Power Electronics Interface for Integrating Multiple Distributed Generators

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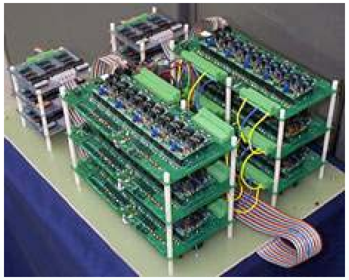
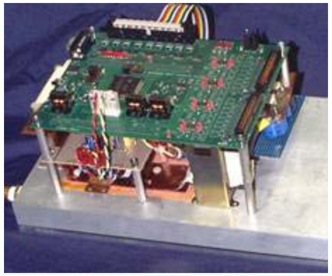
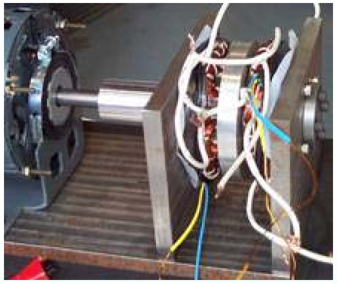
Outline

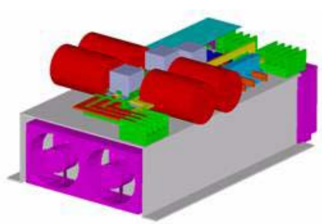
- Power Electronics and Electrical Machinery Research Center (PEEMRC) at ORNL
- DER work at PEEMRC
- Five power electronics interface integration topologies
- Conclusions

Power Electronics and Electric Machinery Research Center

- PEEMRC is *the* U.S. Department of Energy's broad-based power electronics and electric machinery research center.
- 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.

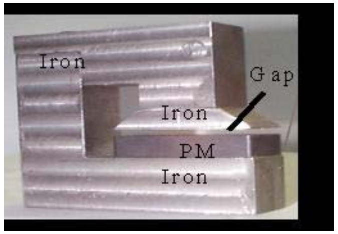





Power Electronics Research Areas



- 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
- **Prognostics** and **failure diagnostic** techniques

Recent Industry Collaborations

- Caterpillar
- GM
- CARTA
- U.S. Army
- Visual Computing Systems
- Detroit Diesel Corp.
- Nartron, Inc.
- American Superconducting Corp.
- Stereotaxis Inc.
- Southern States Inc.

Power Electronics for Microturbines Projects

- Review of existing power electronics interface technologies for microturbines in the range from 20 kW to 1 MW. (for DOE – finished 03/30/2003)
- 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.

