Developing Hybrid and Sustainable Energy Solutions for the Increasing Power and Mobility Needs of the Warfighter

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Wikipedia Definitions:

Hybrid power systems, like the name implies, combine two or more modes of electricity generation together.

Sustainable energy sources are most often regarded as including all renewable energy sources, such as hydroelectricity, solar energy, wind energy, wave power, geothermal energy, bioenergy, and tidal power.

"The U.S. Defense Department must change the way it uses energy on the battlefield as conflicts become longer and more expeditionary."

Deputy Defense Secretary William Lynn, April 26, 2011.

Traditional Deployed Power Sources

- Legacy Diesel Generators
- Tactical Quiet Generators
- Newer Intelligent Generators

Deployable Renewable Energy Sources

- Solar Energy
- Wind Energy
- Fuel Cells

Typical Types of Solar Panels

- Rigid Panels
  - Monocrystalline
  - Polycrystalline
- Flexible Panels
  - Amorphous Silicon (a-Si)
  - Copper Indium Gallium Selenide (CIGS)
  - Cadmium Telluride (CdTe)

Best Research-Cell Efficiencies

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Multijunction Concentrators
- ▼ Three-junction (2-terminal, monolithic)
- ▲ Two-junction (2-terminal, monolithic)

Single-Junction GaAs
- △ Single crystal
- ◬ Concentrator
- ▽ Thin film

Crystalline Si Cells
- ■ Single crystal
- □ Multicrystalline
- ◆ Thick Si film
- ● Silicon Heterostructures (HIT)

Thin-Film Technologies
- ● $Cu(In,Ga)Se_2$
- ○ CdTe
- ○ Amorphous Si:H (stabilized)
- ◆ Nano-, micro-, poly-Si
- □ Multijunction polycrystalline

Emerging PV
- ○ Dye-sensitized cells
- ● Organic cells (various technologies)
- ◆ Inorganic cells

Efficiency (%)

0 4 8 12 16 20 24 28 32 36 40 44 48 50

1975 1980 1985 1990 1995 2000 2005 2010

42.4% 35.8% 32.6% 28.8% 27.6% 25.0% 23.0% 20.4% 20.3% 16.7% 12.5% 11.1% 9.7% 8.1%

Spectrolab (metamorphic, 299x) | Fraunhofer ISE (metamorphic, 454x) | Boeing-Spectrolab (lattice matched, 364x) | Spire Semiconductor (metamorphic, 406x)
Boeing-Spectrolab (metamorphic, 240x)
Boeing-Spectrolab (metamorphic, 179x)
NREL (inverted, metamorphic)
NREL (inverted, metamorphic, 325.7x)
Boeing-Spectrolab
Sharp (IMM, 1-sun)
Boeing-Spectrolab
NREL (inverted, metamorphic, 1-sun)
NREL/ Spectrolab
Spectrolab
Japan Energy
NREL
NREL
Spectrolab (4.0 cm², 1-sun)
Radboud Univ.
IES-UPM (1026x)
Varian (205x)
Varian (216x)
NREL
SunPower (96x)
Amonix (92x)
Fraunhofer ISE (232x)
Stanford (140x)
Kopin
Varian
FhG-ISE
Radboud Univ.
IBM (T. J. Watson Research Center)
Spire
UNSW
UNSW
UNSW
NREL
Cu(In,Ga)Se₂ (14x)
Sanyo
Sanyo
Sanyo
Sanyo
Spire
Stanford
UNSW
UNSW
UNSW / Eurosolare
FhG-ISE
ZSW
Sandia National Lab
Westing-house
ARCO
Georgia Tech
Georgia Tech
Georgia Tech
NREL
NREL
NREL
NREL
NREL
NREL
ZSW
RCA
Varian
UNSW
Sharp (large-area)
Mobil Solar
No. Carolina State Univ.
Solarex
University So. Florida
NREL
AstroPower (small-area)
NREL
Univ. Stuttgart (45 µm thin-film transfer)
NREL (CdTe/CIS)
United Solar (aSi/ncSi/ncSi)
ARCO
Boeing
Kodak
Boeing
Euro-CIS
United Solar
Matsushita
Monosolar
Kodak
Boeing
AMETEK
Photon Energy
Sharp
IBM (CTZSS)
Boeing
University of Maine
Boeing
Solarex
ARCO
United Solar
EPFL
EPFL
Kaneka (2 µm on glass)
United Solar
EPFL
EPFL
Konarka
NREL / Konarka
Univ. Linz
Solarmer
Groningen
Siemens
Plextronics
University Linz
University Linz
RCA
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(Rev. 09-2010)

Flexible Solar Panels

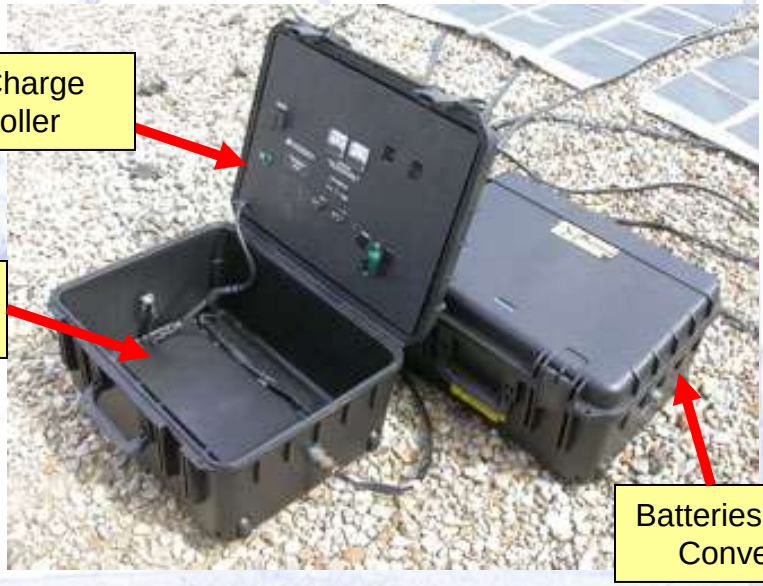
- Most practical for deployable applications
- 1 – 4500 watt panels
- Much lighter weight than rigid panels
- Less prone to damage vs. rigid panels
- Flexible and can be folded at seams
- Durable waterproof & UV resistant
- Operating temperature range of -40° to 80°C
- Complies with environmental Mil-Std 810F
- Most can operate with punctures & holes at reduced power

