# ORNL Power Electronics Research for DER Utility Interfaces

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***Power Electronics and Electric Machinery Research Center***

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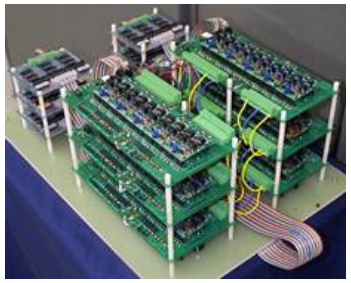
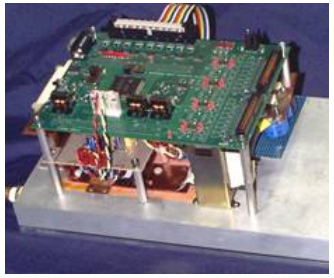
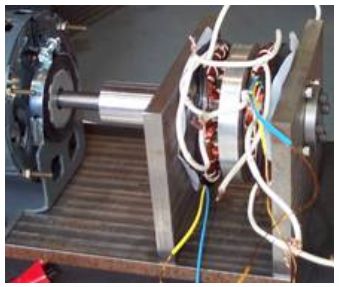
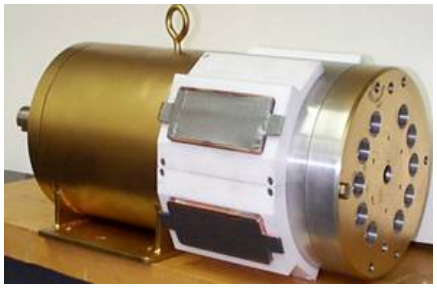
# Power Electronics and Electric Machinery Research Center

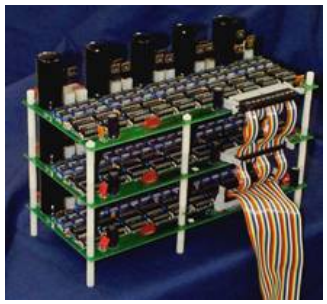
- PEEMRC is *the* U.S. Department of Energy's broad-based power electronic and electric machinery research center.
- www.ornl.gov/estd/PEEMRC
- The center has dramatically advanced technology in:
  - Multilevel inverters
  - Soft-switched inverters
  - Non-active power compensation
  - Motor control techniques
  - Efficient, compact electric machines

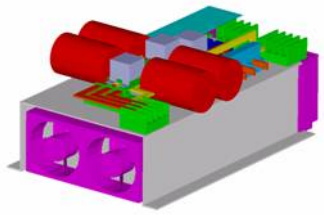
# National User Facility

- PEEMRC has been designated a DOE National User Facility.
- > 700 square meters of laboratory space for developing prototype inverters, rectifiers, and electric machine technology.
- Center has had 25 patents granted with several more pending.
- 20 personnel, 10 with advanced degrees in electrical engineering, mechanical engineering, physics, nuclear engineering.

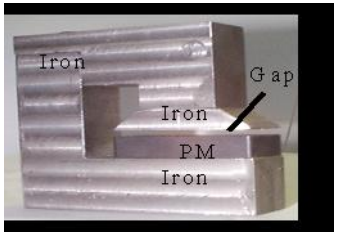
# Power Electronics Research Areas





- Interface with **distributed energy resources** such as microturbines, fuel cells, and solar cells
- **Multilevel converters** for utility applications such as static var compensation, voltage sag support, HVDC intertie, large variable speed drives
- **Harmonics**, **power quality**, and **power filters**
- **Hybrid electric vehicle (HEV)** applications such as motor drives or dc-dc converters
- **Soft-switching** inverters and dc-dc converters
- Application of **wide-band gap power electronics**
- **Simulation, modeling** and **analysis of power electronics** for transportation and utility applications

