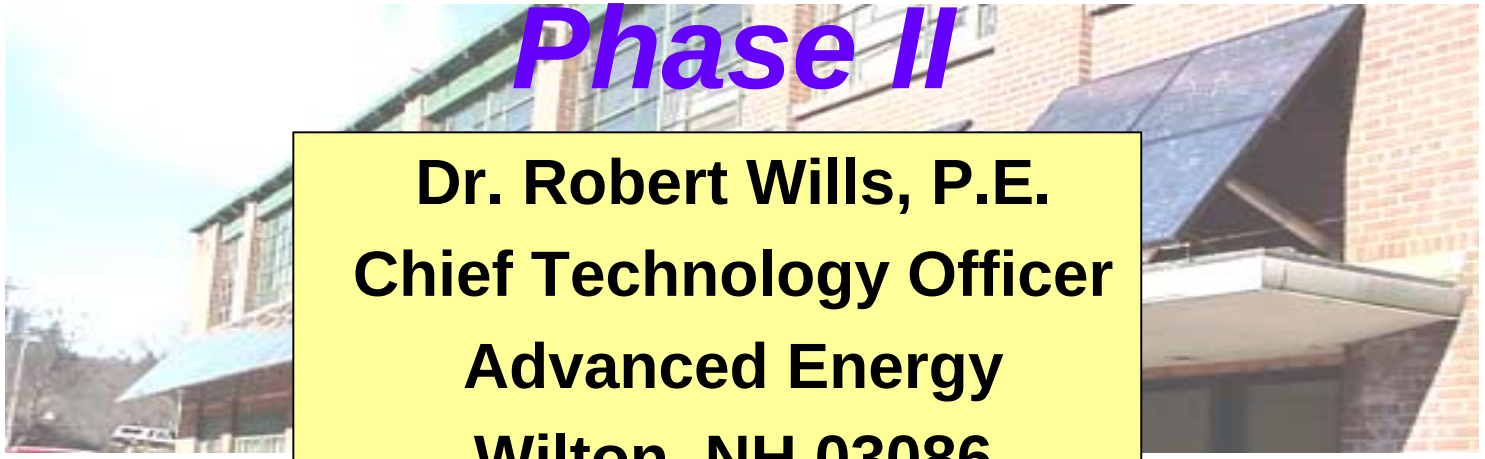
Advanced Energy The Power of Choice™

Advanced Hybrid Controller Phase II



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About Advanced Energy

- Inverter Manufacturer based in Wilton, NH
- 28% owned by Plug Power
- More than 2000 GC-1000 inverters in the field.
- 200 10kW inverters shipped for Plug Power fuel cell systems this year
- MM-5000 inverter started shipping in September
- $3.8 Million in sales in 2001

ACT– Our World Class Manufacturing Partner

- All Manufacturing is handled by ACT in Marlboro, MA (a 45-minute drive from AEI)
  - 200K sq. ft manufacturing
  - ISO 9001 qualified
  - Full Box Build/direct order fulfillment

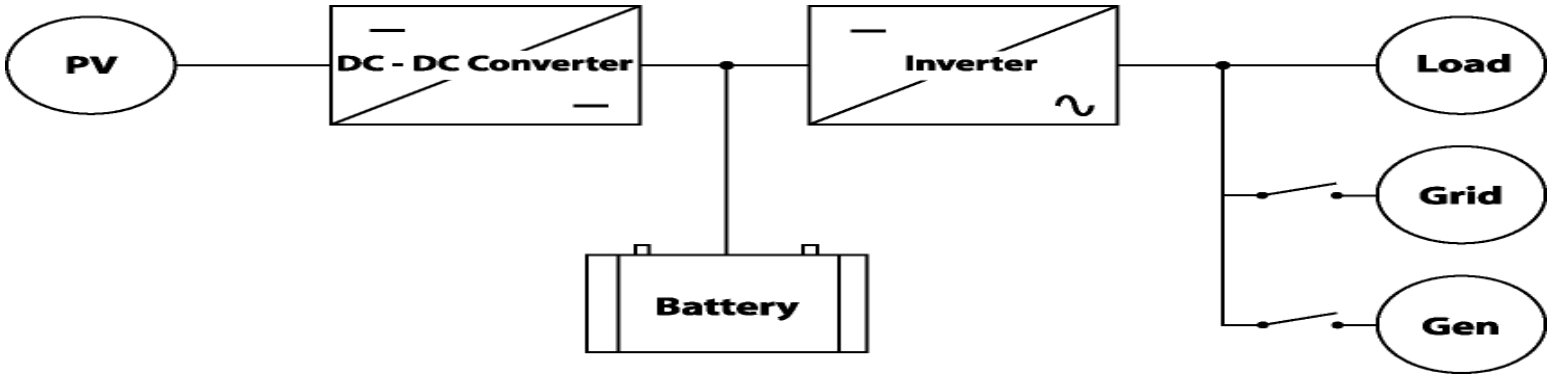
More about AEI

- Hybrid systems to 150 kW in the past
- Worked on the development of IEEE 929, 1547, and the New York Std Interconnect Requirements.
- Member of the National Electrical Code Panel 14 (Photovoltaics and Fuel Cells).
- Fundamental Anti-Islanding Patent