Ten Panel Solar Power System

Solar Panel J-Box

Solar Charge Controller

Solar Panel Storage



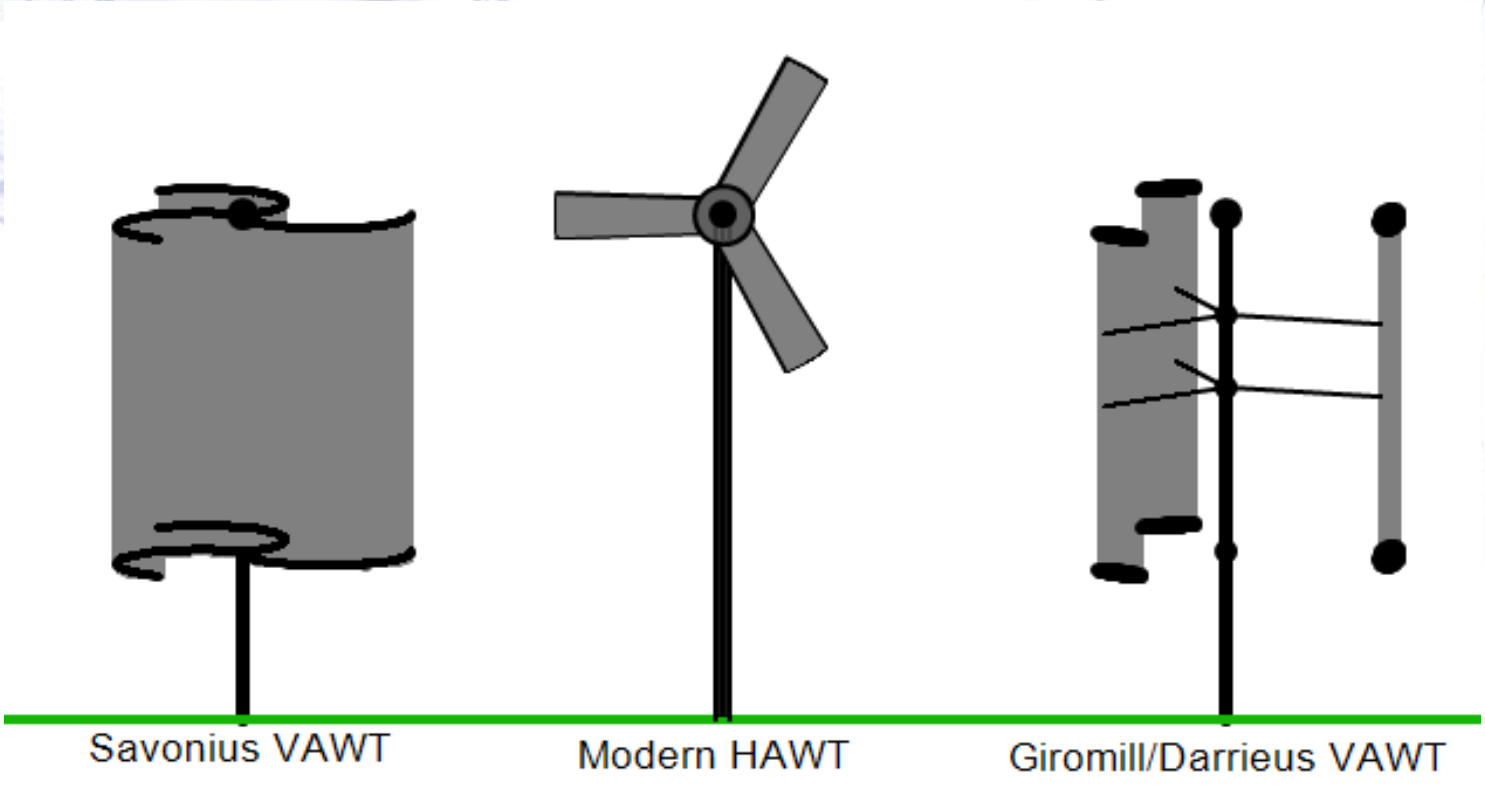
Batteries &Power Conversion

Solar Fly System Set Up

Typical Types of Wind Turbines

- Horizontal Axis Wind Turbine (HAWT)
- Vertical Axis Wind Turbine (VAWT)

Typical Types of Wind Turbines



Transportable Wind Turbines

- Currently, HAWT are the most practical for deployment
- Compact size 3 or 5-blade turbines produce up to 3500 Watts
- Most models weigh 50 lbs. or less
- Quieter than typical wind turbines
- Available carbon fiber telescoping masts are strong yet light weight.
- The entire system can be easily setup by two people in only a few minutes.

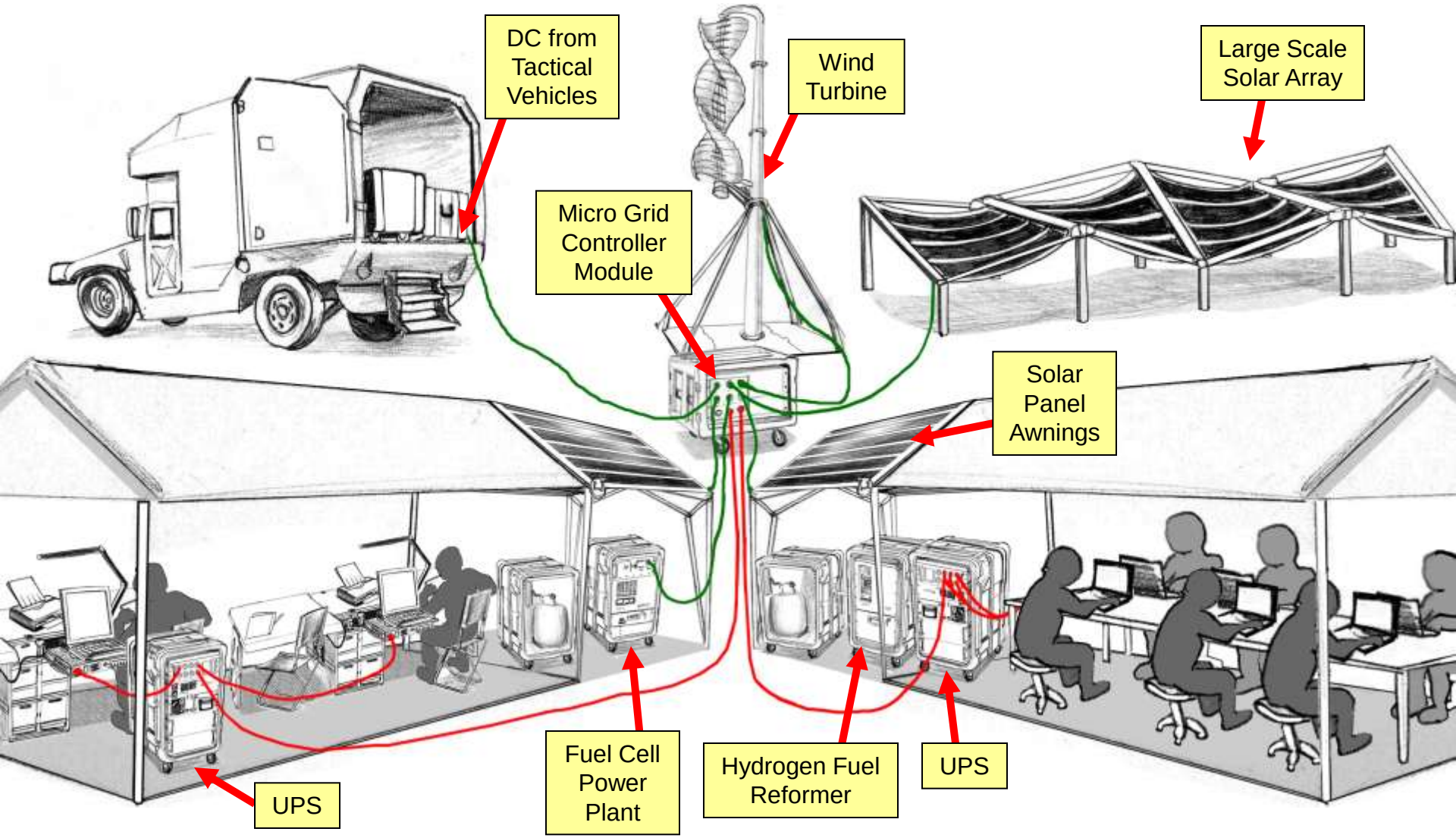
Typical Types of Fuel Cells

- Polymer Electrolyte Membrane (PEMFC)
- Direct methanol (DMFC)
- Alkaline (AFC)
- Phosphoric Acid (PAFC)
- Solid Oxide (SOFC)
- Molten Carbonate (MCFC)

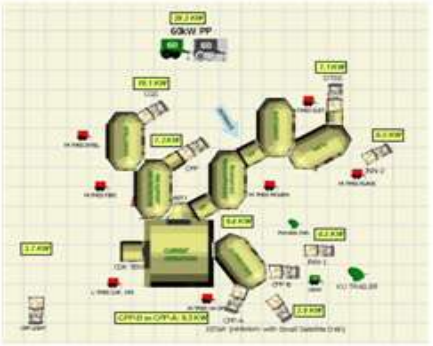
Alkaline Fuel Cell Power Plant

- Well suited for replacing 1-15 kW diesel fueled generators in tactical applications
- Internal Metal Hydride Fuel Cell stack provides hours of continuous runtime at full load
- Does not require expensive platinum
- Instant start capability vs. delayed
- More rugged than other fuel cells
- Smaller than other FC for same rating
- Intrinsic energy storage
- Operates in lower temperatures