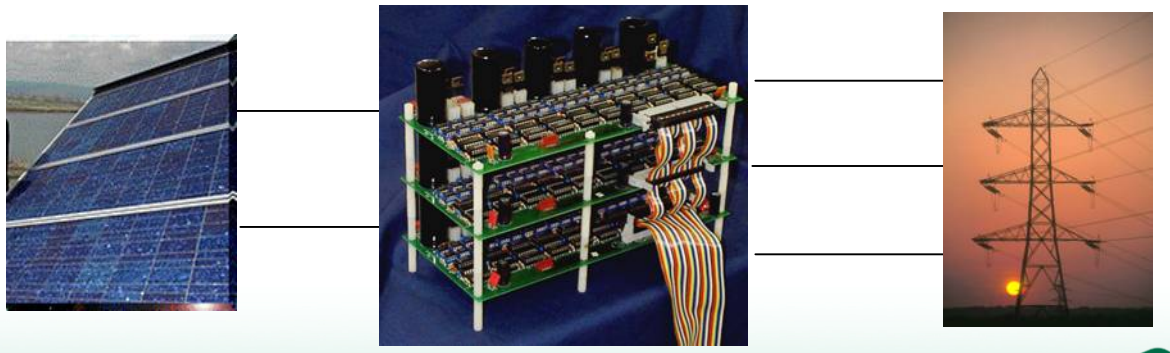
# Electric Machine Technology Research Areas




- **Novel electric machine technology**
  - *Permanent magnet* (axial and radial gap)
  - *Switched reluctance*
  - *Induction* (novel designs and rotor bar technology)
  - *DC machines* (advanced brush technology, soft-commutated, homopolar)
  - *Superconducting generator*
- **Motor control –** sensorless motor drive techniques, circuits and control for extended constant power range for high speeds
- **Design, thermal, efficiency**, and **performance models** for AC machines
- **Prognostics** and **failure diagnostic** techniques

# Power Electronics for Solar Energy

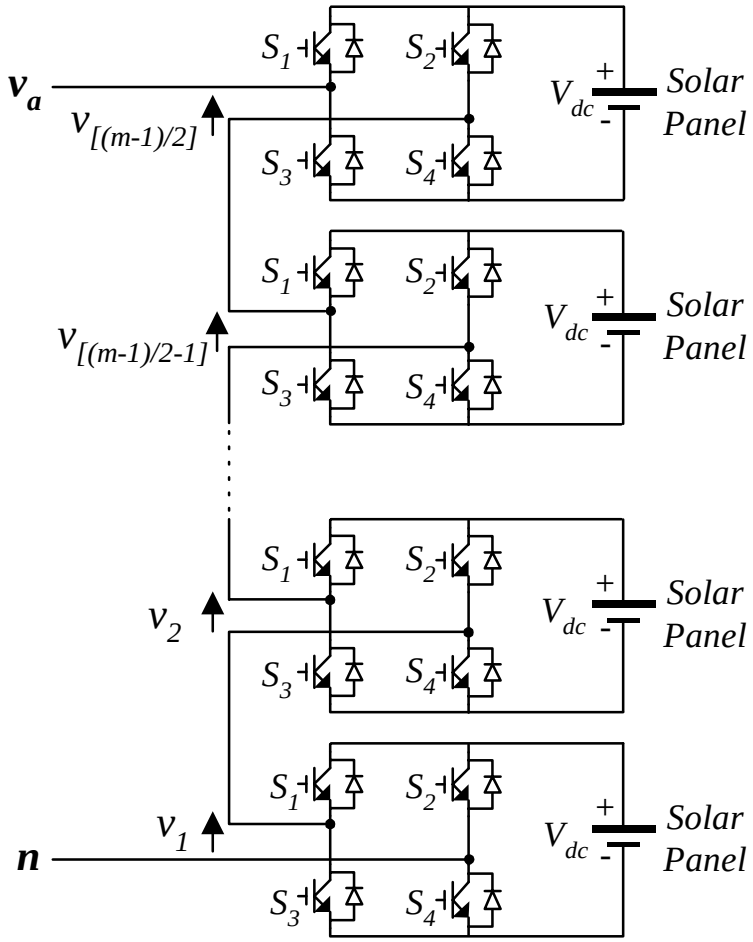
- The Multilevel Inverter is ideally suited for converting the dc output of solar cells into three phase ac power.
- Efficient - low switching losses.
- Fault tolerant capability – Upon failure of a solar panel, or H bridge, it can automatically be reconfigured to maintain operation.
- Can be designed to achieve minimum THD as the incident light intensity on the solar cells changes.



