category	IP43 (electronic components), IP22 (connection area)				
Weight	0,5 kg		0,6 kg	0,65 kg	
Dimensions (h x w x d)	100 x 113 x 40 mm		100 x 113 x 50 mm	100 x 113 x 60 mm	
STANDARDS					
Safety	EN/IEC 62109-1, UL 1741, CSA C22.2				

1a) If more PV power is connected, the controller will limit input power.
1b) The PV voltage must exceed Vbat + 5V for the controller to start.
Thereafter the minimum PV voltage is Vbat + 1V
2) A PV array with a higher short circuit current may damage the controller.

Data communication with Victron Energy products

Matthijs Vader

Introduction

Many of our customers integrate our products into their own systems, using data communication protocols. There are several options to establish data communication. The purpose of this document is to explain the different options, and help you choose one.

Communicating to a complete system? Use Modbus-TCP

Rather than going for direct communication with Inverters, battery monitors or Solar chargers, consider using ModbusTCP. This has two advantages:

1. ModbusTCP is easier than most other protocols
2. Retrieve precalculated system, as available on the Color Control GX

Looking for internet related protocols? Use the JSON API or MQTT

Once uploaded to the VRM Portal by a Color Control GX, or another device running our Venus OS, the data can be requested via our VRM JSON API.

Besides that API, MQTT is also available.

Products with data communication

The following product lines have a data communication port, with protocol information available for 3rd parties:

Product range	Products in that range	Onboard comm. port	3rd party protocol	How to connect
Color Control GX	Gateway to almost all Victron products that have a data communication port	Ethernet	Modbus-TCP	Modbus-TCP
Battery monitoring	BMV-600S, BMV-602S and BMV-600HS	BMV-60xS Text (TTL)	CAN and BMV Text	Via interface
	BMV-700 and BMV-700H	VE.Direct	VE.Direct	Direct or via interface
Inverters	Phoenix Inverter models from 1200 to 5000VA	VE.Bus	CAN and MK2/MK3	Via interface
	Phoenix Inverter 250, 375 and 500VA	VE.Direct	VE.Direct	Direct of via interface
Multi Inverter/chargers	Complete range: all Multis and Multi compacts	VE.Bus	CAN and MK2/MK3	Via interface
Quattro's	Complete range	VE.Bus	CAN and MK2/MK3	Via interface
Skylla-i/-IP44 battery chargers	Complete range	VE.Can	CAN	Direct
BlueSolar Chargers	BlueSolar MPPT 150/70 and 150/85 (VE.Can)	VE.Can	CAN	Direct
	BlueSolar MPPT 75/10 to 150/100 (VE.Direct)	VE.Direct	VE.Direct	Direct or via interface
Lynx Ion (Lithium Ion BMS)	Lynx Ion, Lynx Ion + Shunt and Lynx Ion BMS	VE.Can	CAN	Direct
Lynx Shunt 1000A VE.Can	Only the Canbus version.	VE.Can	CAN	Direct
Peak Power Pack	Complete range	VE.Direct	VE.Direct	Direct or via interface

Protocol overview

At Victron Energy we have the following protocols:

Protocol	3rd party connections allowed	Topology	Physical	International standard	More information
Modbus-TCP	Yes (preferred)		TCP/IP	Modbus-TCP	Further down in this document
VE.Direct	Yes (preferred)	Point to point	RS232 / TTL	Proprietary	On our website, see next page for link
VE.Can / NMEA2000	Yes	Drop cables / Daisy chain	CANBUS	J1939 & NMEA2000	
VE.Bus	No	Daisy chain	RS485	Proprietary	See MK2/MK3 protocol
MK2/MK3 Protocol	Yes	Point to point	RS232	Proprietary	On request
BMV Text	Yes	Point to point	RS232	Proprietary	On our website, see next page for link
VE9bit RS485	No	Point to point	RS485	Proprietary	Deprecated

VE.Net	No	Daisy chain	RS485	Proprietary	Deprecated

And then there are JSON and MQTT, see introduction.

NMEA2000 Certified products

This table lists all Victron products that have an NMEA2000 or VE.Can communication port, and the status of NMEA2000 certification. Note that the mentioned NMEA2000 database version number is the database version used by the latest firmware of each product.

Part number	Product	NMEA2000 Certified?	NMEA2000 DB
ASS030520000	BMV-60xS to NMEA2000 interface	Yes	v1.301
ASS030520100	VE.Bus to NMEA2000 interface	Pending a firmware update due to the new AC PGN's	
LYN040102100	Lynx Shunt VE.Can	Yes	v1.301
LYN040301000	Lynx Ion	No	
LYN010100100	Ion Control	No	v1.301
SCC010070000	BlueSolar MPPT 150/70 (12/24/36/48V-70A)	No	v2.000
SKI024080000	Skylla-i battery charger 24V/80A (1+1)	Yes	v2.000
SKI024080002	Skylla-i battery charger 24V/80A (3)	No	v2.000
SKI024100000	Skylla-i battery charger 24V/100A (1+1)	Yes	v2.000
SKI024100002	Skylla-i battery charger 24V/100A (3)	No	v2.000

Staying up-to-date

Send an email, asking to be on the protocol-mailing-list. If you have received protocol documentation from us by email, you are on this list automatically.

Details per protocol

VE.Can / NMEA2000

Canbus is the preferred protocol for third parties to communicate with our products. Our CANbus protocol is based on the NMEA2000 and J1939 protocols.

Further down in this document is a list per product with supported NMEA2000 PGNs. All data and settings that are not covered by the NMEA2000 standard PGNs are available through proprietary PGNs. More information is in the manuals of the Canbus-enabled products on our website, and in the document "VE.Can registers - public.docx". Look for it on the Whitepapers page on our website.

Detailed information on the NMEA2000 PGN's is available for purchase on the NMEA website. See the NMEA 2000® Appendix B POWER SUBSET.

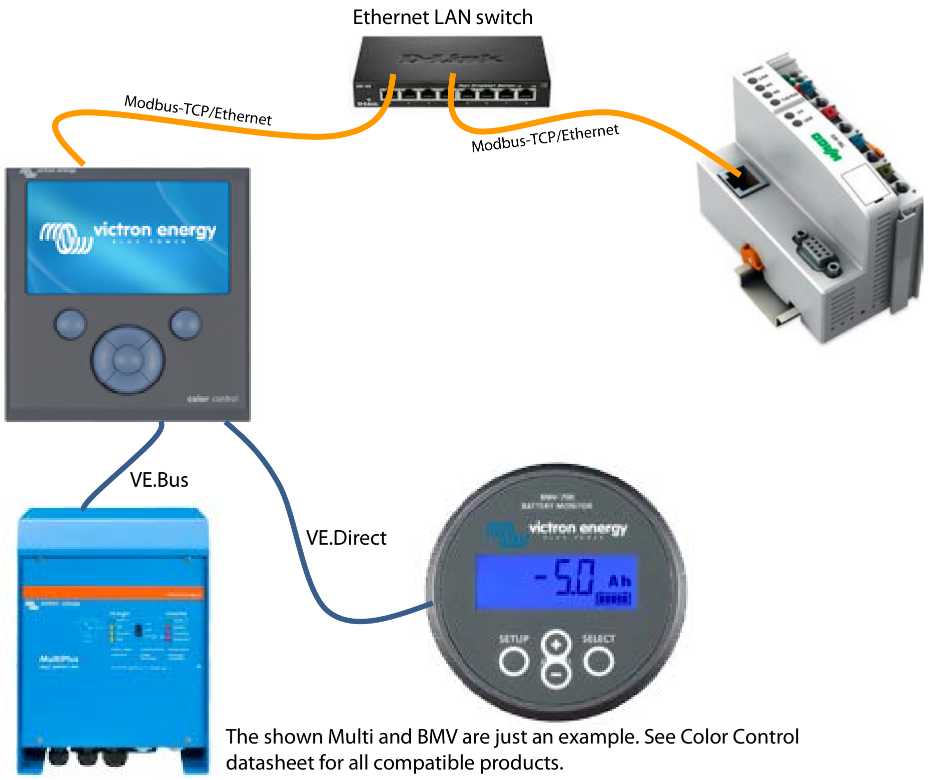
VE.Direct

VE.Direct is a combination of what we used to call the HEX protocol and the BMV text protocol. It combines the advantages of both: in text-mode the products automatically transmit all important parameters every second. To implement code which reads and interprets this data is extremely simple. If more functionality is needed, such as changing settings, one can switch to the HEX protocol. Communication ports on new Victron products will always be either VE.Can or VE.Direct ports. The VE.Direct port is for products where a full Canbus connection adds to much cost. VE.Direct documentation is available on our website.

Modbus TCP
The industry standard Modbus TCP is a well-known and open communication protocol, used in many PLCs and SCADA systems. The Victron Color Control GX acts as a Modbus-TCP gateway. Connect it to the Victron products that you want to monitor, and then communicate from your PLC to the Ethernet LAN port on the Color Control GX. It allows reading information, and writing operational parameters, such as Multi on/off and input current limiter settings. Changing configuration settings, such as battery capacity or float or absorption voltages, is not yet possible.

Check the Color Control GX Datasheet to find out which products are supported by the Color Control GX.

We use the default Modbus TCP port number, which is 502. The unit id, sometimes called 'slave address', specifies what product connected to the CCGX needs to be addressed. See the tab 'Unit ID mapping' in the Modbus-TCP excel sheet. The register addresses are listed on the first tab of the excel sheet, in column C. There are two data types, uint16 and int16. After receiving the value, divide it by the Scale factor to get the value in the unit as specified in column G.



VE.Bus

VE.Bus is our proprietary protocol used by the Inverters to synchronize their AC outputs. There are VE.Bus communication ports on our Inverters, Multi's and Quattro's. The synchronization feature is mission-critical. Direct third-party connections are not allowed. All interfacing has to be done via Modbus TCP (preferred), "VE.Bus to CANbus/NMEA2000 interface", or via the MK2/MK3:

MK2/MK3 Protocol

The MK2.2 and MK3 provide a galvanically isolated connection to VE.Bus, and it translates the VE.Bus protocol into the "MK2/MK3 Protocol". The MK2/MK3 Protocol allows reading information, turning the device on and off, changing the current limits and configuring a device.