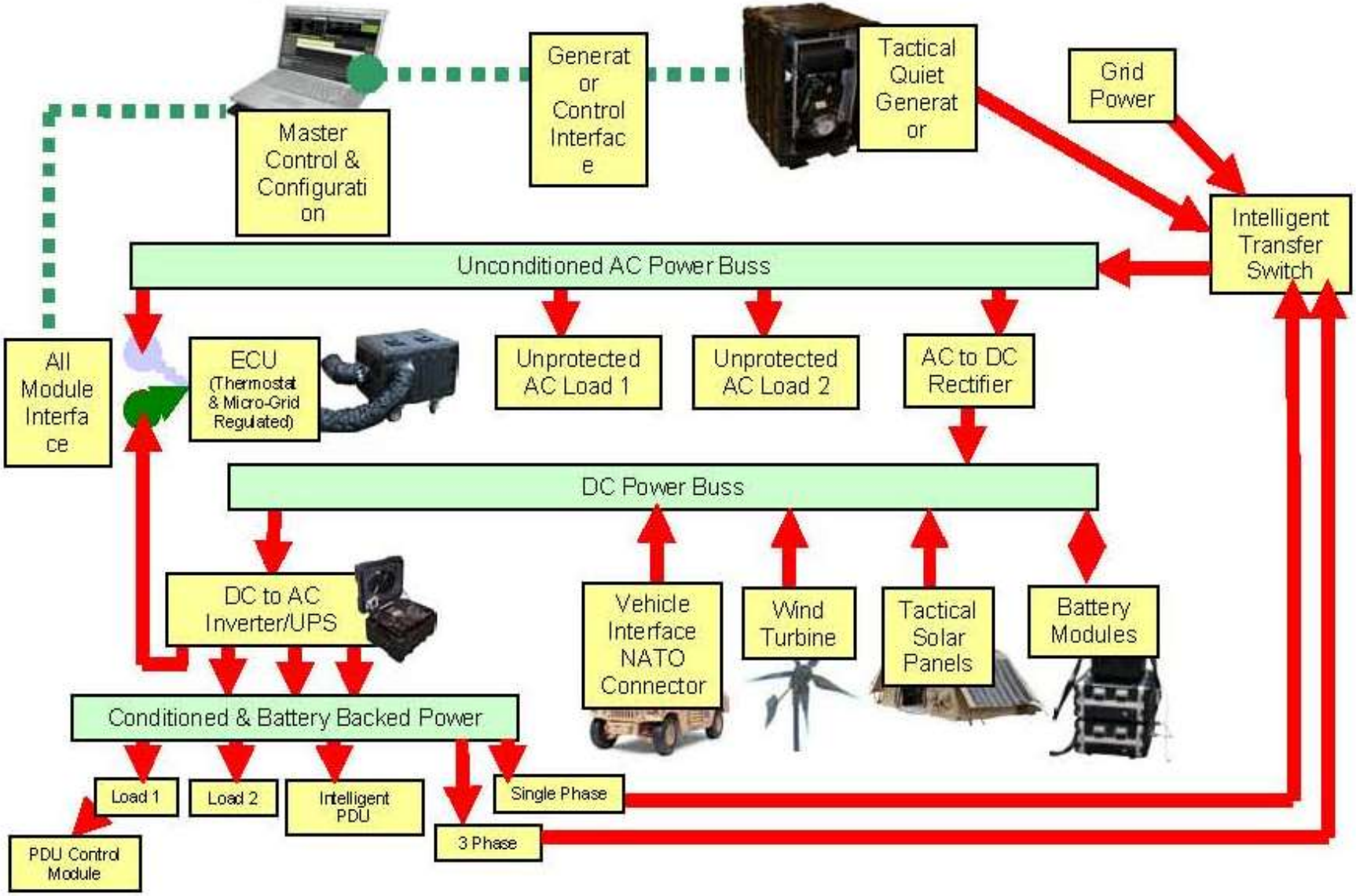
Hybrid Powered Base



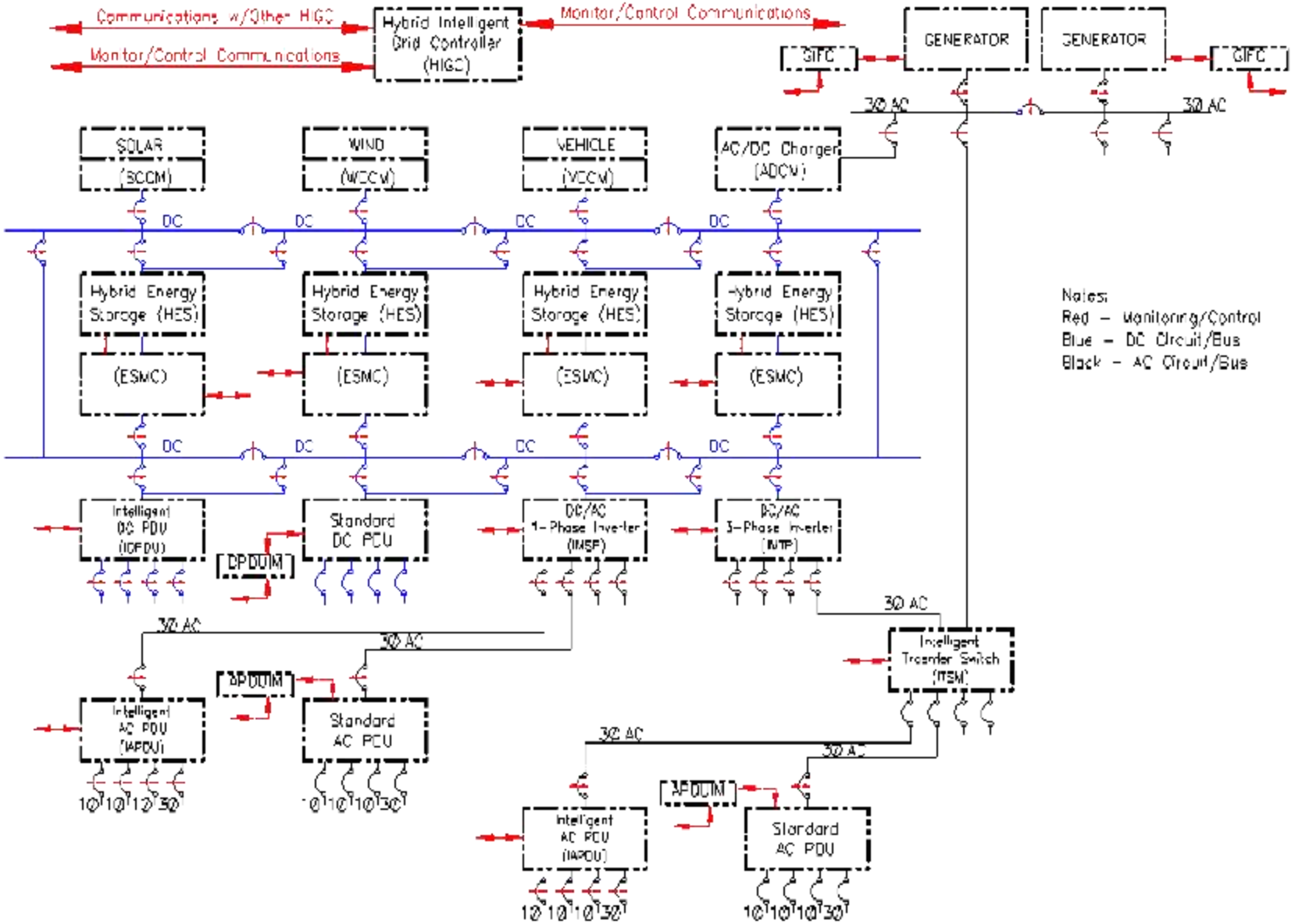
System Architecture Based on Modular MicroCell Design



Intelligent MicroCell Power System Architecture



System Electrical and Control Interface Diagram



The system is comprised of the following modules:

- Master Control & Configuration Display Module (MCCDM)
- Hybrid Intelligent Micro Grid Controller (HIGC)
- Generator Interface/Control Module (GIFC)
- Intelligent AC Transfer Switch Module (ITSM)
- Solar DC Charge Controller (SCCM)
- Wind Generator DC Charge Controller (WCCM)
- Vehicle NATO Connector Interface DC Charge Controller Module (VCCM)

The system is comprised of the following modules: (continued)

- Energy Storage Module & Controller (ESMC) Li-Ion Based
- Intelligent AC Power Distribution Unit (IAPDU)
- AC PDU Interface Module (APDUIM)
- Intelligent DC Power Distribution Unit (IDPDU)
- DC PDU Interface Module (DPDUIM)
- DC to AC Inverter Module Single Phase (IMSP)
- DC to AC Inverter Module Three Phase (IMTP)
- AC to DC Charger Module (ADCM)