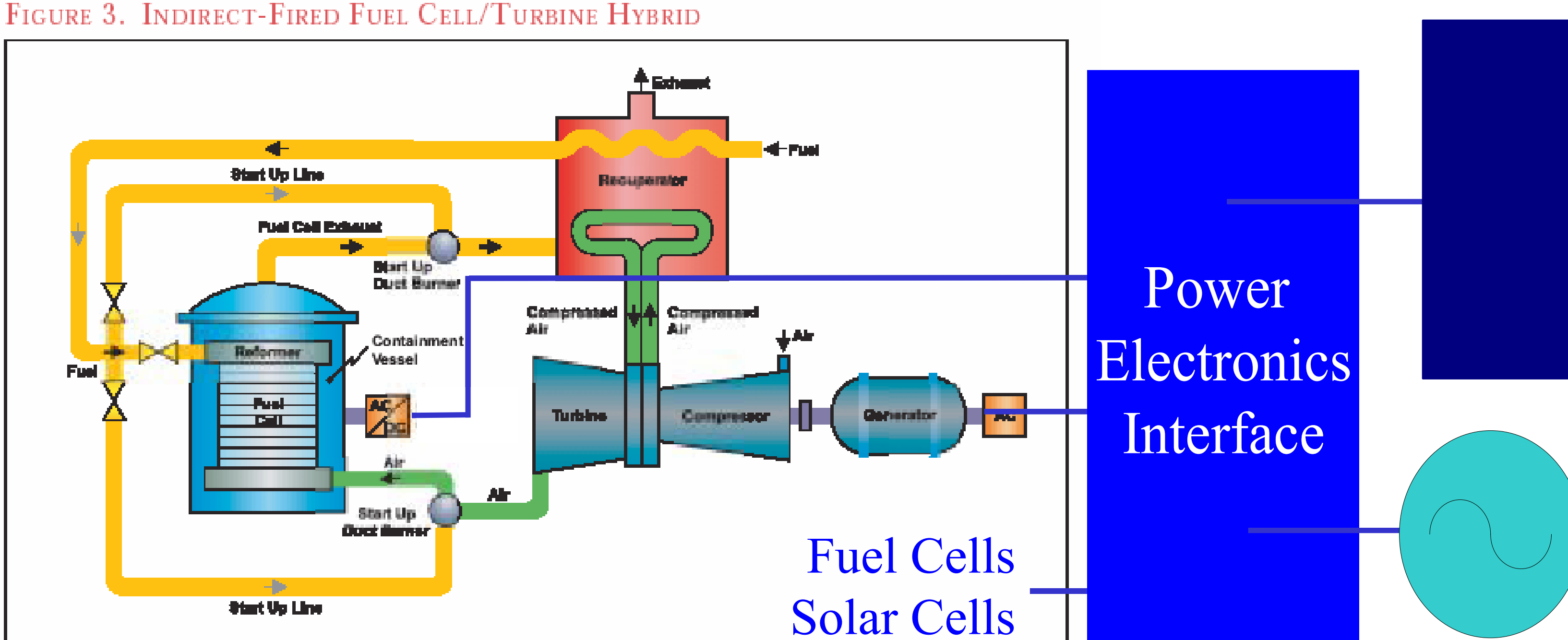
Fuel Cell Projects

- ORNL is installing a 200 kW fuel cell (PAFC) for a combined heat and power (CHP) demonstration.
  - Interface issues with local utility are being 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.** (DOE SECA project – due 09/30/2003)

Objective

FIGURE 3. INDIRECT-FIRED FUEL CELL/TURBINE HYBRID



Fuel Cells
Solar Cells
Microturbines
Batteries
Wind turbines
Gas turbines

Grid

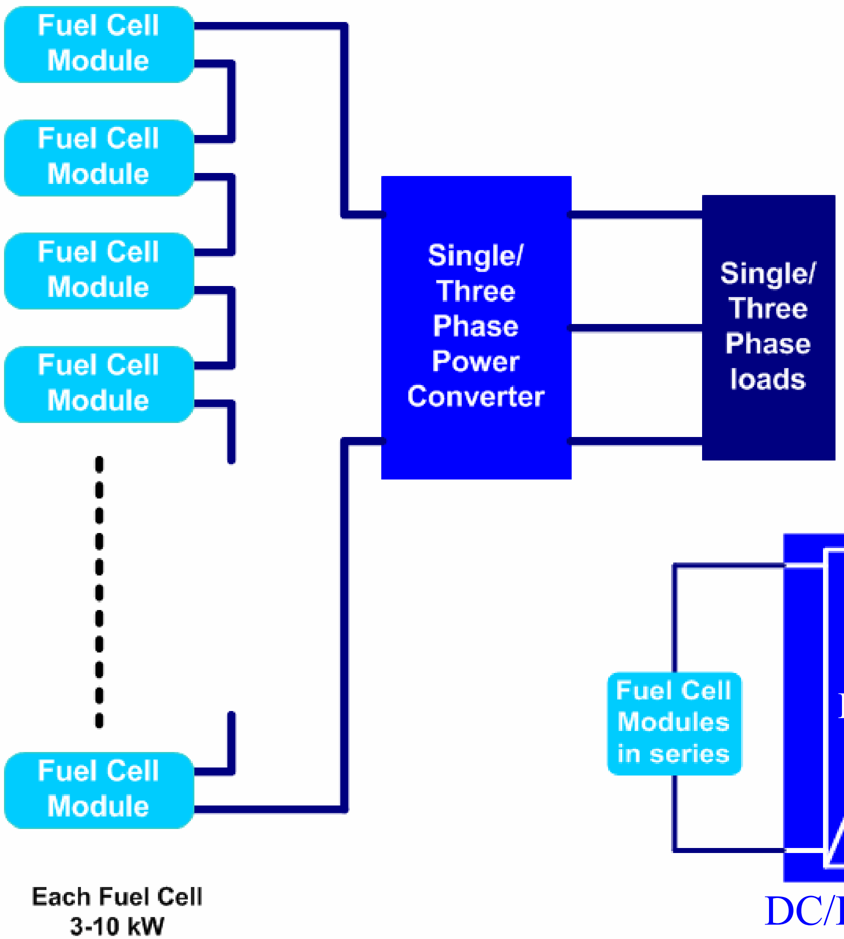
- From US DOE – NETL Hybrid Power Systems Program Plan