Note that implementing the MK2/MK3 protocol is a task which is not to be underestimated. It is a complicated protocol, and unless there is a huge commercial interest, we cannot give any support or help during the implementation(!). Make sure to have a look at Appendix 2 in that document, which is an annotated example for a typical UI.

Note that there is no difference in protocol between the MK2 and MK3 interfaces.

BMV-60xS Text Protocol (deprecated)

All of our BMV-600's feature a serial communication interface which allows simple access to detailed battery status information. This protocol only allows reading information from the battery monitor. Setting parameters or 'synchronizing' the BMV is not possible. Note that this Text protocol is now part of the VE.Direct protocol. The successor of the BMV-600, the BMV-700, works with the VE.Direct protocol. See earlier in this document for more information on the VE.Direct protocol.

VE.Net (deprecated)

VE.Net is a proprietary protocol used by some of our control panels. Third party connections are not possible. New products will not be equipped with VE.Net. They are equipped with VE.Can or VE.Direct instead.

VE 9bit RS485 (deprecated)

This protocol was used to communicate to our Multi's and Quattro's before they had paralleling and three phase capabilities. This protocol is no longer maintained. Documentation is not available.

Accessories to communicate with VE.Bus (Inverter, Multi, Quattro)

Partnumber	Product name	RS-232	Canbus	SMS	Web	Ethernet	SNMP
ASS030120200	Victron Interface MK2.2b – RS232	X					
ASS030130000	Victron Interface MK2-USB	X[1]					
ASS030140000	Victron Interface MK3-USB	X[2]					
ASS030520100	VE.Bus to NMEA2000 interface		X				
ASS030520105	VE.Bus to VE.Can interface		X[3]				
BPP000300100R	Color Control GX		X		X	X	
VGR000200000	Victron Global Remote 2			X	X		
VGR200100000	Victron Ethernet Remote			X	X	X	X

Accessories to communicate with a VE.Direct product

Partnumber	Product name	RS-232	Canbus	SMS	Web	Ethernet	SNMP
ASS030530000	VE.Direct to USB interface						
ASS030520500	VE.Direct to RS232	X					
ASS030520300	VE.Direct to NMEA2000 interface		X				
ASS030520400	VE.Direct to VE.Can interface		X[4]				
BPP000300100R	Color Control GX		X		X[5]	X	

1 The Victron Interface MK2-USB is an MK2.2b with built-in RS232 to USB Converter.
2 The Victron interface MK3-USB also has a built-in RS232 to USB Converter. There is no RS232 version of the MK3 available.
3 The VE.Bus to VE.Can interface is the same as the VE.Bus to NMEA2000 interface. The only difference is the canbus connection. The VE.Bus to VE.Can interface has two RJ-45 sockets; the other one has the NMEA2000 Micro-c plug.
4 The VE.Direct to VE.Can interface is the same as the VE.Direct to NMEA2000 interface. The only difference is the canbus connection. The VE.Direct to VE.Can interface has two RJ-45 sockets; the other one has the NMEA2000 Micro-c plug.
5 Data, including historic data, can be accessed via. All data is stored in our database. Logs can be downloaded, see chapter "Getting the data from VRM".

Accessories to communicate with a BMV-60xS battery monitor

Partnumber	Product name	RS-232	Canbus	SMS	Web	Ethernet	SNMP
ASS030071000	BMV Data Link RS232	X					
ASS030520000	BMV-60xS to NMEA2000 interface		X				
ASS030520020	BMV-60xS to VE.Can interface		X				
VGR000200000	Victron Global Remote 2[6]			X	X		
VGR200100000	Victron Ethernet Remote[7]			X	X	X[8]	X

FAQ – General

Q1: Do I need an MK2 or MK3 for each product in a system with multiple VE.Bus products in parallel or three-phase?
No. Per VE.Bus system you need only one of those interfaces.

Q2: Do I need a VE.Bus to NMEA2000 interface for each product in a system with multiple VE.Bus products in parallel or three-phase?
No. Per VE.Bus system you need only one of those interfaces.

Q3. Why is it not possible that my application directly communicates with the Victron via VE.Bus messages?
VE.Bus is our proprietary protocol used by the Inverters to synchronize their AC outputs. It is not possible to connect directly because as soon as other people are on that bus we cannot guarantee the proper working of paralleled and three-phase operations. Note that even in all our own display and control products that talk to VE.Bus, for example the Color Control GX and the VE.Bus to NMEA2000 interface, we have an MK2/MK3 IC. So even at Victron we are not talking directly to VE.Bus.

FAQ – Canbus communication

Q10: Which version of J1939 is actually implemented (J1939/11, J1939/15, J1939/14...)?
We are using the NMEA2000 protocol, which is based on ISO 11783-3 (Datalink Layer) and ISO 11783-5 (Network management). ISO 11783-3 is virtually identical to the SAE data link layer SAE J1939-21. The network layer (ISO 1183-5) is based on SAE J1939-81.

Q11: Is the bus speed 250kbps?
Yes, the bus speed is 250kpbs

Q12: Is the identifier extended (29-bits)?
Yes, the ISO11783 standard defines the use of the extended identifier (29-bits).

Q13: Are the data fields always 8 bytes long?
Yes, the data fields are always 8 bytes long.

Q14: Can you send us the PGN definition?
This detailed documentation has to be bought from the NMEA website. You can buy the Power PGN's. The product name is "NMEA 2000® Appendix B POWER SUBSET PGN (NMEA Network Messages) – Electronic", USD 500,= for non-members. Note that for the VE.Bus AC messages you need some SAE documentation as well. More information on the used PGN's is further down below in this document.

Q15: Are all the messages broadcasted or do they have to be requested/polled?
The important messages (AC status, Battery status, etc.) are broadcasted. Others have to be polled.

Q16: Do I need to terminate the canbus?
Yes you do. Use one 120Ohm 0,25W 5% resistor at both ends of the canbus. Connect it between CAN-H and CAN-L. Victron Energy sells a set of VE.Can terminators with part number ASS030700000.

[6] The Victron Global Remote has two communication ports. It can connect to a BMV and a VE.Bus product or system at the same time.
[7] The Victron Ethernet Remote has only one communication port, it can connect to one device.
[8] Data can be accessed via a local, password secured, website, running on a web server in the Victron Ethernet Remote. Note that only the current values can be accessed. Historic data is not available on the local web server.

Q17: Do I need to power the canbus?
That differs per product. Some products power the canbus themselves others don`t. To power the canbus, supply anywhere between 9 and 36Volts to V+ and V-. See also the pin outs below. A small list at the time of writing:

Skylla-i	Powers the canbus, isolated
Skylla-IP44	Powers the canbus, non-isolated
Lynx Shunt VE.Can	Powers the canbus, isolated
Lynx Ion BMS	Powers the canbus, isolated
Lynx Ion + Shunt	Powers the canbus, isolated
Lynx Ion	Does not power the canbus, depends on the Lynx Shunt VE.Can to power both the VE.Can and the BMS canbus
Color Control GX	Does not power the canbus, and needs a powered canbus to operate
VE.Bus to NMEA2000 interface	Does not power the canbus, and needs a powered canbus to operate
VE.Bus to VE.Can interface	Does not power the canbus, and needs a powered canbus to operate
BMV-60xS to NMEA2000 interface	Does not power the canbus, and needs a powered canbus to operate
VE.Direct to NMEA2000 interface	Does not power the canbus, and needs a powered canbus to operate
VE.Direct to VE.Can interface	Does not power the canbus, and needs a powered canbus to operate
BlueSolar MPPT 150/70	Does power the canbus, not isolated. See manual for info on a resistor that is mounted to prevent ground loops.

The mentioned 9 to 36Volt is conform the NMEA2000 standards. Most of our products accept an input voltage from 7 to 70VDC, see the datasheets.

Q18: What is the difference between NMEA2000 and VE.Can?
The only difference is in the physical connection and the isolation:

	VE.Can	**NMEA2000**
Physical connector	RJ-45	Micro-C
Isolation	Differs per product, see Q17 above and/or datasheet	Always

Q19: What is the pin out of VE.Can?
The two RJ-45 sockets on each product that has VE.Can are paralleled. Note that we use RJ-45 also for VE.Bus or VE.Net connections, see the datasheet to make sure that your product has a VE.Can connection.

1	Not connected
2	Not connected
3	NET-C (V-)
4	Not connected
5	Not connected
6	NET-S (V+)
7	CAN-H
8	CAN-L

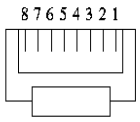


Figure 1:
End view of RJ45 Plug

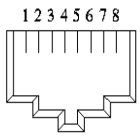
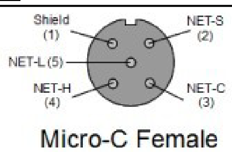


Figure 2:
Looking into an RJ45 Jack

Q20: What is the pin out of NMEA-2000?

1(brown):	Shield
2(red):	NET-S (V+)
3(black):	NET-C (V-)
4(white):	NET-H (CAN-H)
5(blue):	NET-L (CAN-L)



Q21: I do not want to implement the full ACL procedure, what fixed source address shall I use?
Address 0xFE is reserved for when you cannot perform an ACL (Address Claim) procedure. You are free to use this address. See also Q24.

Q22: What is Victron's NMEA2000 manufacturer code?
It is 358 (0x166)

Q23: Instances: I have multiple BMV's (or another canbus product) in the same network, how do I address them?
You need to use instances to differentiate between multiple similar products in the same network. There are different types of instances within NMEA2000:

Device instance
The device instance is sent in PGN 0xEE00, ISO Address Claim, as a combined field of Device Instance Lower (ISO ECU Instance) and Device Instance Upper (ISO Function Instance).
The Device instance is used by Victron chargers (Skylla-i/-IP44, VE.Can MPPTs) to configure them in the same group and synchronize them.