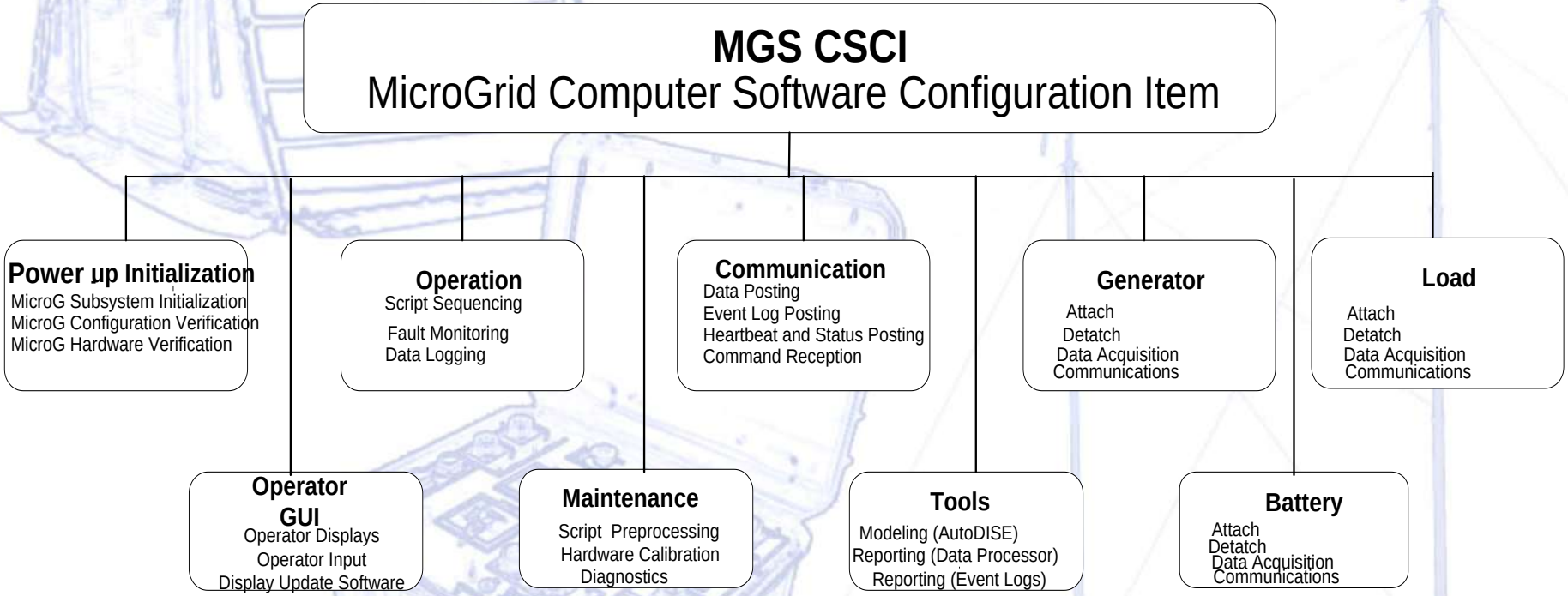
Master Control & Configuration Display Module (MCCDM)

- Main interface to the system
- Tactical based Laptop computer or a larger Desk Top depending on system size.
- Menu based human interface and configuration data management.
- Allows specific configurations for power generation, load balancing, automated module fault restoration and system optimization.
- Data element modules contain and support multi-level configuration access protection.

This module has three basic functions:

1. Configuration Set Up
2. Monitoring
3. Performance and Data Gathering

Micro Grid Computer System Software Architecture



N2 Chart with Micro Grid States and Modes

State	Mode	Submode							
Non-Operational	Transport	**System OFF**	Unload						
	Emplaced	Load	**System SetUp**	Power On		Command Maintenance			
			Power Off	**Initialization**	System Verification Enabled	Command Maintenance			
Operational	Standby		Command Power Off	Command Reboot	**Standby**	Command Maintenance	Command Battle Short	Command Online	
					Command Standby	**Maintenance**	Command Battle Short	Command Online	ABORT Button
	Grid Control				Command Standby		**Battle Short**	Command Online	ABORT Button
					Command Standby			**Grid Control Online**	System Fault ABORT Button
					Command Standby				**Grid Control ABORT**

Hybrid Intelligent Grid Controller (HIGC)

- Master controller of the configured system or sub-system depending on system size and complexity
- Modular and can be configured from 15 kW to over 750 kW based on application
- Module takes the input power resource and distributes and controls as configured without any dependence on additional controller modules
- Interface to support setting up a configuration via a portable device when the master control and configuration display module is not configured in small applications
- Default configuration/operations reside in this module for all battle short algorithmic functions and actions

Generator Interface/Control Module (GIFC)

- Configured to allow interface to the range of size generators
- Interprets the system commands to the control functions of the generator for starting, paralleling and status functions
- Capability to monitor consumables such as fuel and oil levels
- Module will take and execute all commands from the HIGC based on the configuration settings and shut down requirements as defined by the algorithmic functions of the system
- Interface module will also contain a fall back or battle short capability as these modules will be located on the generator and may not necessarily be located close to the HIGC

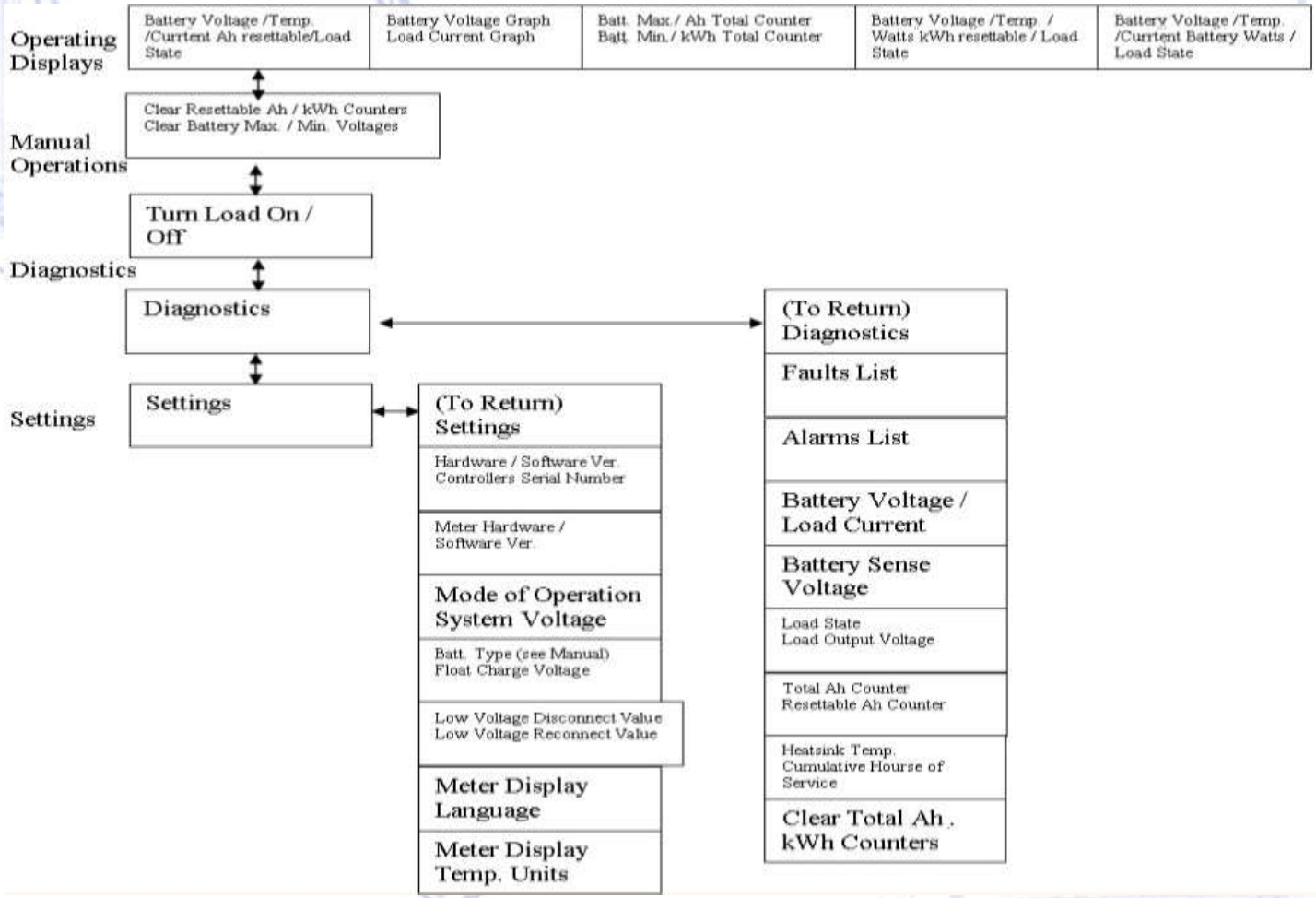
Intelligent AC Transfer Switch Module (ITSM)

- The Intelligent Transfer Switch Module interfaces to power generating sources and is configured in a fall back configuration that will allow the power to be distributed to the AC support bus
- ITSM has an intelligent interface that will operate based on the command requirements of the Hybrid Intelligent Grid Controller
- Upon loss of generating power, the HIGC can command the ITSM to disconnect from the generator and connect battery supplied inverters to the AC bus allowing continued operation of critical loads
- ITSM can support a local grid power sources and switch to the grid power to the AC support bus
- ITSM available in either 1-phase or 3-phase configurations