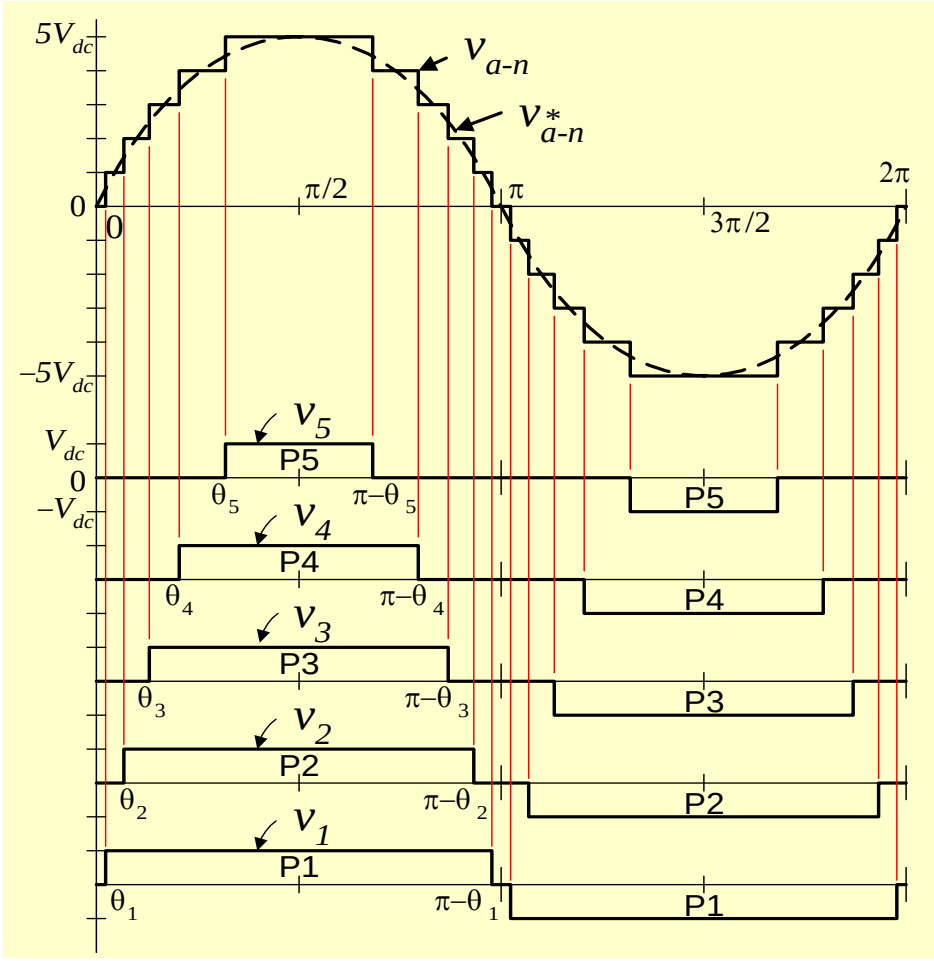
# Multilevel Converter

- Synthesize a sinusoidal voltage from several levels of dc voltages.
- Uses DC sources such as ultacapcitors, solar cells, or batteries and can generate single-phase or three-phase output.
- Fundamental frequency switching technique yields very low switching losses and high converter efficiency.
- Key technical issue is to eliminate low frequency harmonics ($5^{th}$,$7^{th}$,$11^{th}$ and $13^{th}$) in the voltage output.