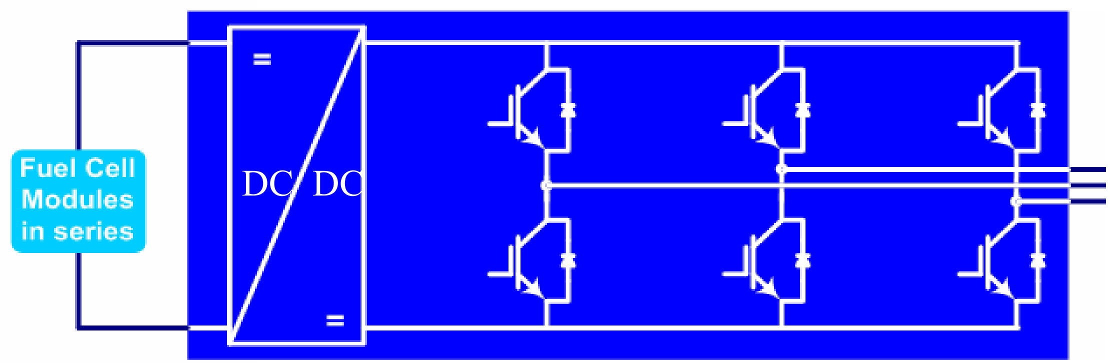
Five Integration Configurations

- Series
- DC distribution
- HFAC distribution
- Cascaded multilevel, and
- Multilevel configurations.

1. Series Configuration

Convert all generated voltages to DC and connect them in series.



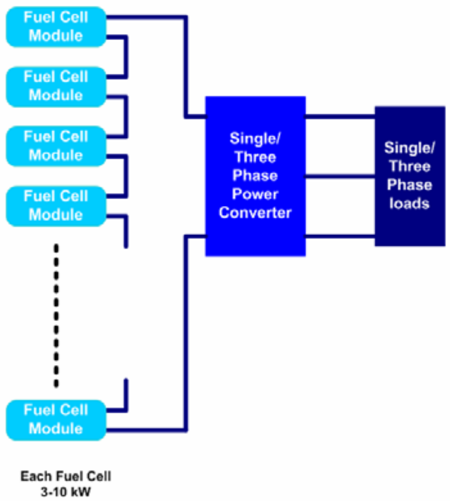


DC/DC voltage regulator

Three-phase inverter

Features

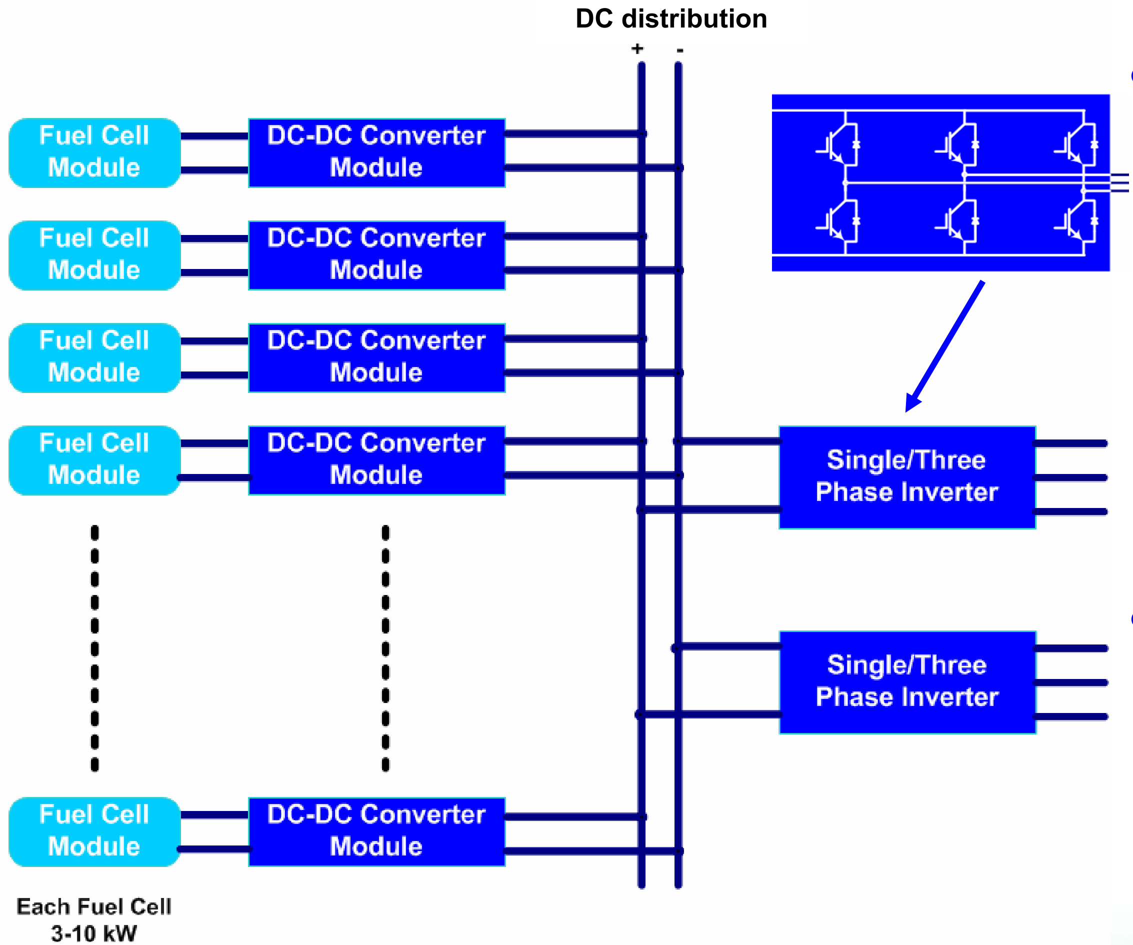
- Advantages
  - Simple series connection; just requires rectifiers to convert the AC voltages generated by turbines to DC.
  - Low device count.
  - Simple control.
  - Commonly used three-phase inverter in a module
  - Cheap