Solar DC Charge Controller (SCCM)

- Rated for 12, 24 or 48 VDC nominal solar panel input
- Ability for programmable or manual recovery
- Seven standard charging or load control configurations
- Intelligent interface to HIGC
- Continuous self-testing and fault notification
- Visual LED status indicators
- Remote battery sense capability
- Remote battery temperature sense

Solar Charge Controller basic software menu configuration supported both by the HIGC and manual mode:



Wind Generator DC Charge Controller (WCCM)

- Capable to support 12, 24 or 48 VDC battery configurations
- Ability for programmable or manual load limiting configuration
- Three standard charging or load control configurations
- Intelligent interface to HIGC
- Continuous self-testing and fault notification
- Visual LED status indicators
- Remote battery sense capability
- Remote battery temperature sense
- Integrated or remote excess power burn off modules
- Wind generator braking based on wind speed

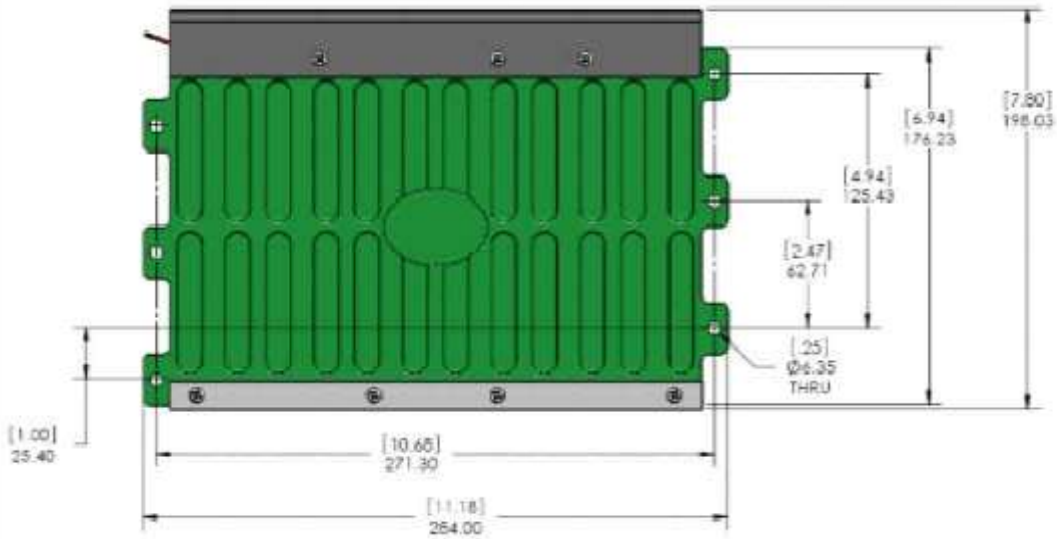
Vehicle NATO Connector Interface DC Charge Controller Module (VCCM)

- Capable to support 12, 24 or 48 VDC battery configurations
- Ability for programmable or manual recovery
- Four standard charging or load control configurations
- Intelligent interface to HIGC
- Visual LED status indicators
- Remote battery sense capability
- Remote battery temperature sense

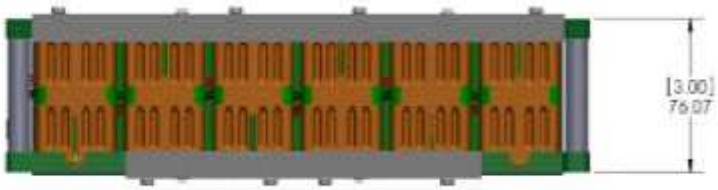
Energy Storage Module & Controller (ESMC) Li-Ion Based

- 3X the Power Density of Standard Lead Acid Batteries
- 1/3 the Weight of Standard Batteries
- Individual Modules have Intelligent Software Monitoring and Control
- Interfaces with Hybrid Intelligent MicroGrid Controller

Individual Li-Ion Energy Storage Module



- 6 series cells, 8 parallel cells
- Weight: 12.75lb
- Length: 7.8”
- Width: 11.2”
- Height: 3.0”
- Voltage: 16.5-25.2VDC
- Capacity:
  - 780Wh (100% DOD),
  - 660 Wh (85% DOD)



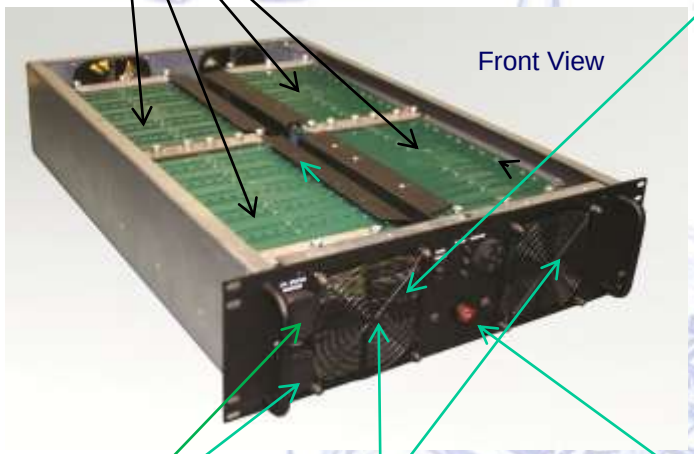
Advanced Li-Ion vs. Traditional Li-Ion

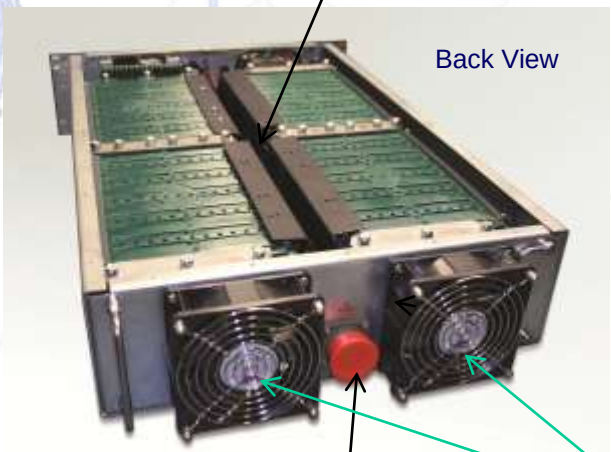
= 4.5 of the BA-2590

135 Wh/kg
>2000 cycles

120 Wh/kg
>300 cycles

(4) Modules/3U = 3.12 kWh Capacity
Or 21.84 kWh in a 21U Transit Case





Battery Modules

Front Panel Monitor (Visual/Audible Alarms)