# Multilevel Converter



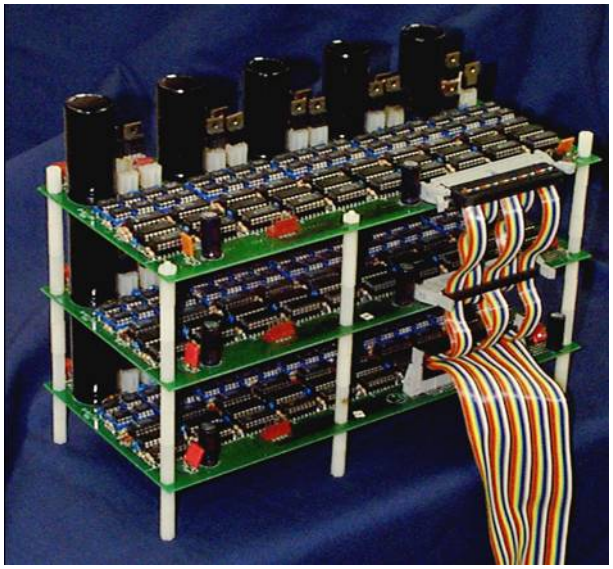

**Single phase m - level structure**
**$V_{dc}$ is the output of a solar cell panel**

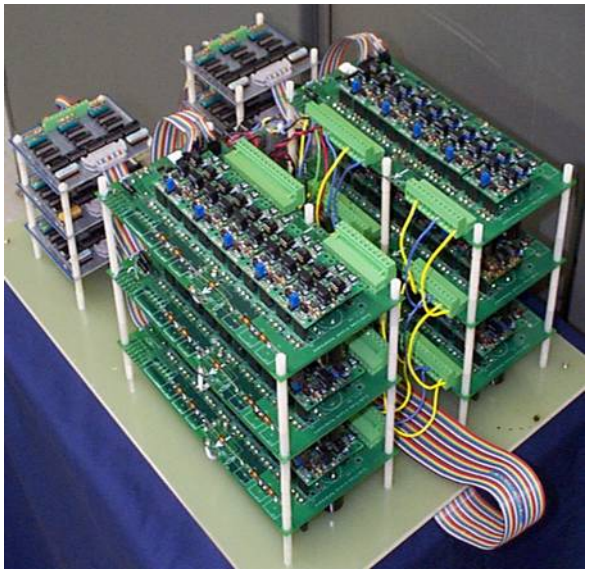



**Line-neutral voltage for 11-level inverter**

# Multilevel Converters

- **Structures developed by ORNL for utility interfaces**
  - Cascaded H-bridges inverter with separate dc sources (U.S. Patent 5,642,275)
  - Back-to-back diode clamped converter (U.S. Patent 5,644,483)
  - Small scale prototypes (300 V, 10 kW) developed for each of these structures to demonstrate feasibility and control issues





# Multilevel Converter Applications Investigated at ORNL since 1993

- Static var compensation
- Active power filter
- Voltage sag compensation
- Back-to-back intertie of asynchronous AC utilities
- Interface between distributed generation sources and utility
- Medium voltage motor drives
- Multilevel pulse width modulation and fundamental frequency switching techniques that minimize total harmonic distortion at any modulation index

# Advantages of Multilevel Inverters

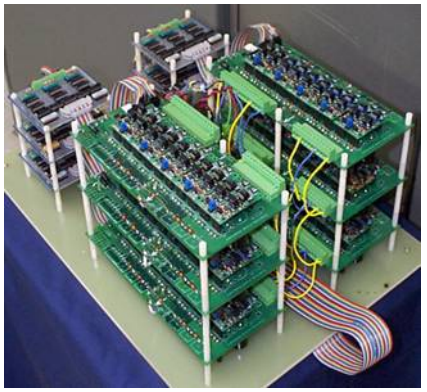
- Modular - lower manufacturing costs
- Compact - no transformer needed
- None or reduced output filters
- Redundant levels for increased reliability
- Possible connections: single-phase, multi-phase, three phase wye or delta
- Low switching frequency yields high efficiency
- Possible control strategies
  - Fundamental Frequency Switching
  - Multilevel PWM