- Disadvantages
  - Individual sources are not controlled.
  - If one source fails, the system will not work – reliability concerns

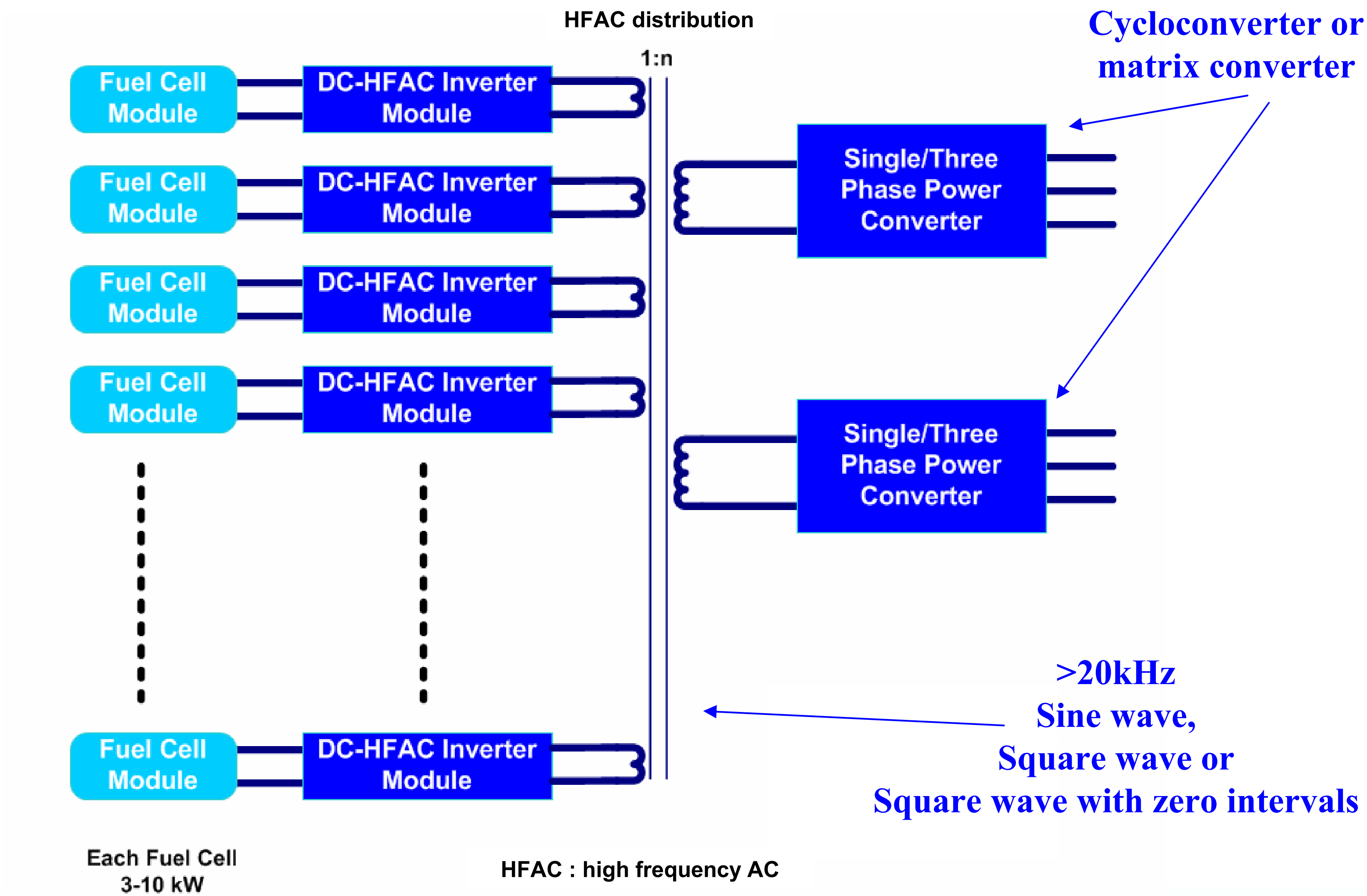
2. DC distribution

Convert all generated voltages to DC and feed them to DC-DC voltage controller/regulators and connect the outputs in parallel..



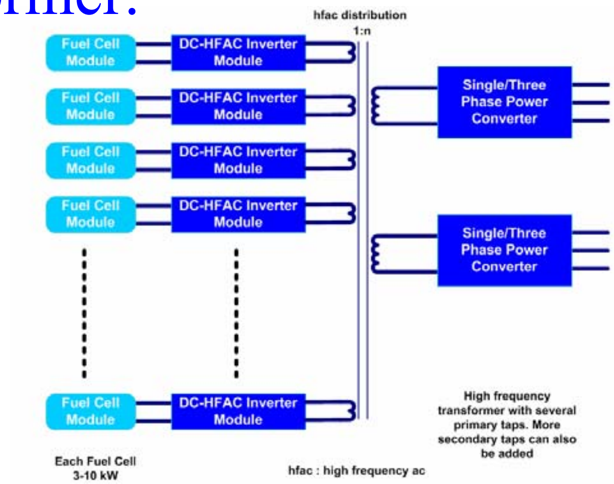
- Advantages
  - Reliability with redundancy.
  - Commonly used three-phase inverter in a module.
- Disadvantages