BMS integrated electronics

Communication Ports

Air Intakes

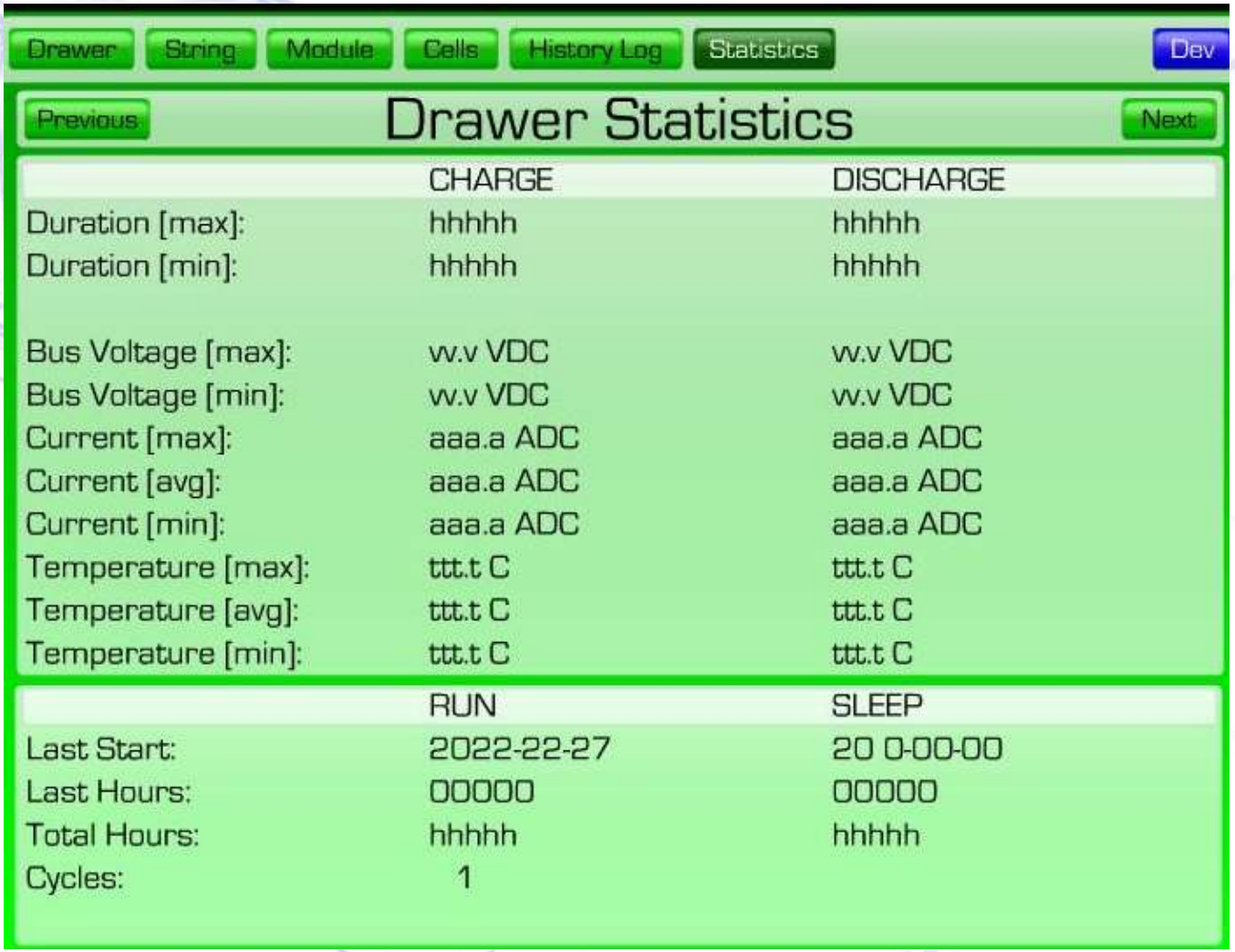
Output breaker

DC Cable connection

Cooling Fans

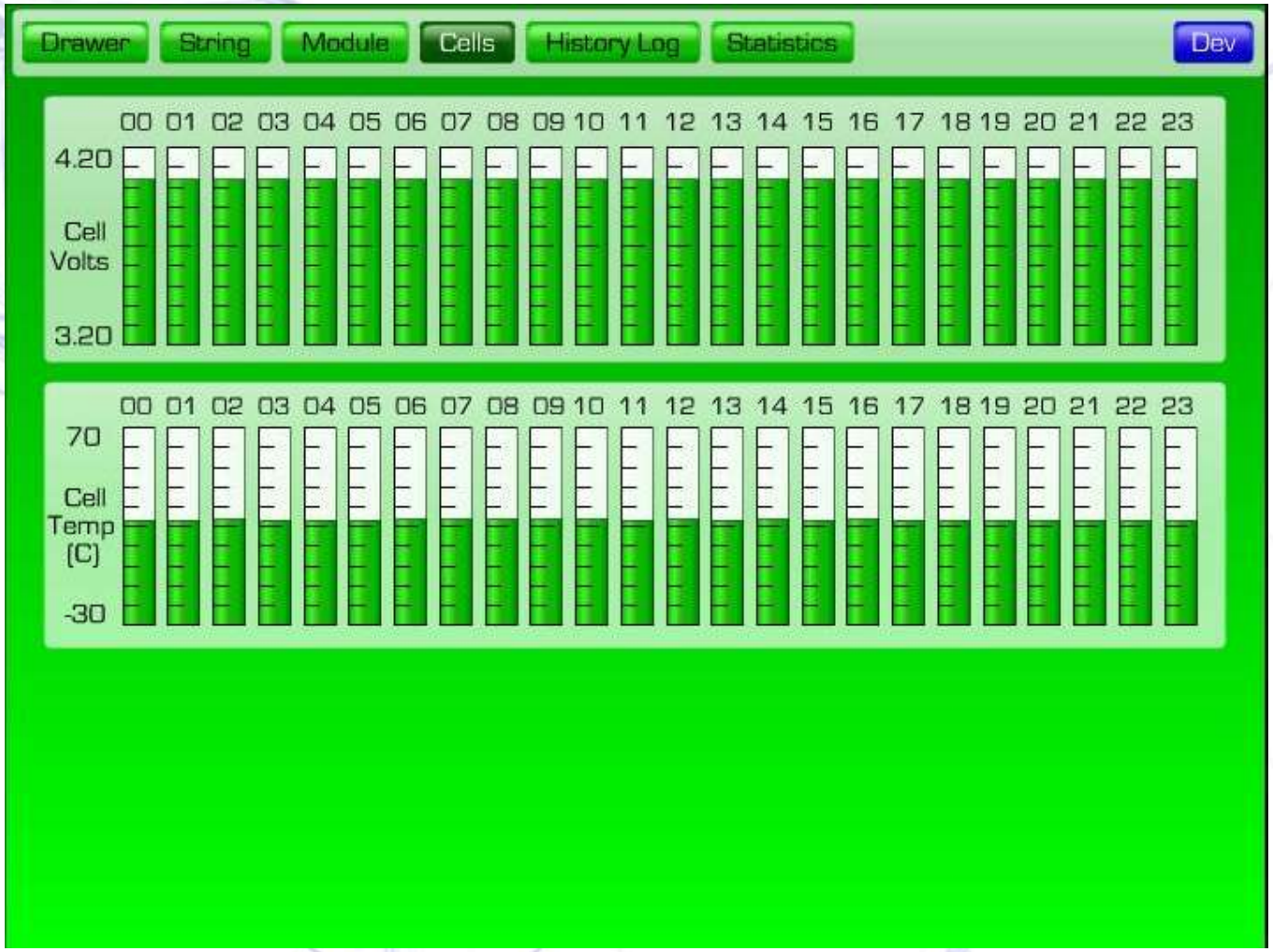
Li-Ion Interface – Drawer Level

Li-Ion Interface – Drawer Statistics



Li-Ion Interface – String Level

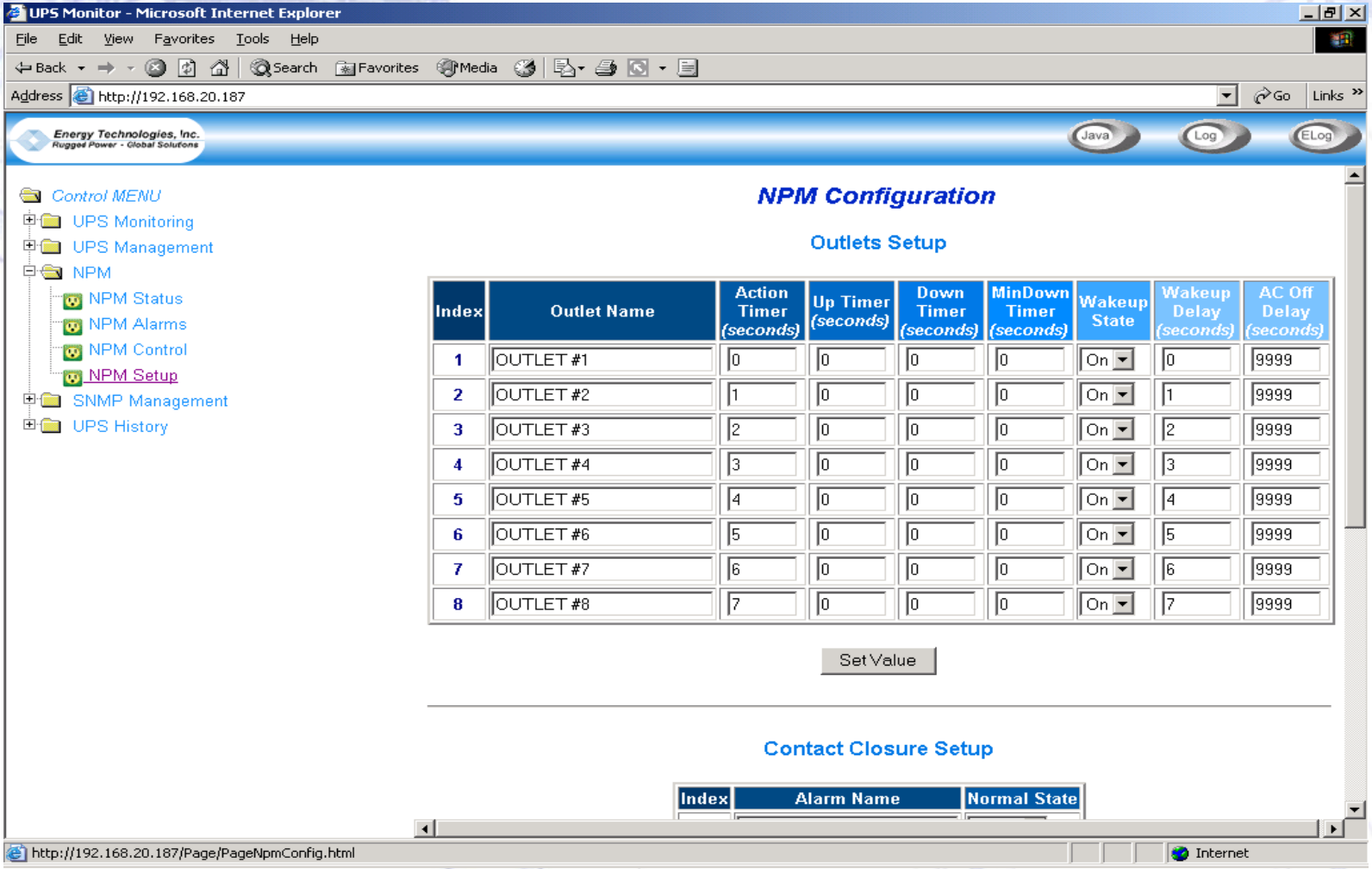
Li-Ion Interface – Cell Level



Intelligent AC Power Distribution Unit (IAPDU)
Intelligent DC Power Distribution Unit (IDPDU)

- Intelligent power distribution modules contain an interface and control module for the input and for each of the individual output connections