The Multimode 5000

- 3 kW & 5 kW Power Management Systems
- *The one box solution* to PV power management:
  - Sells excess power to the grid
  - Provides reliable power when the grid fails
  - Interfaces with a backup generator
  - Integrated Controller

Block Diagram



- 100A MPPT DC-DC Converter ~ 5kW PWM sinewave inverter
  - Connections:
    - » DC: PV, Battery
    - » AC: Load, Grid, Generator
    - » Comm: Opto-isolated RS485
    - » Control: Auto Generator Start

The Advanced Hybrid Controller Project

Aim

To improve hybrid & minigrid power system performance by:

- »Simplifying Integration
- »Increasing Reliability
- »Reducing Cost
- »Increasing Flexibility

Summary of Phase I Results

- Identified need for:
  - A Standard Component Communications Protocol
  - Separation of Inverter and Controller
- Droop mode control is the optimal means for paralleling multiple units in standalone mode
- Heuristic optimization of single-unit systems

Phase II Tasks

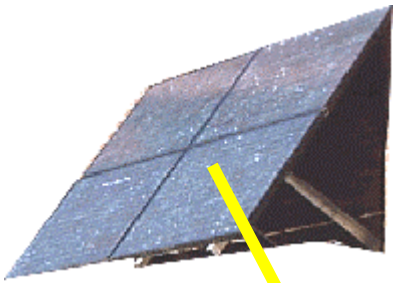
1. A single-unit AHC controller with working hardware
2. Protocols for controller to inverter, and remote controller communications
3. Global optimization program. Analyzes data logs, determines optimum operational setpoints
4. Minigrid simulator in object oriented (C++) code. Test bed for aggregation and optimal SA & DR dispatch algorithms

Advanced Hybrid Controller (AHC)

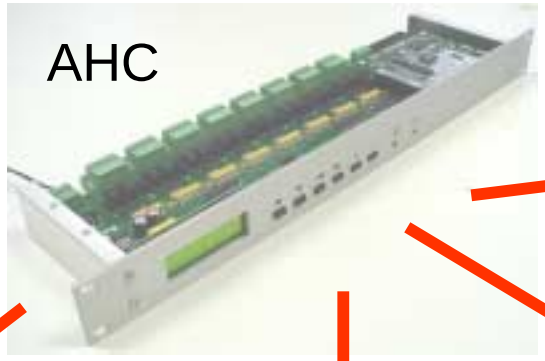
- Intel 386 with DOS
- ERTOS real time operating system
- 8+ MB data storage

- RS-485 Local Communications
- RS-232 for console or modem
- Ethernet port
- Two versions – rack mount and modular
- Hardware cost $200-$400 in low quantity

Demonstration Hybrid System Components



PV Array



Load

Inverter

Batteries

Generator

The AHC has Internet Connectivity!

- TCP/IP Protocol Stack
- FTP (file transfer)
- HTTP (Web page data display)
- Telnet
  (remote console control)
- PPP dial out to Internet Service Provider (ISP)
- PPP dial in from any computer (AHC is PPP server)
- *Allows connection via local ISP (continuously or periodically) for control and monitoring*

Using the Internet for DG Communications

- As DR becomes more widespread, the need for communications will increase. Using ISPs and the Internet will eliminate the need for private networks or modem banks
- This is a much lower cost alternative for utilities as the infrastructure is already in place.
- Encrypted data can be securely transferred over the internet

DR Control Example

1000 PV systems with 10kWh of storage each

10 MWh of Dispatchable Energy Storage

Schedule

Export from 4 to 6 PM

Data

Unit # 1234 failed

Monitoring Data

ISP

Utility Data Center

Schedule File

DR Control Example – Economic Analysis

- Customer buys system for the UPS / home autonomy function. Purchase supported by State incentive program. Battery is customer owned
- Customer benefits from free system monitoring
- Utility pays for communications equipment
- Up to 100 cycles per year to 50% DOD will have little impact on battery life (500 kWh / year)
- Marginal cost is communications equipment, maintenance & management (E.g. $250 over 10 years = $25/year)
- Cost/kWh could be as low as $0.05/kWh