  - Circulating current problem.
  - Higher device count

3. HFAC distribution



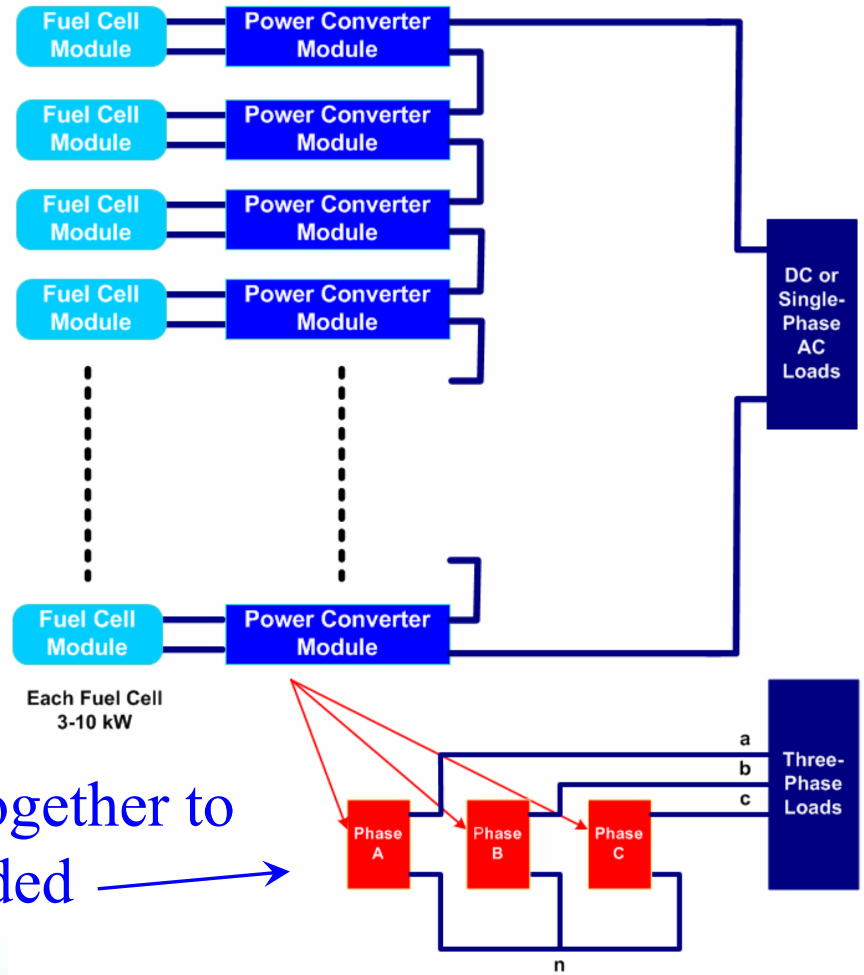
Features

- Advantages
  - Isolation and
  - Voltage boost provided by the transformer.
  - Less filtering required
  - Smaller passive components
- Disadvantages
  - Expensive transformer
  - Possibility of transformer saturation
  - High device count because AC switches are required for the secondary
    - AC switches are not commonly available.
  - Complex control