Data instances (Battery Instance, DC Detailed Instance, Switch bank instance, etc.)
These instances are embedded in the different PGN's. All Victron products support changing these instances through a complex write, PGN 0x1ED00, Complex Request Group Function Code 5, write fields.

System instance
The system instance is also sent in PGN 0xEE00, field 8. It is not used. All Victron products do support changing this instance by sending a complex command.

Instance conflicts
If you have connected multiple products sending out the same PGN with the same data instance number, you might encounter a data instance conflict. Typically this can be seen on display's showing an alternating value. E.g. The VE.Direct to NMEA2000 interface and VE.Bus to NMEA2000 interface are both sending out PGN 127508 with Battery instance 0. To solve this issue one of the Battery instances needs to be changed to another (unique) number. We recommend to change the Battery instance of the VE.Bus to NMEA2000 instance to 5.

.

Display manufacturers
The display manufacturers use different types of instances to show data for multiple batteries, inverters or chargers:

Garmin needs the data-instances to be different.

Raymarine needs the device instance to be different in order to show information for (for example) multiple batteries. They use the data-instance to connect multiple products, for example gps-es, as a way of redundancy.

Maretron sometimes needs the data-instances to be different, and some other times they need to device instance to be different.
Note: this information about other manufacturers is mostly learned by experience. If you have more information about this, which could be useful to others, please let us know via mvader@victronenergy.com.

Q24: Do the Victron VE.Can and NMEA2000 products used fixed network address or do they support NMEA address claim ISO 602928?
All our products have implemented the address claim procedure. See also Q21.

Q25: I want to read the State of Charge (0 to 100%) as calculated by the Multis and Quattros. I do understand that this SOC is only reliable if there are no DC loads or other battery chargers in the system (almost impossible on a boat, but in a self-consumption system this is very possible). And I cannot find the SOC in the PGNs.
Correct, the information is in PGN 127506, but transmission of that PGN is disabled by default, because it is not valid in all systems. To enable transmission of this PGN, change the transmission interval. To do this at protocol level, see NMEA2000 documentation, PGN 126208 - NMEA - Request group function (field 1 = 0x00). And then field 3, transmission interval. To do this at PC level, use Actisense NMEA Reader or other PC software that has this functionality.

Q26: Which products have a bag of VE.Can RJ-45 terminators included?
These products are shipped with two pieces of VE.Can RJ-45 terminators:

- Color Control GX
- MPPT 150/70 and MPPT 150/85 Solar Charge Controllers
- Lynx Ion + Shunt all models
- Lynx Ion BMS all models
- Lynx Shunt VE.Can
- VE.Bus to VE.Can interface
- VE.Direct to VE.Can interface
- Skylla-i control
- CANUSB

These products are shipped without:

- Ion Control (not necessary since terminators *are* included with the Lynx Ion + Shunt)
- BMV-60xS to VE.Can interface
- VE.Can to NMEA2000 Micro-C male cable
- VE.Can resistive tank sensor (not necessary, terminators are included with the CCGX)

Note that it will normally not be necessary to purchase the terminators separately.

Canbus PGN overview per product

Use below tables to see where to find what data. There is a freely available PDF file on the NMEA2000 website that also gives a good overview. Go to, and then the link called "NMEA2000 Parameter Group Descriptions (Messages) with Field Description". To get the detailed information in order to decode the PGNs, see Q14 in the FAQs.

VE.Bus products (Multi's, Quattro and Inverters)

Data	PGN Name	PGN dec	PGN hex	Field	Remarks
Battery voltage	Battery Status	127508	0x1F214	2	
Battery current	Battery Status	127508	0x1F214	3	
State of Charge (%)	DC Detailed Status	127506	0x1F212	4	This PGN is disabled by default, since the reported value is only valid in systems with no other chargers or dc loads. Use the proper NMEA method to enable it, which is a complex request.
Battery temperature	Battery Status	127508	0x1F214	4	
Charger on/off switch	Charger Status	127507	0x1F213	5	
Charge state	Charger Status	127507	0x1F213	3	Off, bulk, absorption, float etcetera.
Inverter on/off switch	Inverter Status	127509	0x1F215	5	
Inverter Operating State	Inverter Status	127509	0x1F215	4	Off, inverting, etcetera.
L1 AC input voltage	J1939-75 PGN	65014	0xFDF6		AC input information is sent from a different network address than all other PGNs. To distinguish, use the device function code from the ACL PGN, which is "154 AC Input monitor" for the AC input information. All other PGN's are sent with device function code "153 Inverter". See manual for more information.
L1 AC input current	J1939-75 PGN	65014	0xFDF6		
L1 AC input frequency	J1939-75 PGN	65014	0xFDF6		
L1 AC input power	J1939-75 PGN	65013	0xFDF5		
L1 AC output voltage	J1939-75 PGN	65014	0xFDF6		These parameters are sent per phase, see manual for information about all phases.
L1 AC output current	J1939-75 PGN	65014	0xFDF6		
L1 AC output frequency	J1939-75 PGN	65014	0xFDF6		
L1 AC output power	J1939-75 PGN	65013	0xFDF5		
Warnings and alarms	Binary Switch Bank Status	127501	0x1F20D		Switch bank instance 0
LED states	Binary Switch Bank Status	127501	0x1F20D		Switch bank instance 1. This message is by default not enabled, see manual on how to enable it.

The Battery instance from PGNs 127508 (field 1), DC Instance from PGN 127506 (field 2) and PGN 127509 (field 3) and Charger Instance from PGN 127507 (field 1) are the same number. Changing one of the instances will change all of the mentioned instances.

Skylla-i/-IP44 battery charger family

Data	PGN Name	PGN dec	PGN hex	Field	Remarks
Battery voltage	Battery Status	127508	0x1F214	2	The 3-output model has 3 instances of PGN 0x1F214, one for each output. Field 1 of this PGN, Battery Instance is used to distinguish between them.
Battery current	Battery Status	127508	0x1F214	3	
Battery temperature	Battery Status	127508	0x1F214	4	
Relay and alarms	Binary Switch Bank Status	127501	0x1F20D		
Charger state	Converter Status	127750	0x1F306	3	Off, bulk, absorption, float etcetera.
AC input current	AC Power / Current Phase	127744	0x1F300	3	AC RMS Current
Charger on/off	Charger Status	127507	0x1F213	5	DEPRECATED: PGNs 127507 and 127503 are deprecated in favor of 127750 and 127744 They are not being transmitted by default. They can still be requested though, and also they can be configured to be transmitted on an interval.
Charge state	Charger Status	127507	0x1F213	3	
AC input current[9]	AC Input Status	127503	0x1F20F	7	
Equalization pending	Charger Status	127507	0x1F213	6	
Equal. time remaining	Charger Status	127507	0x1F213	8	

Note that the Skylla-i/-IP44 will switch off when there is no mains available. It will therefore also stop sending and responding to Canbus messages.

[9] The AC Input Status PGN 127503 is not present on the Skylla-IP44

BlueSolar MPPT 150/70 and 150/85

Data	PGN Name	PGN dec	PGN hex	Field	Remarks
Battery voltage	Battery Status	127508	0x1F214	2	Battery instance 0
Battery current	Battery Status	127508	0x1F214	3	Battery instance 0
Battery temperature	Battery Status	127508	0x1F214	4	Battery instance 0
PV voltage	Battery Status	127508	0x1F214	2	Battery instance 1
PV current	Battery Status	127508	0x1F214	3	Battery instance 1
Relay and alarms	Binary Switch Bank Status	127501	0x1F20D		
Charger state	Converter Status	127750	0x1F306	3	Off, bulk, absorption, float etcetera.
Charger on/off	Charger Status	127507	0x1F213	5	DEPRECATED: PGN 127507 is deprecated in favor of 127750. They are not being transmitted by default. They can still be requested though, and also they can be configured to be transmitted on an interval
Charge state	Charger Status	127507	0x1F213	3	
Equalization pending	Charger Status	127507	0x1F213	6	
Equal. time remaining	Charger Status	127507	0x1F213	8	

The Battery instance for PGNs 127508 can be changed. After you did that, you can still distinguish between the Battery and PV information by looking at the DC detailed status PGN, 127506 0x1F212. It will report the DC Type, field 3, as Battery or Solar Cell. Field 2, DC Instance, equals the Battery instance in the Battery Status PGN for battery and solar information.

BMV-60xS and BMV-700 Battery Monitors

Data	PGN Name	PGN dec	PGN hex	Field	Remarks
Battery voltage	Battery Status	127508	0x1F214	2	Battery Instance 0
Battery current	Battery Status	127508	0x1F214	3	Battery Instance 0
State of Charge (%)	DC Detailed Status	127506	0x1F212	4	DC instance 0
Time Remaining	DC Detailed Status	127506	0x1F212	6	DC instance 0
Consumed Ah	Proprietary VREG 0xEEFF	61439	0xEFFF		Is also broadcasted at 1.5 seconds interval, see manual.
Starter battery voltage	Battery Status	127508	0x1F214	2	Battery Instance 1. Only sent for BMV-602.
Relay and alarms	Binary Switch Bank Status	127501	0x1F20D		See manual for more information

Notes:

- Battery instance 0 and DC Instance 0 are the same instance number, only the name is different in the NMEA2000 documentation.
- Above table is valid for the latest firmware version of the BMV to NMEA2000 interface cable, v1.06. Previous firmware versions used PGN 127502 instead of 127501 to report relay and alarm status.