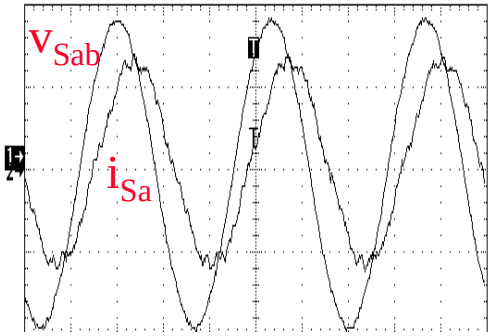
# Cascade Inverter as Voltage Sag Supporter

- Collaboration with a commercial supplier to develop 15 kV, 5 MVA prototype.
- Supports voltage sags of 30% for 30 seconds.
- Approximately 90% of problem sags will be eliminated.
- Suppression of voltage harmonics and distortion.
- Applicable from 4.6 kV to 25.7 kV.
- Unit design is modular, transportable, and has self-control and protection.
- Economical solution for most of a customer's power quality needs.

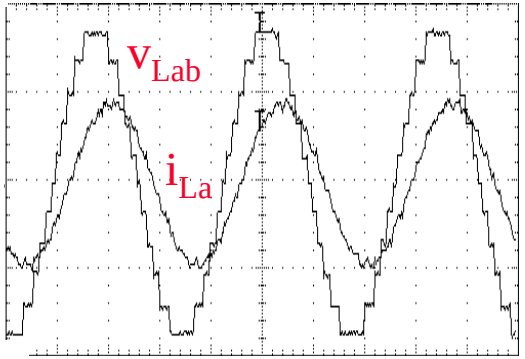
# Back-to-Back Multilevel Diode-Clamped Inverter

- Input current controlled to have unity displacement power factor with a total harmonic distortion of 3%
- Efficiency of multilevel inverter greater than 98% for loads greater than 40% of its rated power (using fundamental frequency switching)

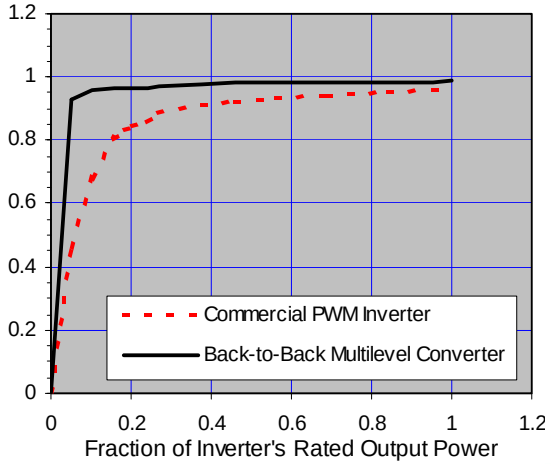





Source voltage and current




Load voltage and current



# Provision of Ancillary Services

- Power electronics interface with solar cells enables the unit to provide additional services besides real power generation:

  - ✓ static var compensation (power factor correction)
  - ✓ voltage regulation (sag compensation)
  - ✓ interface with energy storage devices
  - ✓ fast/seamless mode transfers (grid-connect/stand alone)
  - ✓ enhanced distribution system reliability
  - ✓ improved distribution system power quality

# Leveraging Transportation Technology for Utility Applications

## Similarities

- Modularity, Integration
- High Efficiency
- Low Cost
- Reliability
- Control
- Bi-directional Power Flow
- Electric Machine Interaction
- Energy Storage
- Minimize EMI

## Differences

- Voltage/Power Scale
- Utility/System Interaction
- Multifunctional
- Communications

# Power Electronics for Microturbines Projects

- Review of existing power electronics interface technologies for microturbines in the range from 20 kW to 1 MW.
- Control of real and reactive power in grid connect or stand alone mode. Enable units to share real and reactive power when several units are connected in parallel.
- Ability to transfer from stand alone to synchronized/grid connect quickly (subcycle time) and seamlessly.