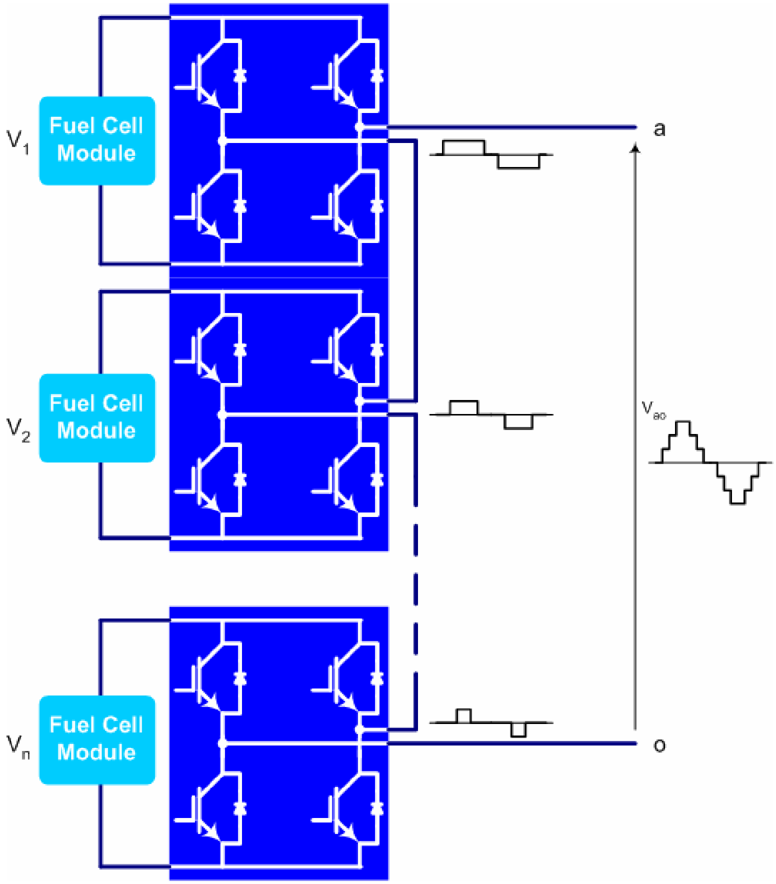
4. Cascaded Multilevel Configuration

- Convert all generated voltages to DC.
- Feed them to single-phase H-bridge inverters.
- Connect the outputs of the H-bridges in series.

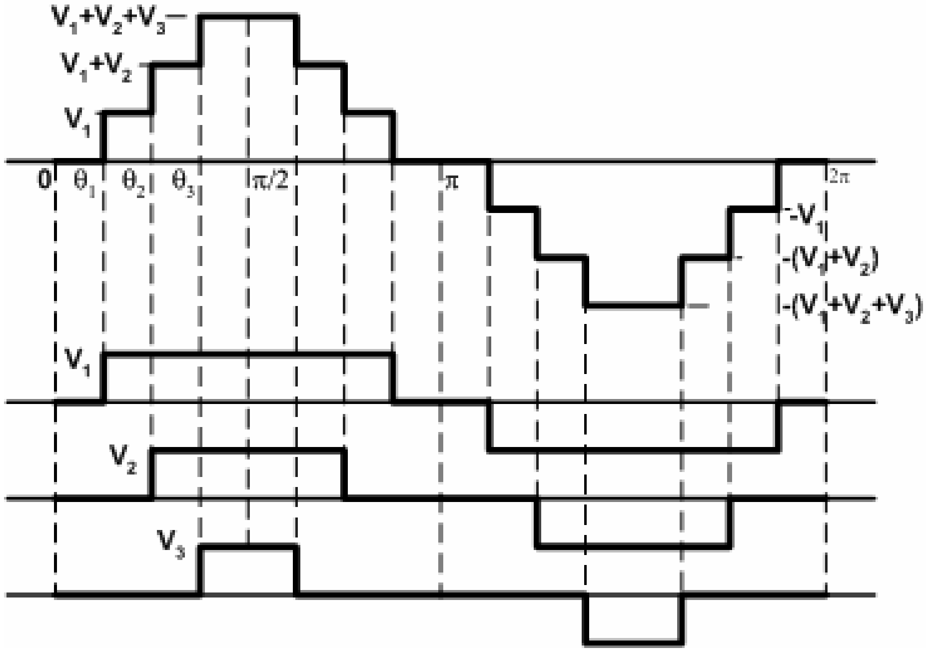


- Connect three of these together to form a three-phase cascaded multilevel inverter