Lynx Shunt VE.Can

Data	PGN Name	PGN dec	PGN hex	Field	Remarks
Battery voltage	Battery Status	127508	0x1F214	2	Battery instance 0. This voltage is measured before the main fuse.
Fused voltage	Battery Status	127508	0x1F214	2	Battery instance 1. This voltage is measured after the main fuse.
Battery current	Battery Status	127508	0x1F214	3	Battery instance 0
Battery temperature	Battery Status	127508	0x1F214	4	Battery instance 0
State of Charge (%)	DC Detailed Status	127506	0x1F212	4	DC instance 0
Time Remaining	DC Detailed Status	127506	0x1F212	6	DC instance 0
Consumed Ah	Proprietary VREG 0xEEFF	61439	0xEFFF		Is also broadcasted at 1.5 seconds interval.
Relay and alarms	Binary Switch Bank Status	127501	0x1F20D		Switch instance 0

Note that Battery instance 0 and DC Instance 0 are the same instance number, only the name is different in the NMEA2000 documentation.

Lynx Ion, Lynx Ion + Shunt and Lynx Ion BMS

Data	PGN Name	PGN dec	PGN hex	Field	Remarks
Battery pack voltage	Battery Status	127508	0x1F214	2	Battery instance 0
Battery pack current	Battery Status	127508	0x1F214	3	Battery instance 0
Battery pack highest temperature	Battery Status	127508	0x1F214	4	Battery instance 0
State-Of-Charge (SOC)	DC detailed Status	127506	0x1F212	4	DC instance 0
Time-To-Go (TTG)	DC detailed Status	127506	0x1F212	6	DC instance 0
Lowest cell voltage in pack	Battery Status	127508	0x1F214	2	Battery instance 1
Highest cell voltage in pack	Battery Status	127508	0x1F214	2	Battery instance 2
Battery voltage	Battery Status	127508	0x1F214	2	Battery instance 10 t/m 25
Battery temperature	Battery Status	127508	0x1F214	4	Battery instance 10 t/m 25

Notes:

- Both the Lynx Ion and the Lynx Shunt VE.Can are sending Battery pack voltage and Battery pack current. Distinction can only be made on product id.
- Battery instance 0 and DC Instance 0 are the same
- One or more 24V 180Ah batteries together in one system are a Battery pack.
- One 24V 180Ah battery, consisting of 8 cells is a Battery.

DEPRECATED: Getting data from VRM with wget

Use the JSON API for this, instead of wget.

DEPRECATED: VRM Juice API

Use the new JSON VRM API, instead of Juice.

Links to interesting products

Note that we have not tested all these products, and they are not affiliated to Victron Energy in any way. We do not take any responsibility.

Consider using our own Color Control GX as the Victron to ModbusTCP converter, instead of below products.

Document History

Rev.	Date	Name	Details
1		Matthijs Vader	Initial version
2		Matthijs Vader	Changed 9bit protocol from Daisy Chain to point to point.
3		Matthijs Vader	Added FAQ section for the Canbus communication.
4	2012-jan-24	Matthijs Vader	Added names of the VE.Bus and BMV protocol documents. And added link to Canbus manuals on our website.
5	2012-may-3	Matthijs Vader	Canbus is the preferred protocol. Added list of products, and how to connect via Canbus. Added information on the HEX protocol. BMV Protocol is now available on our website. Various rewording and layout changes. Added 'Staying-up-to-date'. Added several items to the FAQ.
6	2012-june-29	Matthijs Vader	Added Q3 to the FAQ (29 bits identifier) Changed Q7 (termination resistors) Inserted Q8 (powering the Canbus)
7	2012-nov-19	Matthijs Vader	Added Q12 (network address without ACL procedure) Added chapter "Canbus PGN overview per product" Renumbered Canbus FAQ
8	2012-nov-21	Matthijs Vader	Added NMEA2000 to Modbus RS485 converter by Offshore Systems (UK) Ltd
9	2013-feb-2	Matthijs Vader	Changed the colors mentioned at Q20, NMEA 2000 cable pin out Added PGN DC Detailed Status 127506 0x1F212 to the VE.Bus PGNs Changed PGN Number 127502 to 127501 in the VE.Bus PGNs Added 7 to 70VDC to Q17 Remarked that VE.Bus Switch bank instance 1 is by default not enabled. Added column to product table: onboard comm. Port Added PGN 127501 to list of Skylla-i and BlueSolar MPPT 150/70 PGNs Added information about instances, Q23 Changed the information in Getting the data from VRM with information for the new VRM website Replaced HEX with VE.Direct
10	2013-apr-20	Matthijs Vader	Added comment about Consumed Ah for BMV-60xs and Lynx Shunt VE.Can Added Q24 Added table on certified products.
11	2013-july-7	Matthijs Vader	Added note that Battery instance and DC instance are the same to BMV-60xS, Lynx Ion and Lynx Shunt VE.Can Updated BMV Canbus table, binary switch bank status instead of control.
12	2013-august-7	Matthijs Vader	Added note that Battery instance and DC instance are the same to BMV-60xS, Lynx Ion and Lynx Shunt VE.Can Updated BMV Canbus table, binary switch bank status instead of control. Fixed typo: a VE.Net to BMV2000 interface was mentioned. Should have been BMV-60xS to NMEA2000.
13	2013-august-13	Matthijs Vader	Added info to Q16, termination
14	2014-february-3	Matthijs Vader	Added part number of our terminators to Q16 Updated VE.Can/NMEA2000 protocol section Added new interfaces (…. to VE.Can interface) Added NMEA2000 database version numbers Added new interfaces such as VE.Direct to RS232 interface Added Modbus-TCP
15	2014-March-24	Matthijs Vader	Updated getting data from VRM with wget section Added VRM JSON API link
16	2014-May-30	Matthijs Vader	Added (JUICE) on page 10. Updated Modbus-TCP: available Added new solar chargers
17	2014-May-31	Matthijs Vader	Added more information and example on Modbus-TCP
18	2014-Sept.-26	Matthijs Vader	Modbustcp now also supports writing values (multi on/off and input current limit) Added Q25 on VE.Bus SOC Added link to changing NMEA2000 instances information on Victron Live.
19	2014-Dec-04	Matthijs Vader	Changed ModbusTCP text: it still said that it was read only in some places. Moved ModbusTCP FAQ to Victron Live.
20	2015-Jan-27	Matthijs Vader	Updated download links, almost all documents are now downloadable from our website instead of needing to ask us by email for one. Added link to Juice API page on Victron Live.
21	2015-Aug-27	Matthijs Vader	Chapter 'Getting data from VRM with wget': changed download link for 'Template to retrieve data'
22	2016-Feb-1	Matthijs Vader	Added Q26; products that are shipped with or without VE.Can RJ-45 terminators
23	2016-Apr-13	Matthijs Vader	Added Phoenix Inverters 250, 3675 and 500VA VE.Direct inverters

			Added link to VE.Direct protocol FAQ as well as VE.Direct RS232 interface More small cleanups and updates left and right
24	2016-Nov-18	Matthijs Vader	Skylla-i and Solar Charger with VE.Can connection: 127503 and 127507 are deprecated in favor of 127750 and 127744
25	2016-Nov-30	Matthijs Vader	Reworded introduction, putting more focus on ModbusTCP Deprecated the Juice and wget methods of getting data from vrm.
26	2017-May-10	Matthijs Vader	Added info on MK3-USB
27	2017-Sept.-21	Martin Bosma	Added info about battery instances for VE.Bus to NMEA 2000/VE.Can interface Added Skylla-IP44 and Lynx Ion BMS Updated text of Q23 and added text about instance conflicts

Which solar charge controller: PWM or MPPT?

20 January 2020

1. Introduction

PWM and MPPT charge controllers are both widely used to charge batteries with solar power.

The PWM controller is in essence a switch that connects a solar array to the battery. The result is that the voltage of the array will be pulled down to near that of the battery.

The MPPT controller is more sophisticated (and more expensive): it will adjust its input voltage to harvest the maximum power from the solar array and then transform this power to supply the varying voltage requirement of the battery plus load. Thus, it essentially decouples the array and battery voltages so that there can be, for example, a 12V battery on one side of the MPPT charge controller and panels wired in series to produce 36V on the other.

It is generally accepted that MPPT will outperform PWM in a cold to temperate climate, while both controllers will show approximately the same performance in a subtropical to tropical climate.

In this paper the effect of temperature is analyzed in detail, and a quantitative performance comparison of both controller topologies is given.

2. The current-voltage curve and the power-voltage curve of a solar panel

The examples throughout the following pages are based on an average 100 W / 36 cell monocrystalline solar panel, with the following specifications:

100 W panel 36 cells				
Pm	100 W	Temp. coeff. of Pm	γ	-0.45 %/°C
Vm	18 V	Temp. coeff. Of Vm	ε	-0.47 %/°C
Im	5.56 A	Temp. coeff. Of Im	δ	0.02 %/°C
Voc	21.6 V	Temp. coeff. Of Voc	β	-0.35 %/°C
Isc	6.12 A	Temp. coeff. Of Isc	α	0.05 %/°C

Table 1: Specifications of the solar panel as used in the examples below

The current-voltage curve of this panel is shown in figure 1

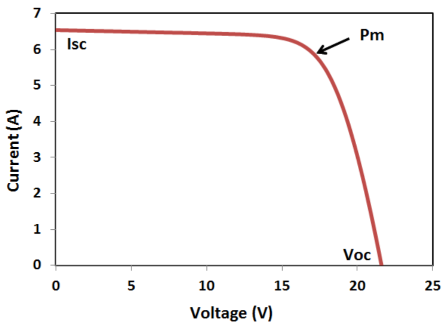
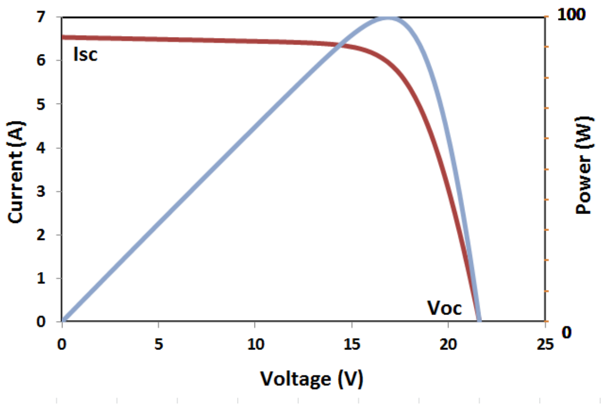


Fig 1: Current-voltage curve of a 100W / 36 cell solar panel
Standard Test Conditions (STC): cell temperature: 25°C, irradiance: 1000 W/m², AM: 1.5

From this basic curve the power-voltage curve can be derived by plotting P = V x I against V.
The result is the blue curve in figure 2 below.