Energy Storage Optimization

- AHC can easily be programmed with advanced charging algorithms such as partial state of charge
- Standard & Peukert corrected AH counting algorithms
- Historical estimates of load and solar resource for minimal PV “spillage”

Potential Markets

- Remote & Village Power
  - Half the world's population does not have electricity (2+ billion people)
- DR Monitoring and Control
  - Distributed Energy Storage
  - Field node for DR Aggregation & resource scheduling and optimization

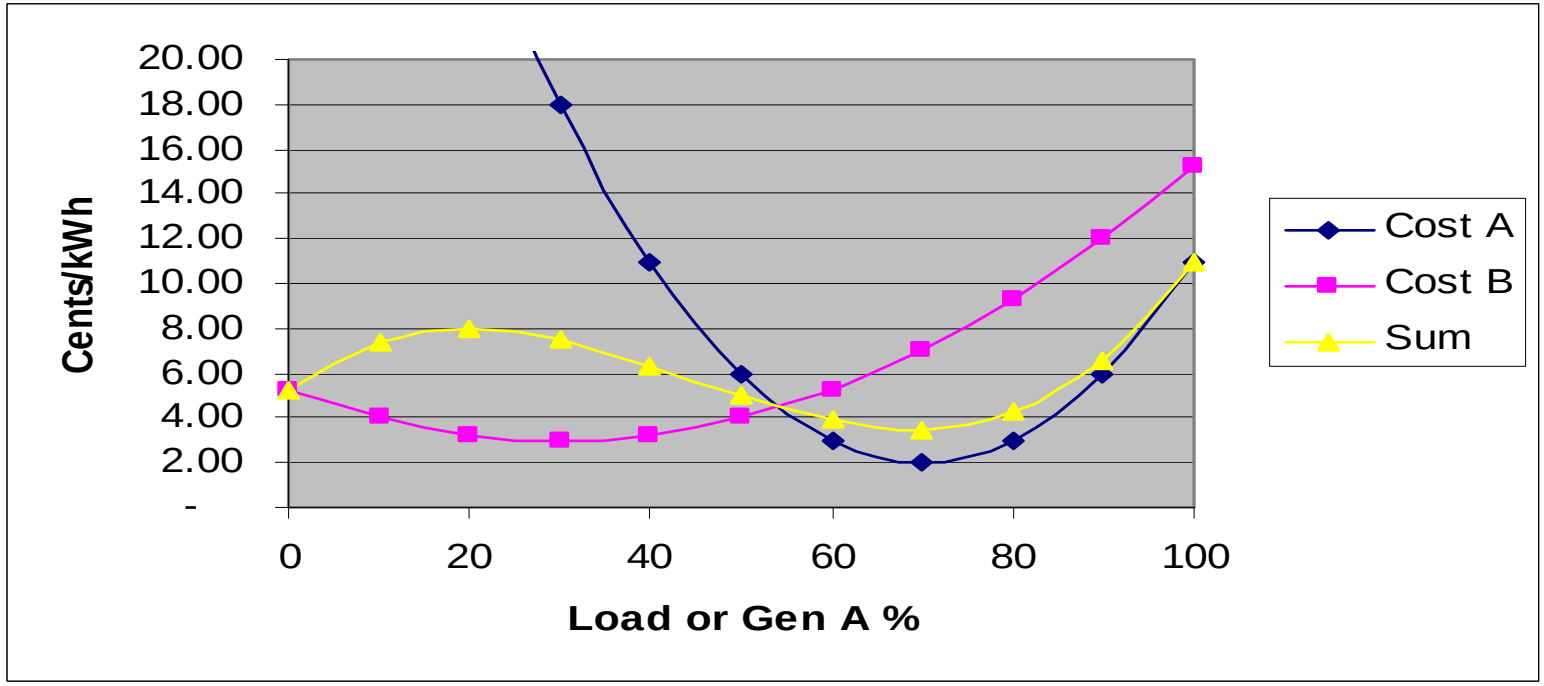
Task 2: Communications Protocols

- Internal Problem
  - Controller to inverter protocol definition is complete.
  - Low Security requirements
- External Problem
  - Internet is best solution
  - Encryption is key

Task 3: Global Dispatch Optimization

- Two approaches
  - setpoint optimization with rule-based controller
  - system optimization
- Increases in processing power make *system-level optimization* possible
- Exploring genetic algorithms for this application
  - Using same method to optimize DR dispatch as was used to optimize our own evolution
- Working with students at Dartmouth College