Cascaded Multilevel Configuration (cont'd)

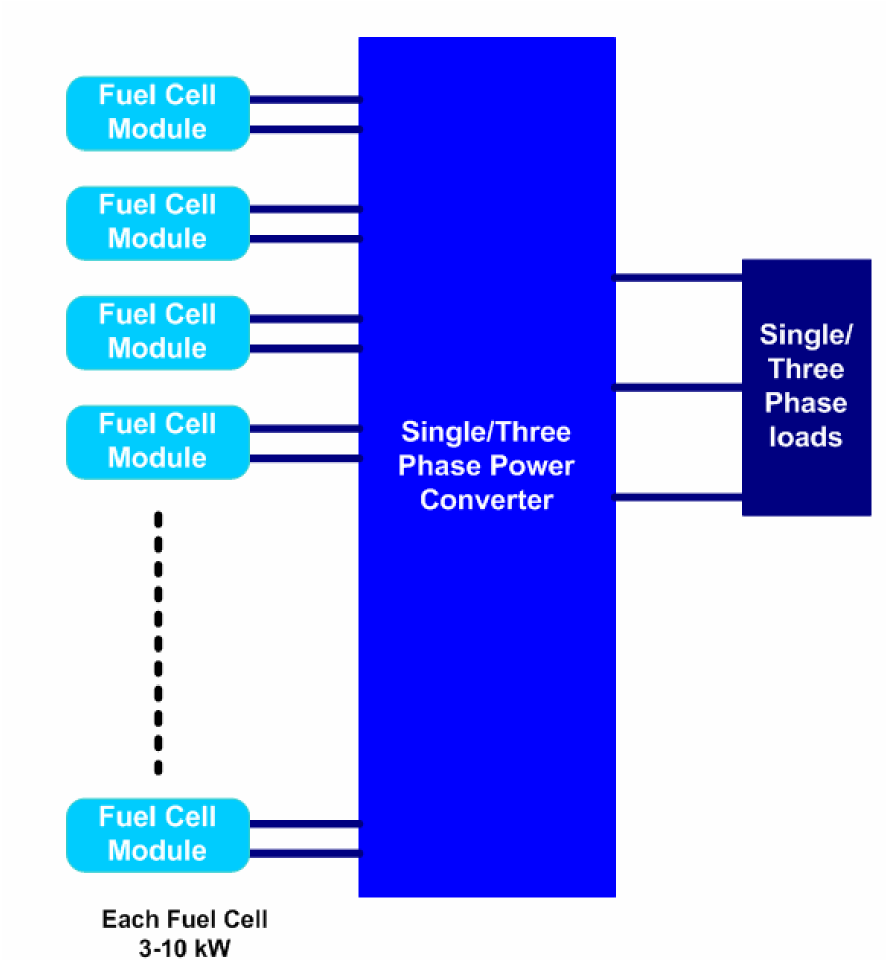


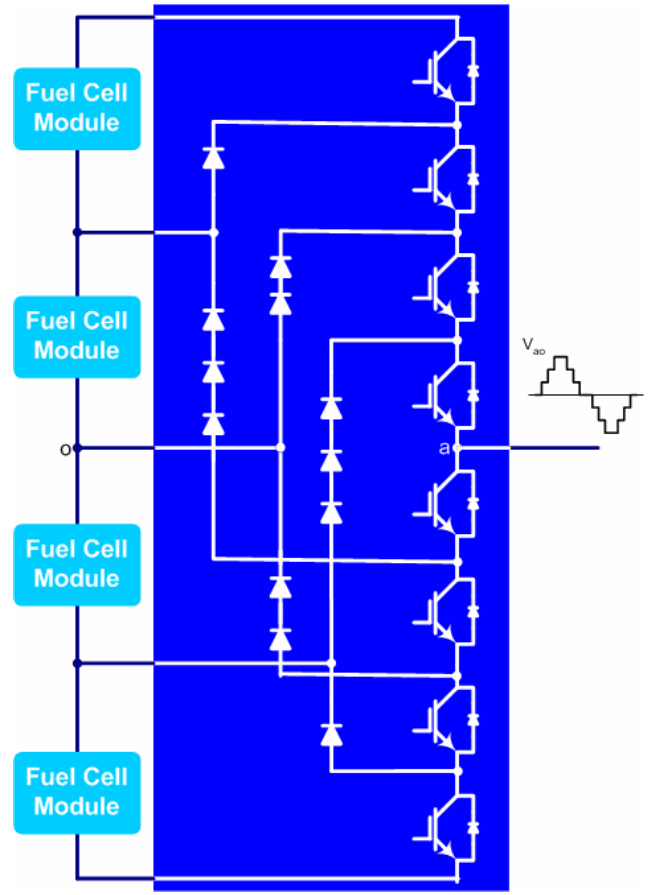
Single-phase n - level structure



Line-neutral voltage for 7-level inverter
(Three H-bridges cascaded)