- Will operate based on the command requirements of the Hybrid Intelligent Grid Controller and/or manual mode
- Algorithms include assigned priority load shedding and sequential start-up and shut-down procedures
- AC version available in either 1-phase or 3-phase configurations
- Dual source input and various output configurations available

Screen shots examples of configuration setup elements:



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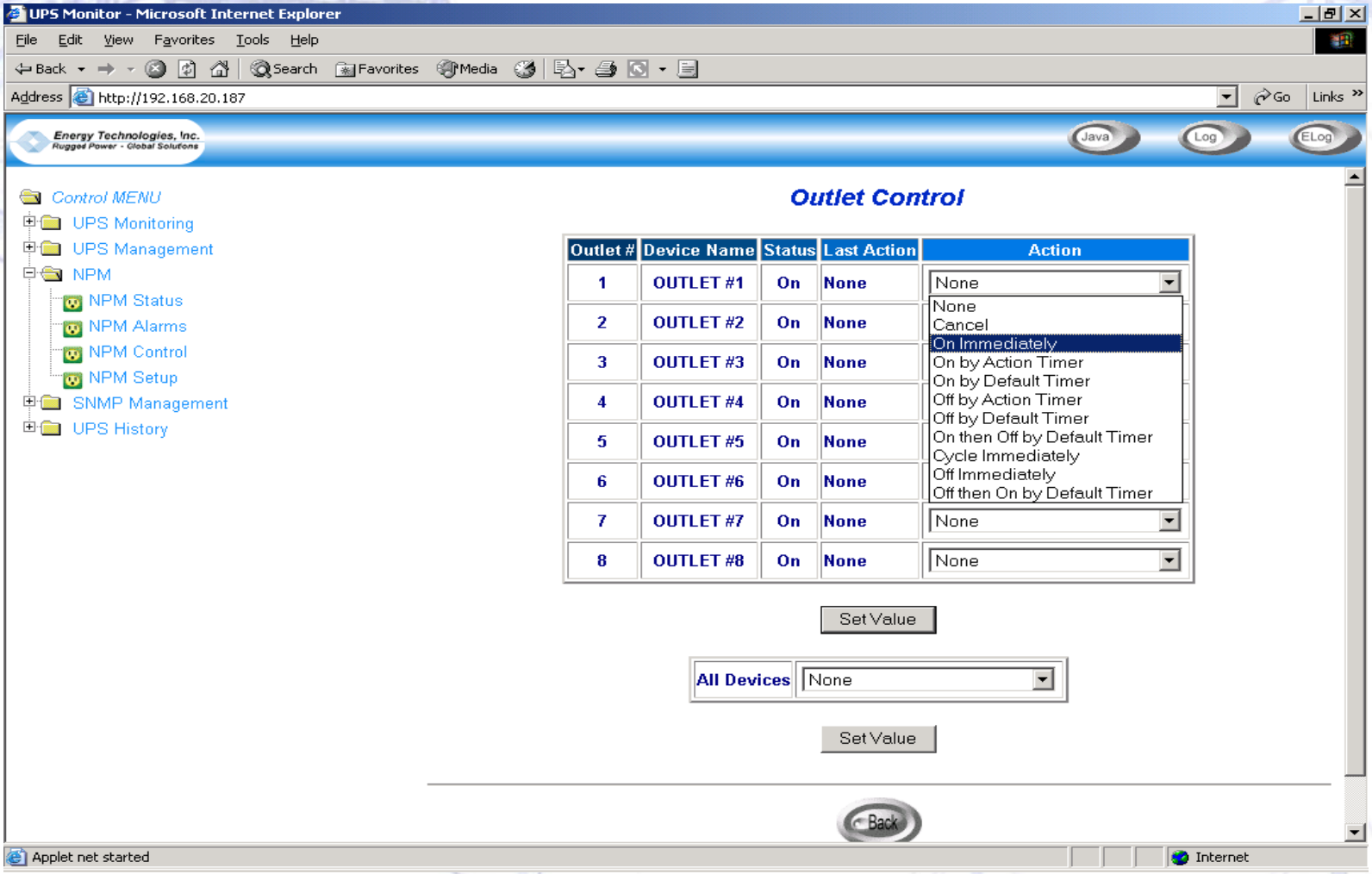
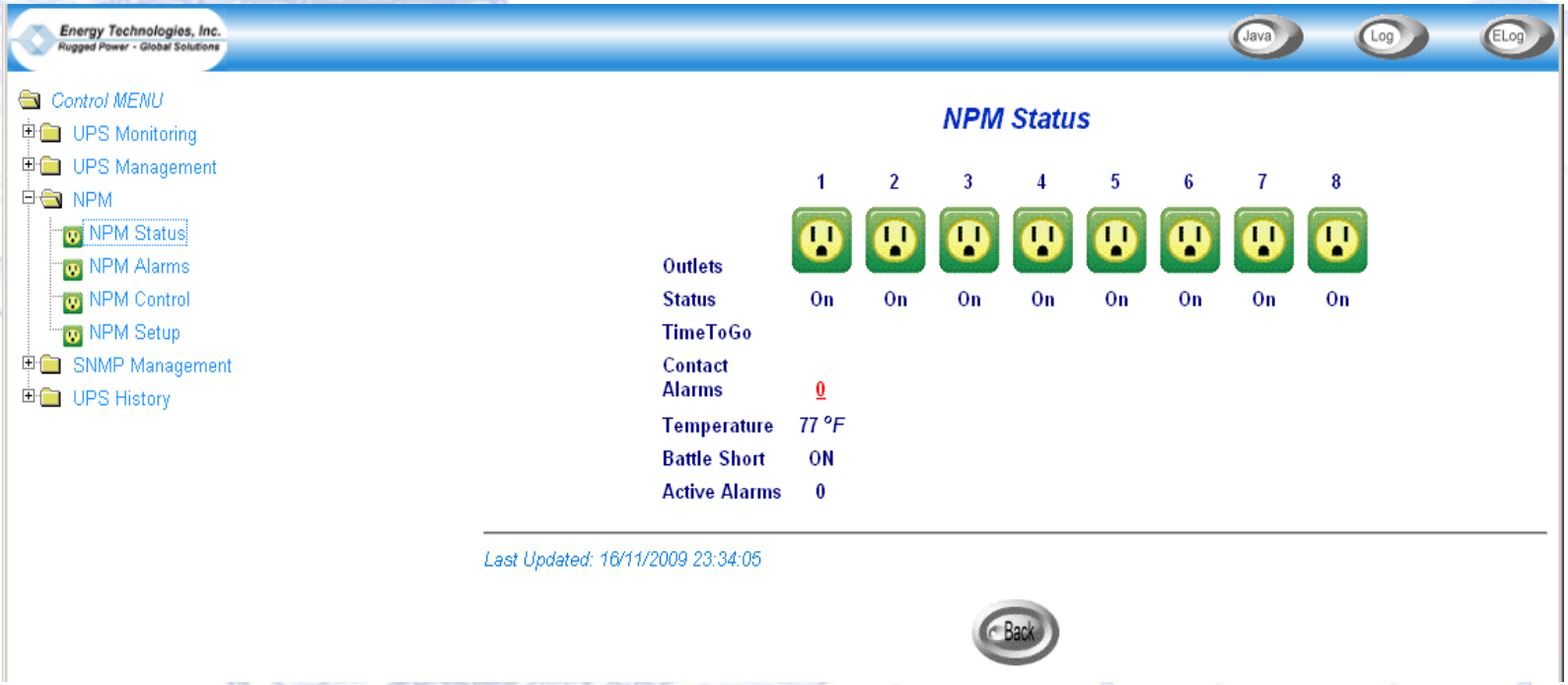