Complex Cost Example

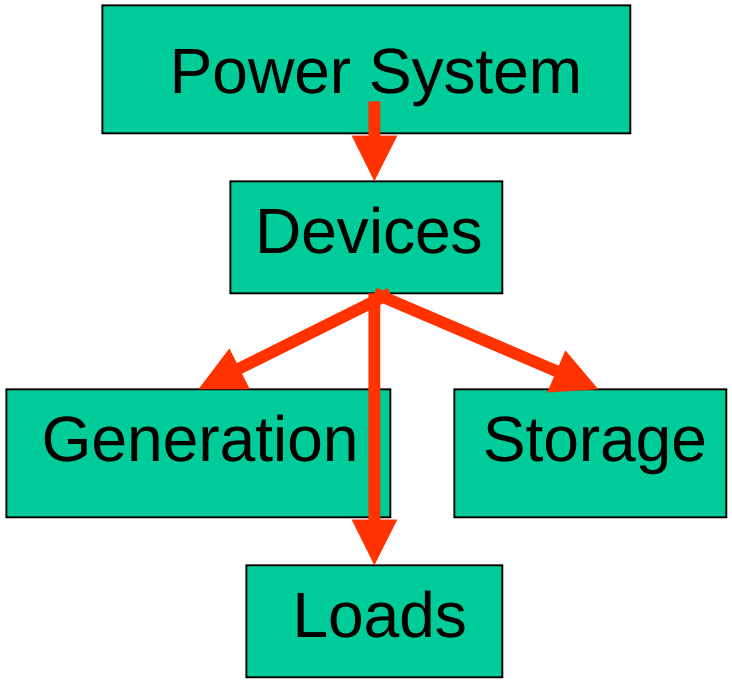


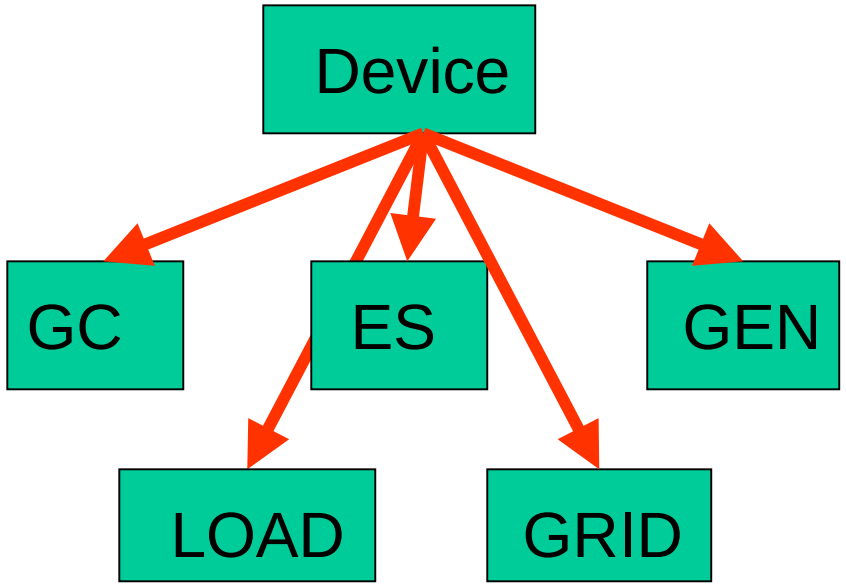
Combined cost curves can give the dispatch function multiple minima

Task 4 – Mini-grid Simulator

- Test bed for DR Aggregation & Optimal Dispatch
- Original application was for remote stand-alone systems with multiple generators
- Also applicable to mini-grids
- Supports intentional islanding of mini-grid when central generation fails (e.g., facility power)
- Will evolve into an aggregation and dispatch software product

Minigrid Simulator Object Model





Simulator Capabilities

- Simulates multiple:
  - Grid Connect Inverters (GC type)
  - Bi-directional Inverters with Energy Storage (ES type)
  - Generators (Gen Type – Diesel, Fuel Cell, Microturbine, etc)
  - Loads

In Grid-Connect and Stand-Alone modes.

Simulator Capabilities

- Data file input or synthetic data for:
  - Solar, Load, Grid Cost & Device Availability
- Device sizing database
- HTML log file
- Manual selection of device availability
- Graphical & CSV file output

Dispatch Strategies – Economics Rule

- In Grid Connect mode
  - Any generation with lower cost than grid is on-line.
  - Recharge energy storage if “off peak”
- In Stand-Alone mode
  - Bring on enough generation to satisfy load, lowest cost first
  - If insufficient, discharge ES. If excess, recharge ES

Simulator Demonstration