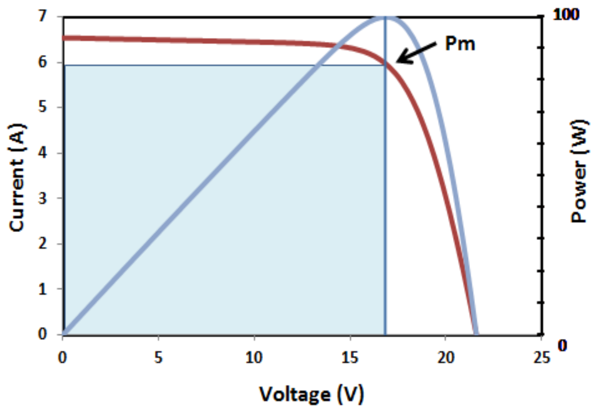
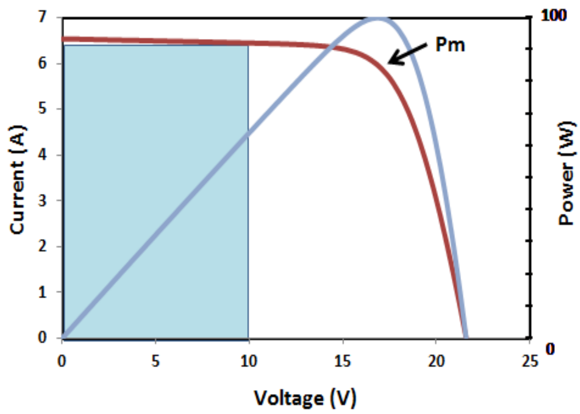


Fig 2: Current-voltage curve (brown) and
power-voltage curve (blue, P = V x I)

Fig. 3: The area of the blue rectangle is
proportional to the product Pm = Vm x Im

Obviously, the power obtained from the panel is zero when it is short circuited (0 x Isc = 0) or when no current is drawn from the panel (Voc x 0 = 0).
In between those two zero power points the product P = V x I reaches a maximum: the Maximum Power Point (Pm = Vm x Im).

The importance of the Maximum Power Point can be visualized as follows:
The product Vm x Im is proportional to the area of the rectangle shown in figure 3. Pm is reached when the area of this rectangle is at its largest. Figure 4 and 5 show two less optimal results obtained when power is harvested at a voltage which is too low or too high.



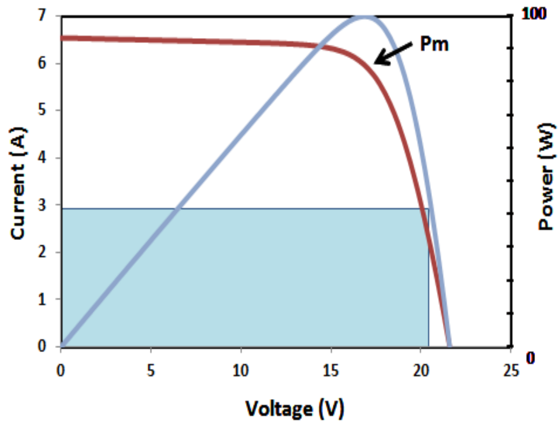


Fig 4: Less power harvested:
voltage is too low

Fig 5: Less power harvested:
voltage is too high

The maximum output of a 100 W solar panel is, by definition, 100 W at STC (cell temperature: 25°C, irradiance: 1000 W/m², AM: 1.5).

As can be seen from figure 3, in the case of a 100 W / 36 cell crystalline panel the voltage corresponding to the Maximum Power Point is Vm = 18 V and the current is Im = 5.56 A.
Therefore 18 V x 5.56 A = 100 W.

Conclusion:
In order to get the maximum out of a solar panel, a charge controller should be able to choose the optimum current-voltage point on the current-voltage curve: the Maximum Power Point. An MPPT controller does exactly that.
The input voltage of a PWM controller is, in principle, equal to the voltage of the battery connected to its output (plus voltage losses in the cabling and controller). The solar panel, therefore, is not used at its Maximum Power Point, in most cases.

3. The MPPT charge controller

As shown in figure 6, the voltage V_m corresponding to the Maximum Power Point can be found by drawing a vertical line through the top of the power-voltage curve, and the current I_m can be found by drawing a horizontal line through the intersection of the V_m line and the current-voltage curve. These values should be equal to the values specified in table 1.

In this example $P_m = 100$ W, $V_m = 18$ V and $I_m = 5.56$ A.
With its microprocessor and sophisticated software, the MPPT controller will detect the Maximum Power Point P_m and, in our example, set the output voltage of the solar panel at $V_m = 18$ V and draw $I_m = 5.56$ A from the panel.

What happens next?
The MPPT charge controller is a DC to DC transformer that can transform power from a higher voltage to power at a lower voltage. The amount of power does not change (except for a small loss in the transformation process). Therefore, if the output voltage is <u>lower</u> than the input voltage, the output current will be <u>higher</u> than the input current, so that the product $P = V \times I$ remains constant.

When charging a battery at $V_{bat} = 13$ V, the output current will therefore be
$I_{bat} = 100$ W / 13 V = 7.7 A.
(Similarly, an AC transformer may supply a load of 4.4 A at 23 VAC (4.4 x 23 = 100 W) and therefore draw 0.44 A from the 230 V mains (230 x 0.44 = 100 W)).

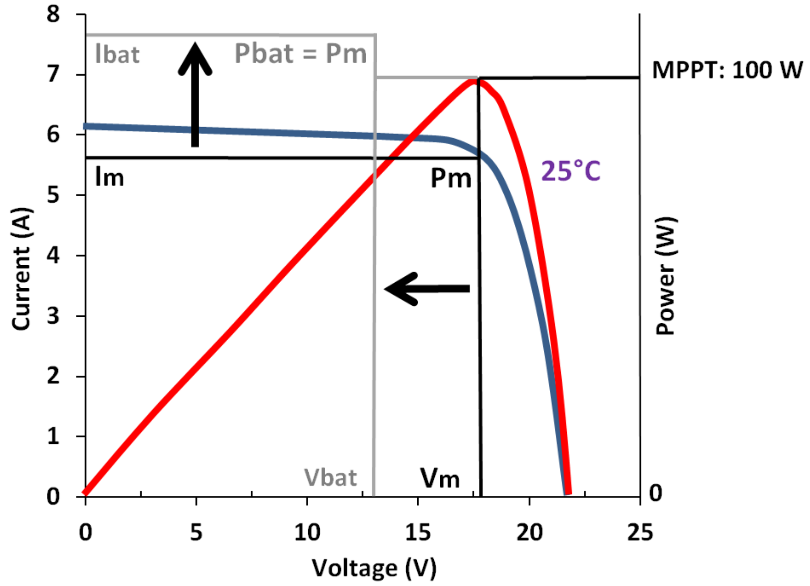


Fig 6: MPPT controller, graphical representation of the DC to DC transformation
$P_m = V_m \times I_m = 18\text{ V} \times 5.6\text{ A} = 100$ W, and
$P_{bat} = V_{bat} \times I_{bat} = 13\text{ V} \times 7.7\text{ A} = 100$ W

4. The PWM charge controller

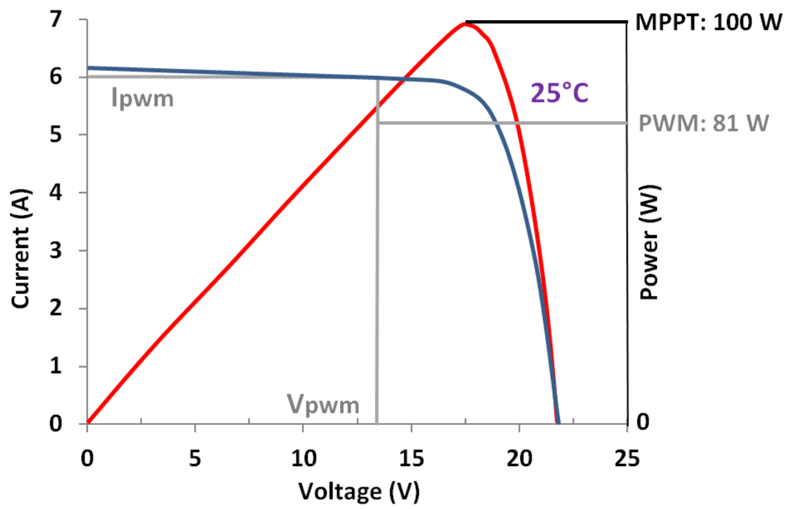


Fig 7: PWM charge controller

In this case the charge voltage imposed on the solar panel can be found by drawing a vertical line at the voltage point equal to Vbat plus 0.5 V. The additional 0.5 V represents the voltage loss in the cabling and controller. The intersection of this line with the current-voltage curve gives the current Ipwm = Ibat.

A PWM controller is <u>not</u> a DC to DC transformer. The PWM controller is a switch which connects the solar panel to the battery. When the switch is closed, the panel and the battery will be at nearly the same voltage. Assuming a discharged battery the initial charge voltage will be around 13 V, and assuming a voltage loss of 0.5 V over the cabling plus controller, the panel will be at Vpwm = 13.5 V. The voltage will slowly increase with increasing state of charge of the battery. When absorption voltage is reached the PWM controller will start to disconnect and reconnect the panel to prevent overcharge (hence the name: <u>P</u>ulse <u>W</u>idth <u>M</u>odulated controller).

Figure 7 shows that in our example, with Vbat = 13 V and Vpwm = Vbat +0.5 V = 13.5 V, the power harvested from the panel is Vpwm x Ipwm = 13.5 V x 6 A = 81 W, which is 19% less than the 100 W harvested with the MPPT controller.