The following screen is only one example of graphic display capabilities:



AC PDU Interface Module (APDUIM)
DC PDU Interface Module (DPDUIM)

- Intended to interface to existing PDU panels to allow the monitoring and control functions of the Intelligent PDU

DC to AC Inverter Module Single Phase (IMSP)
DC to AC Inverter Module Three Phase (IMTP)

- Available in either 1-phase or 3-phase output configurations
- Available in either 12, 24 or 48 VDC input configurations
- Monitoring and control interface to Hybrid Intelligent Grid Controller
- Pure, sinewave AC output

AC to DC Charger Module (ADCM)

- Available in either 1-phase or 3-phase input configurations
- Available in either 12, 24 or 48 VDC output configurations
- Monitoring and control interface to Hybrid Intelligent Grid Controller
- Configurable to allow for accelerated charge rates for the batteries
- Supports all battery technology charge curves

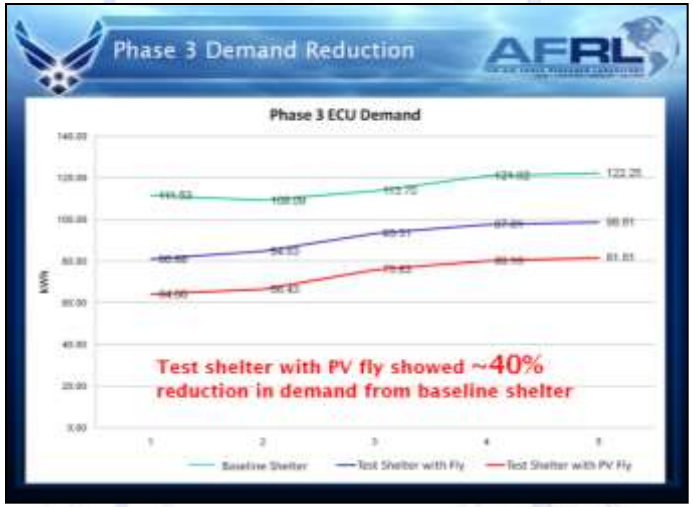
Hybrid Power Base

Demonstrations and Evaluation Testing

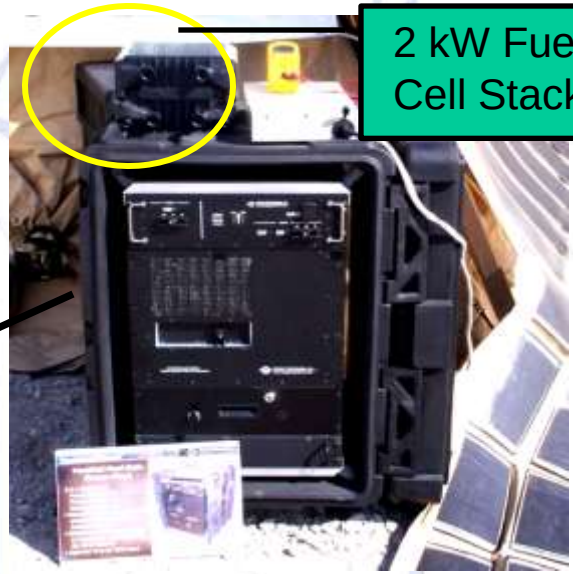
- AFRL Ft. Irwin
- Twenty-nine Palms ExFOB
- US Army Ft. Irwin
- US Air Force Tyndall AFB
- Southern Command
- Navy Crane

Advantages of a Solar Fly

- Fly shown to reduce ECU power consumption by 26% in AFRL tests
- Fly integrated with Photovoltaic (PV) cells generated > 4 kW
- Wind generators can provide 1.2 kW
- Participating in NetZero JCTD at Ft Irwin
- 40% reduction in demand with PV



Joint Committee on Tactical Shelters (JOCOTAS)

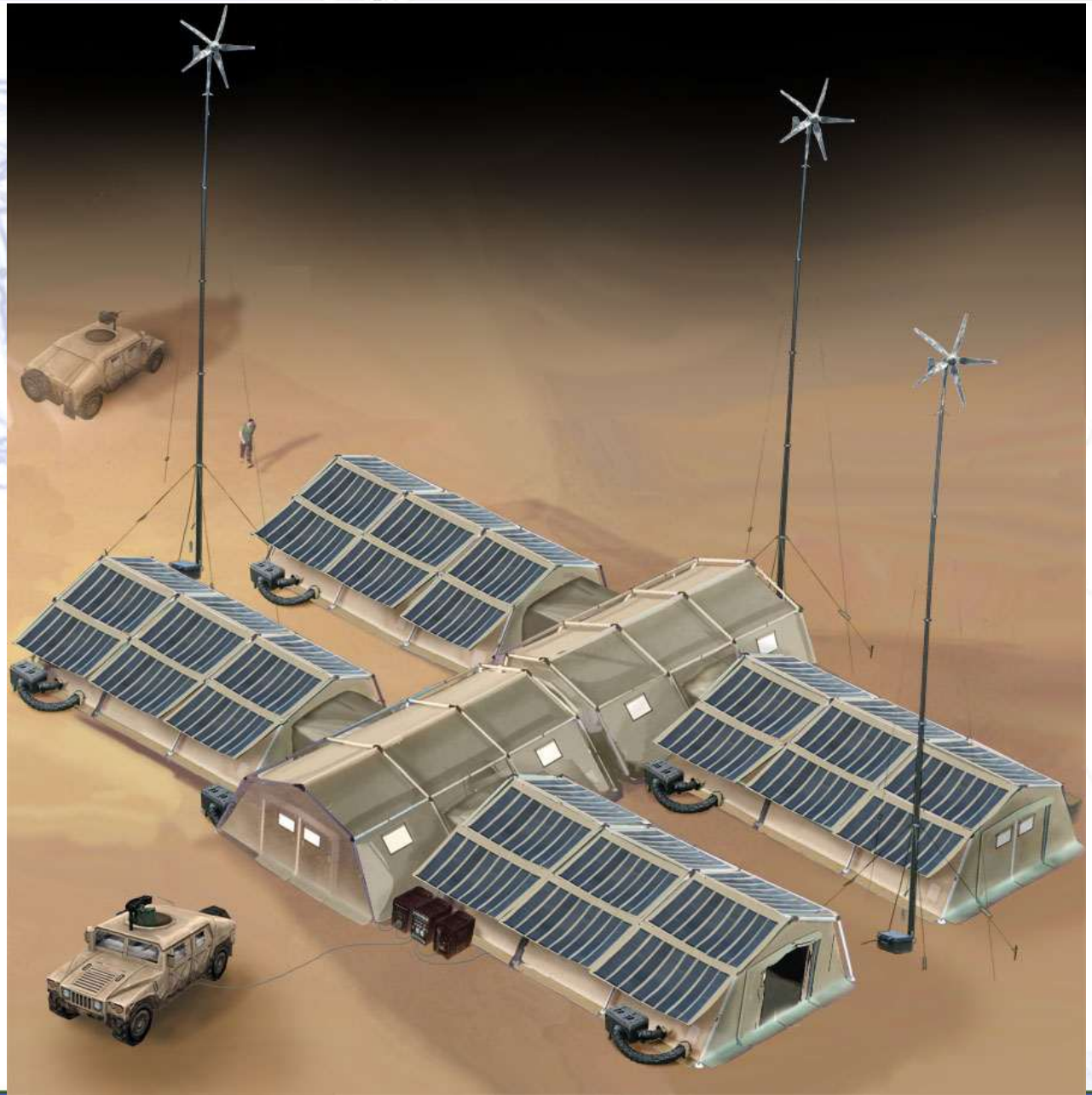


Twenty-nine Palms ExFOB System Set Up

US Army Ft. Irwin Solar Fly Set Up

Developing Hybrid and
Sustainable Energy Solutions

Joint Service Power Expo
Myrtle Beach, SC 3May2011



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