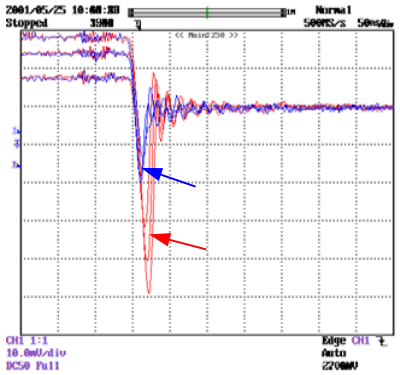
# Fuel Cell Projects

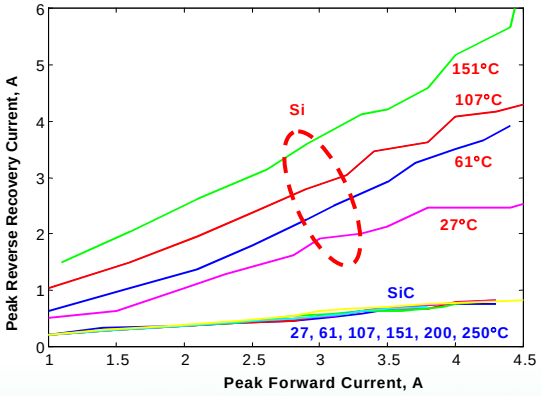
- ORNL is installing a 200 kW fuel cell for a combined heat and power (CHP) demonstration.

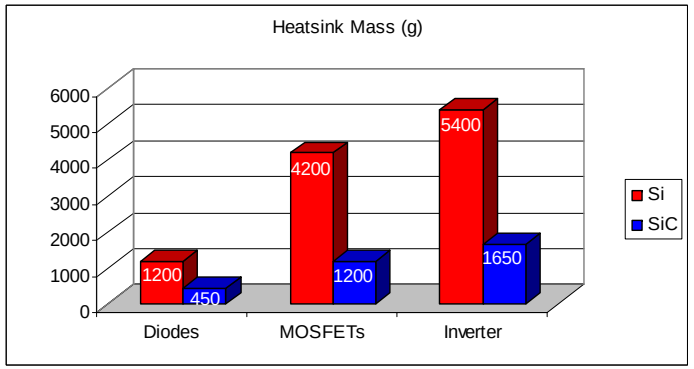
- Interface issues with local utility to be investigated.
- Seamless switching from stand-alone to grid-connected.
- A 2.2-kW alkaline (KOH) fuel cell also being installed.
- Analysis of fuel cell and power electronics system interactions.
- Electric power management systems by use of energy storage (batteries, ultracapacitors) to aid fuel cell during load transients.
- Project to investigate the ganging of multiple solid-oxide fuel cell stack modules.