Clearly, at 25°C a MPPT controller is preferable to a PWM controller.

Temperature, however, does have a strong effect on the output voltage of the solar panel. This effect is discussed in the next section.

5. The effect of temperature

5.1 The effect of temperature is much too large to neglect

When a panel heats up due to the sun shining on it, both the open circuit voltage and the Maximum Power Point voltage become lower. The current however remains practically constant. In other words: the current-voltage curve moves to the left with increasing temperature, as shown in figure 8.

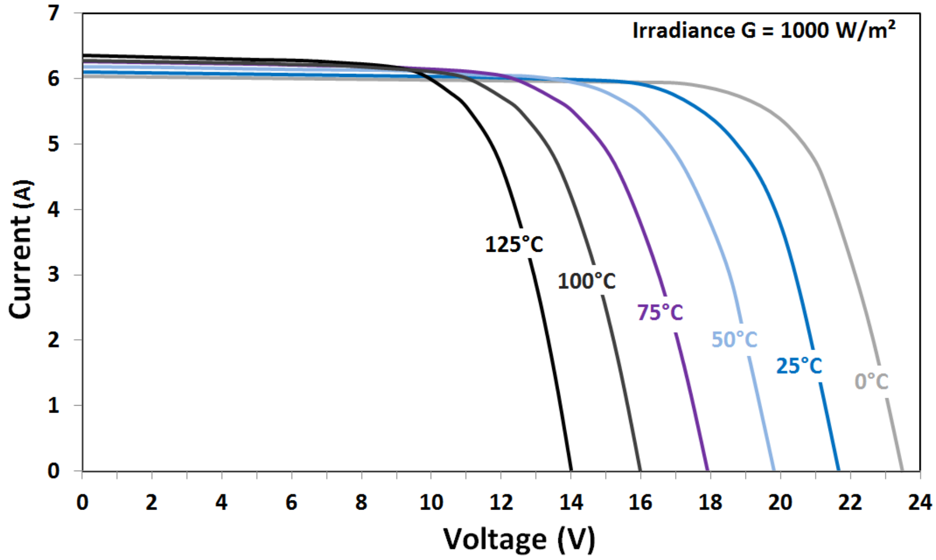


Fig 8: The current-voltage curve moves to the left with increasing temperature

Obviously, as shown in figure 9 below, the Maximum Power Point also moves to the left, and downwards because the product Vm x Im decreases with increasing temperature.

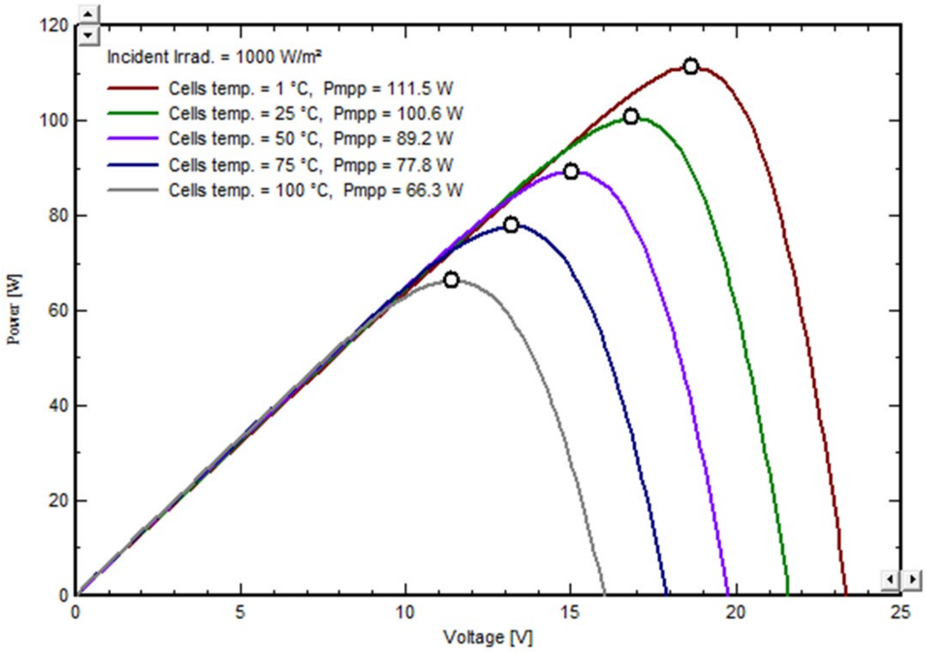


Fig 9: The Maximum Power Point moves to the left and downwards with increasing temperature

5.2. The MPPT controller when cell temperature is 75°C

MPPT power, current and voltage can be derived as follows from the specification of the solar panel:

Pm (75°C) = Pm (25°C) x (1 + (75°C - 25°C) x γ) = 100 x (1 + (50 x – 0.45 / 100) = 77.5 W

And, following the same method:

Im (75°C) = 5.6 A

Vm (75°C) = 13.8 V

And a check: Im (75°C) x Vm (75°C) = 5.6 x 13.8 = 77.3 W. This is a difference of 0.2 W compared to the Pm (75°C), as calculated earlier, so this is close enough and correlates.

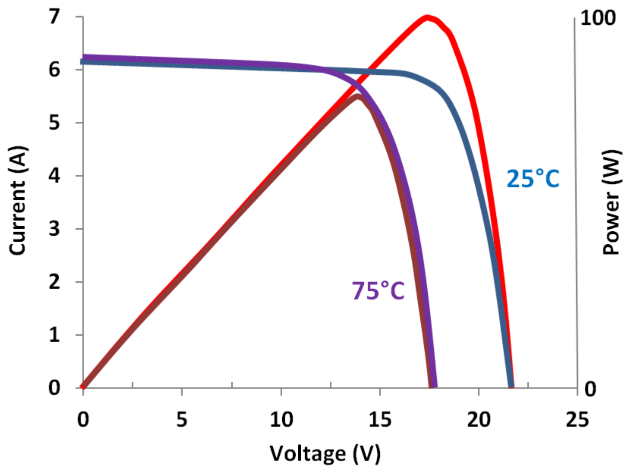


Fig 10: Current-voltage and power-voltage curves at 25°C and 75°C

Note:
Most panel manufacturers do not specify the temperature coefficients of Im (δ) and Vm (ε), and if they do, ε is often given a value which is far too low. The result is that calculating Vm with the help of its temperature coefficient gives an incorrect value (which is far too optimistic in most cases) and Im x Vm will also be wrong, i.e. Im x Vm ≠ Pm which is mathematically impossible.

5.3 The PWM controller when cell temperature is 75°C

Still assuming a battery voltage of 13 V, the voltage imposed on the panel will be 13.5 V. With the help of figure 11 the PWM current can be found by drawing the vertical voltage line and the horizontal current line. The resulting PWM current is 5.95 A and solar panel output is 13.5 V x 5.7 A = 77 W.

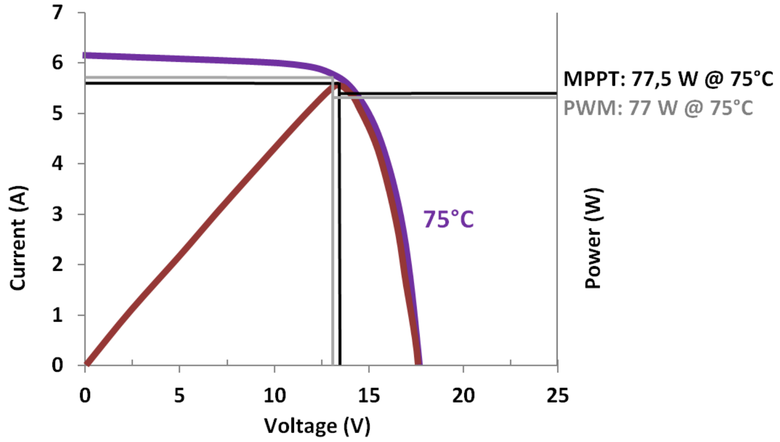


Fig 11: Comparison of MPPT and PWM performance at 75°C panel temperature
Black lines: MPPT (77.5 W).
Grey lines: PWM (77 W). MPPT performance advantage: nil

Conclusion: at Tcell = 75°C and Vbat = 13 V the difference in performance between the two controllers is negligible.

5.4 Cell temperature 100°C

It is interesting to see what happens at even higher temperatures.
Figure 12 shows what happens at 100°C.

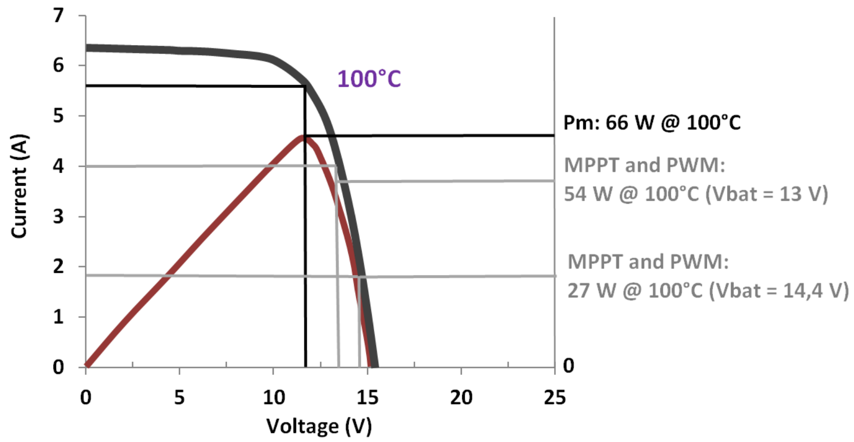


Fig 12: At 100°C panel temperature the Maximum Power Point voltage is 11.7 V

Most MPPT controllers cannot transform a lower voltage to a higher voltage, as that's not what they are made for. If the MPPT voltage Vm becomes lower than Vbat, they will therefore operate like a PWM controller, connecting the panel directly to the battery.
As shown in figure 11: if Vbat = 13 V, the current harvested from the panel will be limited to 4 A.

And the situation becomes worse with increasing battery voltage (or increasing temperature): the charge current quickly reduces to only a few amps.
However, if the MPPT controller could in this situation still operate at the Maximum Power Point, it could harvest 66 W, whether Vbat is low or high!

6. The solution

Clearly, in our example, both MPPT and PWM controllers do not perform at high cell temperatures.

The solution to improve MPPT controller performance at high cell temperatures is to increase panel voltage by increasing number of cells in series.
Obviously, this solution is not applicable to PWM controllers: increasing the number of cells in series will reduce performance at low temperature.

In case of the MPPT controller: replace the 12 V / 100 W panel by a 24 V / 100 W panel or by two 12 V / 50 W panels in series. This will double the output voltage and the MPPT controller will charge a 12 V battery with 66 W (5.1 A @ 13 V), at 100°C cell temperature, see figure 13.

An additional advantage: because the panel voltage has doubled, the panel current is reduced by half (P = V x I and P has not changed but V has doubled).

Ohm's law tells us that losses due to cable resistance are Pc (Watt) = Rc x I^2, where Rc is the resistance of the cable. **What this formula shows is that for a given cable loss, cable cross sectional area can be reduced by a factor of four when doubling the array voltage.**

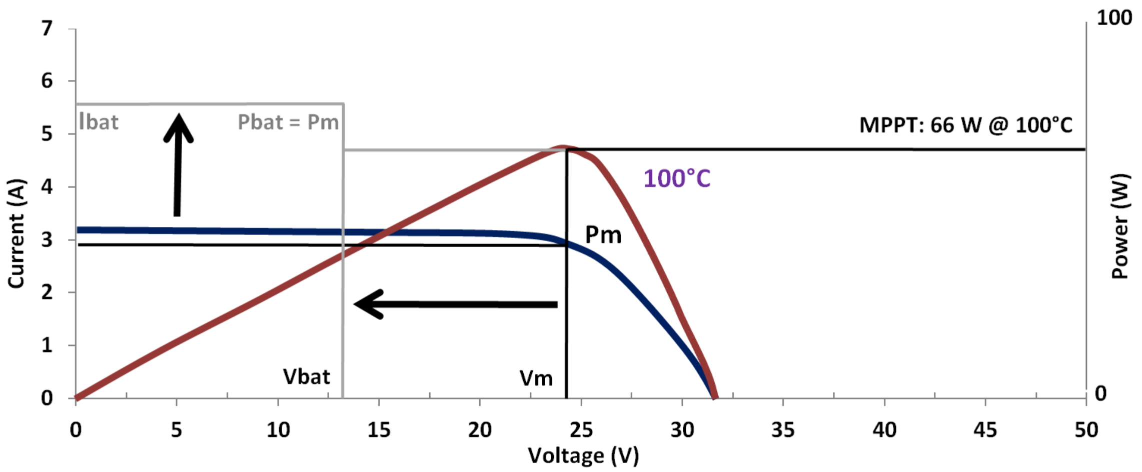


Fig 13: Two 12 V / 50 W panels in series instead of one 12 V / 100 W panel
Pm = Vm x Im = 23.4 V x 2.8 A = 66 W and
Pbat = Vbat x Ibat = 13 V x 5.1 A = 66 W

Conclusion:
When using an MPPT charge controller there are two compelling reasons to increase the PV voltage (by increasing the number of cells in series):

a) **Harvest as much power as possible from the solar array, even at high cell temperature.**
b) **Decrease cable cross sectional area and therefore decrease cost.**

7. Relative performance graphs

7.1 Relative performance as a function of temperature

Let us now assume that the MPPT controller is connected to a solar array with sufficient cells in series to achieve an MPPT voltage several volts higher than the highest battery voltage.
For example:
12 V battery: 72 cells (a 24 V array) or more
24 V battery: 108 cells (a 36 V array) or more
48 V battery: 216 cells (a 72 V array) or more

The PWM controller is connected to a solar array of exactly the same Wp power, with the usual number of cells in series and used to charge a 12 V, 24 V or 48 V battery: respectively 36, 72 or 144 cells.

The relative performance of the two controllers as a function of cell temperature can be compared as shown in figure 14.

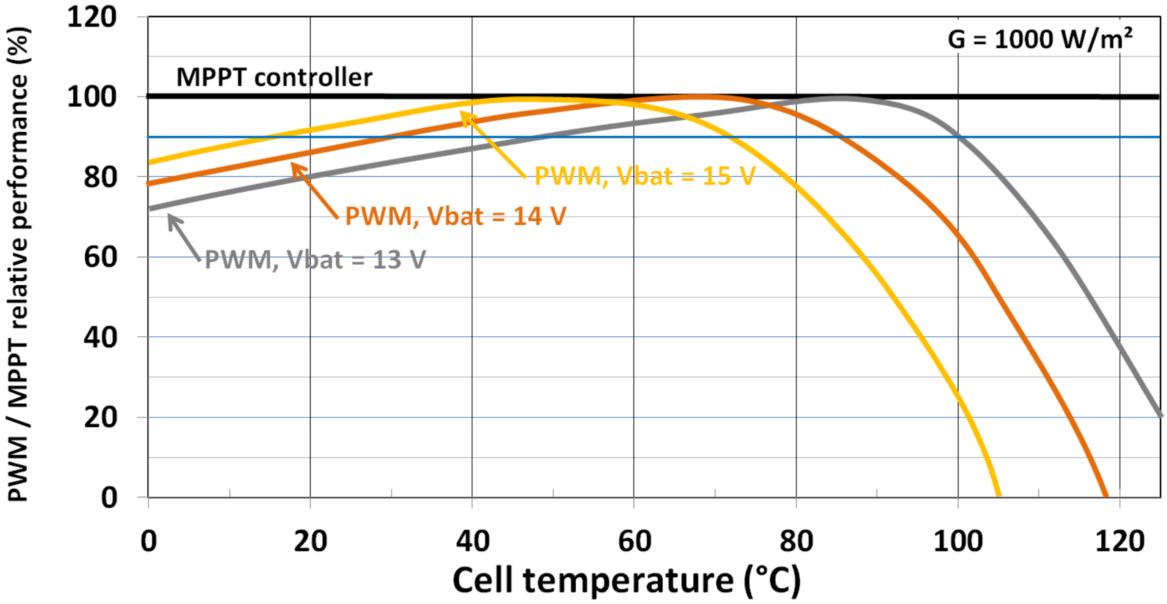


Fig 14: Relative PWM / MPPT performance comparison as a function of cell temperature and battery voltage under STC and assuming 0.5 V loss in the cabling plus controller.

The performance of the MPPT controller is set at 100%. PWM performance will match MPPT performance (100% relative performance) when the battery voltage plus losses in the cabling and the controller happens to be equal to the MPPT voltage. Three PWM relative performance curves are shown, based on three different battery voltages, and, as expected, the 100% point is achieved at lower temperatures when the battery voltage increases.

7.2 Absolute performance as a function of temperature

Including temperature dependence of Pm results in figure 15 below.
The performance of the MPPT controller is set at 100% at 25°C using STC.

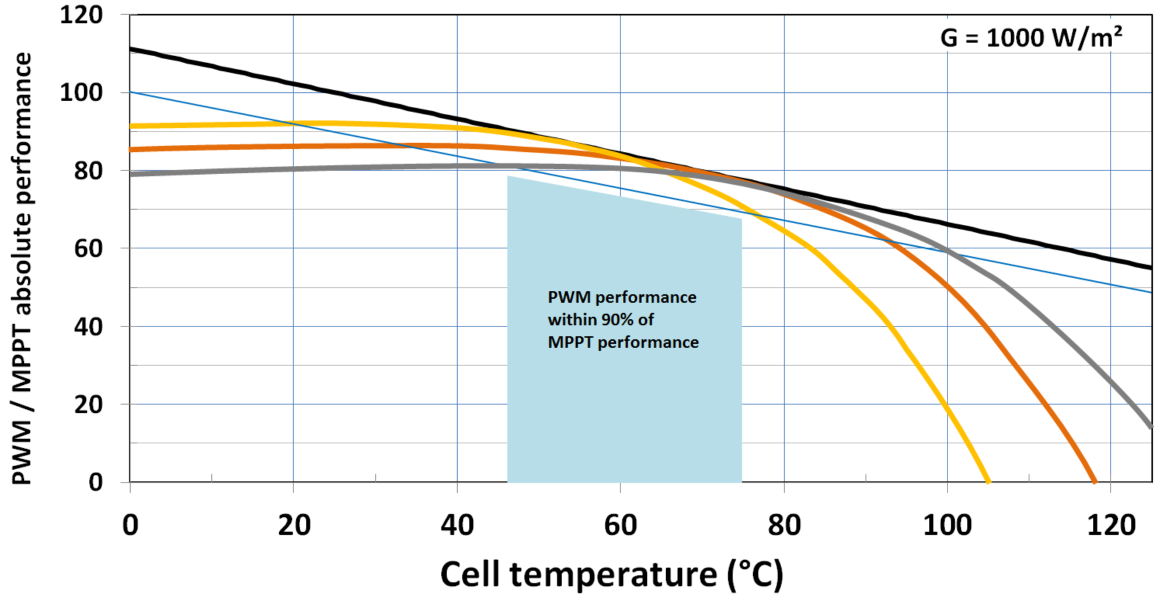


Fig 15: Absolute PWM / MPPT performance comparison as a function of cell temperature and battery voltage under STC and assuming a 0.5 V loss in the cabling plus controller.

The blue area shows that a PWM controller performs nearly as well (within 10%) as an MPPT controller over a relatively wide battery charge voltage (13 V to 15 V) and temperature range (45°C and 75°C).
The 10% limit is given by the thin blue line in figure 14 and 15.

Before drawing any conclusions a few other solar cell and system parameters have to be considered.