# Wide Bandgap Semiconductor Applications

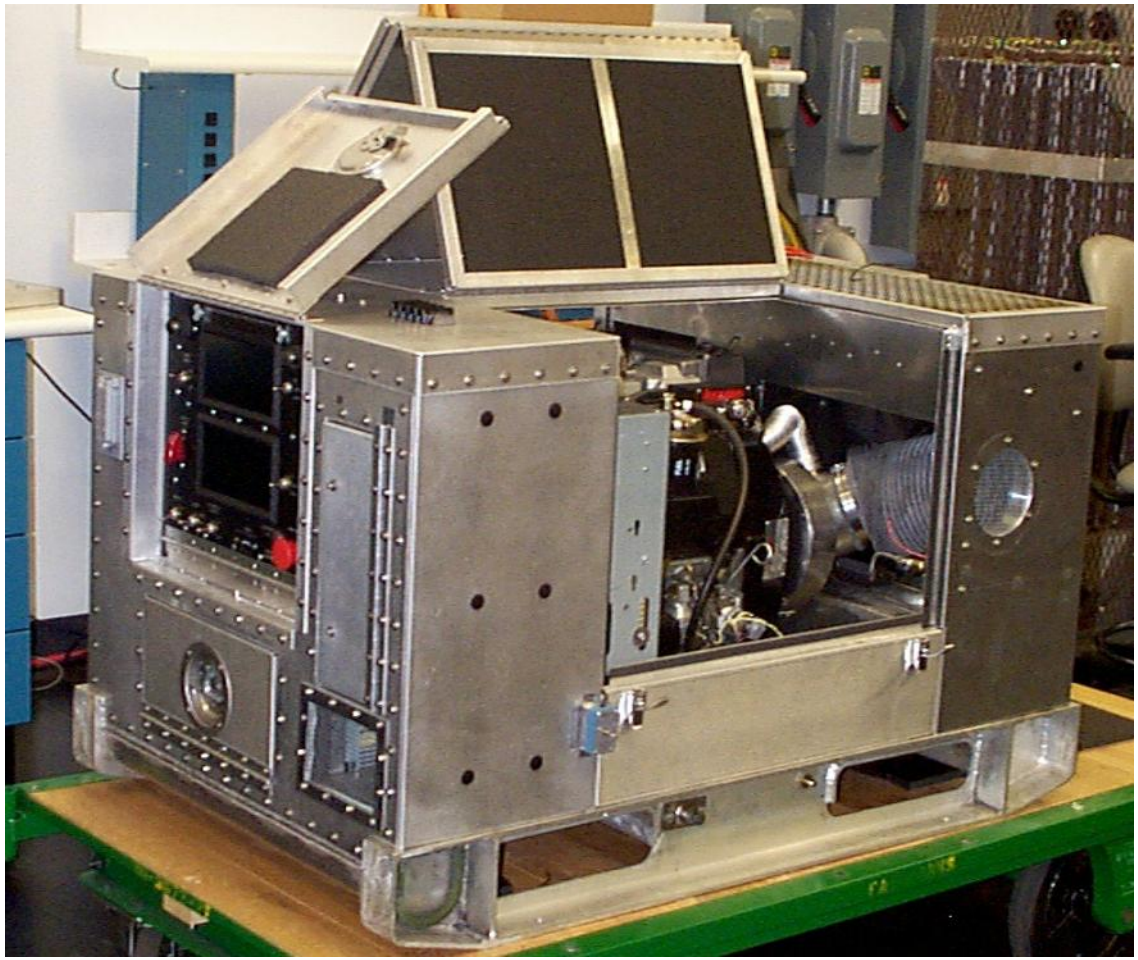
- ORNL, UT, and Vanderbilt have investigated the use of wide bandgap semiconductors for use in HEV and utility applications.
- Wide bandgap Schottky diodes are commercially available (600 V, 20 A). Other devices (thyristors, GTOs, MOSFETs) are laboratory prototypes.
- New packaging techniques, gate drivers, and circuit topologies are needed to take advantage of the properties of these new materials.





# Power Electronics Based Military Gen-Set



- 10 kW and 80 kW units
- Incorporates bi-directional converter as interface with batteries
- Power density improved by 100%
- Digital display and control

# Additional joint projects with The University of Tennessee

- Methodology to compute the switching angles for any modulation index that produce the smallest total harmonic distortion (THD) in a multilevel inverter.
- Nonactive power compensation definitions and passive energy storage requirements.
- Reconfigurable connections of multiple DER modules.

# Summary

- ORNL has extensive experience in power electronics for utility applications and addressing interface issues.
- Leveraging power electronics technology developed for transportation and other industries can shorten development time and lower cost of modules.
- Multilevel inverter has several properties that make it ideal as an interface for solar panels.