7.3 The influence of irradiance

The output of a solar panel is approximately proportional to irradiance, but Vm remains nearly constant as long as irradiance exceeds 200 W / m². Irradiance therefore does not materially influence the MPPT / PWM performance ratio as long as irradiance exceeds 200 W / m² (see figure 16).
But at low irradiance (overcast sky, wintertime) Vm drops rapidly and an MPPT controller connected to an array with a much higher nominal voltage than the battery, will perform far better than a PWM controller.

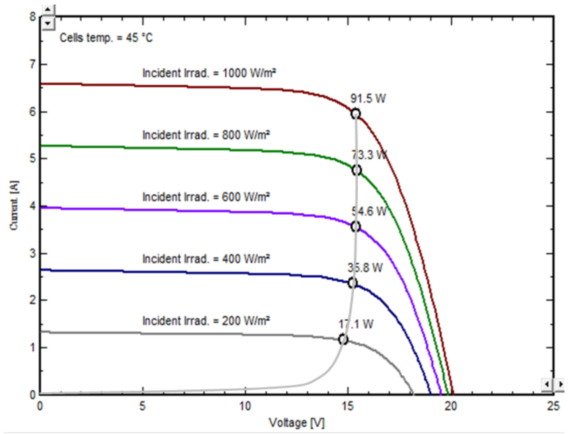


Figure 16: Dependence of Mp and Vmp on irradiance

7.4 Monocrystalline or Polycrystalline

According to manufacturer's datasheets Vm is, on average, slightly lower in the case of polycrystalline panels. In the case of a 12 V panel the difference is 0.35 V to 0.7 V and the temperature coefficient is similar for both technologies. The consequence is that the PWM curves in figure 13 and 14 move 5 to 10°C toward the left in the case of a polycrystalline panel.

7.5 Partial shading

Partial shading lowers the output voltage. MPPT therefore has a clear advantage over PWM in the case of partial shading.

7.6 Losses in cabling and the controller

In a good installation these losses are small compared to the effect of temperature. Note that throughout this paper, power, voltage and current are taken at the panel output and do not take any losses into account, unless stated otherwise.

7.6 Cell temperature

The next question to answer is: what is the temperature of the solar cells in practice.

A first indication is given by the NOCT (Normal Operating Cell Temperature) which nowadays is specified by most solar panel manufacturers.

NOCT conditions are defined as follows:

- Ambient temperature: 20°C
- Irradiance: 800 W/m^2
- Air Mass: 1.5
- Wind speed: 1 m/s
- Mounting: open back side (free standing array)
- No electrical load: no power is drawn from the panel

According to manufacturer's data, on average NOCT = 45°C. This means that under the conditions as stated, solar cell temperature is 25°C higher than ambient temperature.

A more general formula to calculate cell temperature T_c is:

$T_c = T_a + G/U$ or $\Delta T = T_c - T_a = G/U$

With

T_a: ambient temperature

G: irradiance (W/m^2)

U: thermal loss factor (W/m^2·ΔT)

And a simple model for the thermal loss factor is:

$U = U_c + U_v \cdot W_v$

Where U_c is a constant component and U_v a factor proportional to wind speed W_v (m/s) <u>at the array</u>.

The resulting thermal formula is:

$T_c = T_a + G/(U_c + U_v \cdot W_v)$ or $\Delta T = T_c - T_a = G/(U_c + U_v \cdot W_v)$

Extrapolating from http://files.pvsyst.com/help/index.html?noct_definition.htm and some other websites, the approximate values for Uc and Uv are:

Freestanding arrays:
Uc ≈ 20 W / m^2·ΔT
Uv ≈ 12 W / m^2·ΔT/m/s

Arrays with the back side fully insulated:
Uc ≈ 10 W / m^2·ΔT
Uv ≈ 6 W / m^2·ΔT m/s

Figure 17 shows the resulting cell temperature increase with respect to ambient temperature for free standing arrays and for arrays with the back side fully insulated.

Clearly, air flow is extremely important.

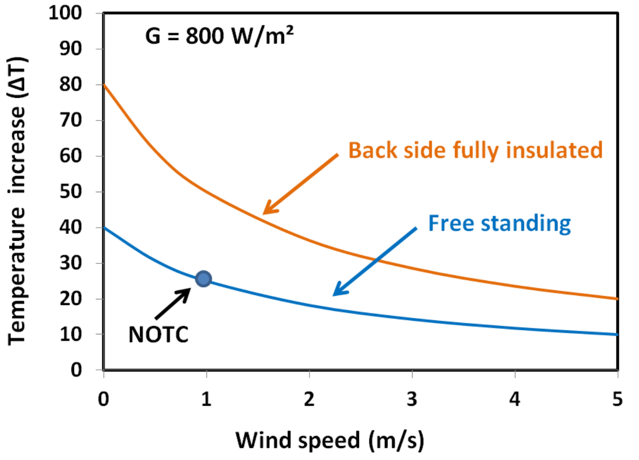


Fig 17: Wind speed and temperature increase

Free standing array
Without wind, the temperature increase of 40°C of a free standing array can result in cell temperatures of 70 to 80°C on a hot sunny day in Europe. Under such conditions PWM performance lags MPPT performance by 10%.

Back side fully insulated
In an array with a fully insulated back side the cell temperature can routinely exceed 100°C. Fully charging the battery with a PWM controller then becomes impossible because charge current will be very low or even zero before the absorption voltage is reached.

In most installations the back side of an array is not fully insulated. When mounted on a sloped roof for example, normally care has been taken to allow for some air flow between the roof and the back side of the solar panels.
The heat capacity of air, however, is very low. The flowing air under the panels may quickly attain equilibrium with the temperature of the panels, leading to no heat exchange at all except for the first few decimeters of the air duct. Therefore, for most of the array, the back side-U value may be the fully insulated U-value.

8. General conclusion

Temperature
A standard crystalline solar panel with a nominal voltage of 12 V consists of 36 cells in series. At 25°C cell temperature, the output current of this panel will be nearly constant up to about 17 V. Above this voltage, current drops off rapidly, resulting in maximum power being produced at around 18 V.

Unfortunately the voltage point at which the current starts to drop off decreases with increasing temperature. Below that voltage point the current however remains practically constant, and is not influenced by temperature.

The output power and output voltage both decrease by about 4.5% for every 10°C of temperature increase.

PWM controller
When a solar array is connected to the battery through a PWM charge controller, its voltage will be pulled down to near that of the battery. This leads to a suboptimal power output wattage (Watt = Amp x Volt) at low and at very high solar cell temperatures.

In times of rainy or heavily clouded days or during heavy intermittent loads a situation may occur where the battery voltage becomes lower than is normal. This would further pull down the panel voltage; thus degrading the output even further.

At very high cell temperatures the voltage drop off point may decrease below the voltage needed to fully charge the battery.

As array area increases linearly with power, cabling cross sectional area and cable length therefore both increase with power, resulting in substantial cable costs, in the case of arrays exceeding a few 100 Watts.

The PWM charge controller is therefore a good low cost solution for small systems only, when cell temperature is moderate to high (between 45°C and 75°C).

MPPT controller
Besides performing the function of a basic controller, an MPPT controller also includes a DC to DC voltage converter, converting the voltage of the array to that required by the batteries, with very little loss of power.

An MPPT controller attempts to harvest power from the array near its Maximum Power Point, whilst supplying the varying voltage requirements of the battery plus load. Thus, it essentially decouples the array and battery voltages, so that there can be a 12 volt battery on one side of the MPPT charge controller and two 12 V (Vmax =18 V) panels wired in series to produce 36 V on the other.

If connected to a PV array with a substantially higher nominal voltage than the battery voltage, an MPPT controller will therefore provide charge current even at very high cell temperatures or in low irradiance conditions when a PWM controller would not help much.

As array size increases, both cabling cross sectional area and cable length will increase. The option to wire more panels in series and thereby decrease current, is a compelling reason to install an MPPT controller as soon as the array power exceeds a few hundred Watts (12 V battery), or several hundred Watts (24 V or 48 V battery).

An MPPT charge controller is therefore the solution of choice:

a) If cell temperature will frequently be low (below 45°C) or very high (more than 75°C).

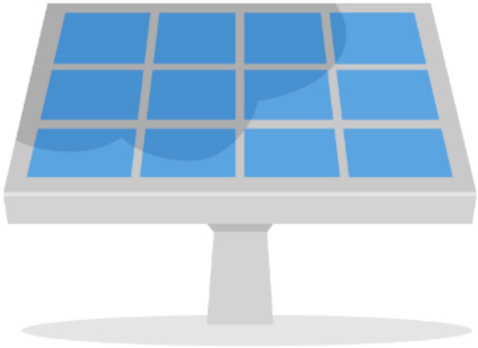
b) *If cabling cost can be reduced substantially by increasing array voltage.*

c) *If system output at low irradiance is important.*

d) *If partial shading is a concern.*

MPPT: Ultra Fast Maximum Power Point Tracking

By constantly monitoring the voltage and current output of your solar (PV) panels, MPPT technology ensures that every drop of available power is rinsed out of your panels, and harvested for storage. The advantage of this is most noticeable when the sky is partially clouded, and light intensity is constantly changing.



Remote Monitoring and Control

Remotely control and monitor the extensive features of your SmartSolar MPPT charger with built-in bluetooth by pairing it with your smartphone or other device via VictronConnect. If your installation is connected to the internet Victron Remote Management Portal (VRM) provides access to the full power of your MPPT, anytime, anywhere; both services are free to use. For remote installations - even when there is no internet connection or phone signal nearby - you may be able to monitor your MPPT by bluetooth-pairing with a LoRaWAN (long-range wide area network) device, available optionally.

Load output

The intelligent Load output function prevents damage caused by running batteries 'flat'. You can configure the voltage at which SmartSolar disconnects a load - thereby preventing excessive drain on your batteries. And here's the clever bit: SmartSolar will attempt a 100% recharge every day. If it can't - during periods of poor weather - it raises the disconnect voltage, daily, until it achieves success. We call this feature BatteryLife because it maintains the health, and extends the life of your battery.