5. Multilevel Configuration

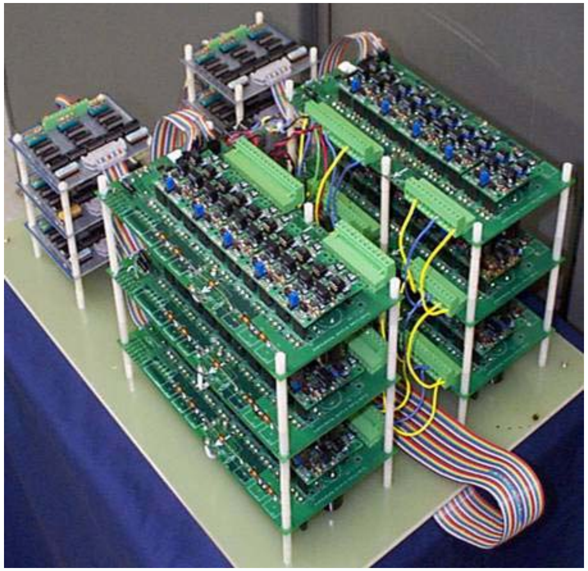




Single-phase diode clamped multilevel inverter

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

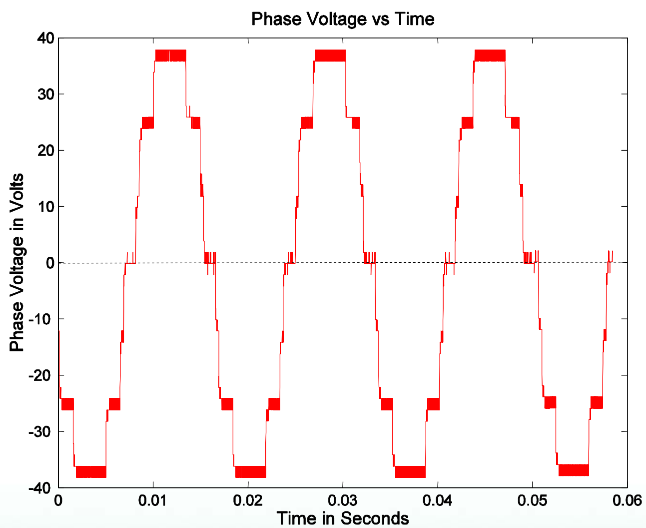


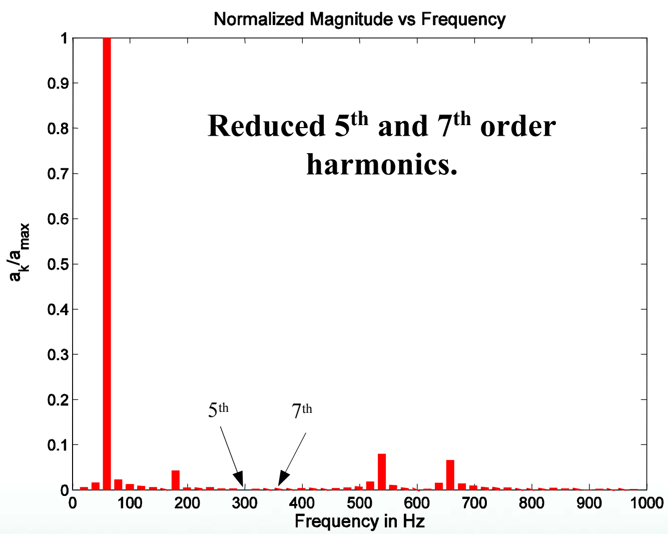
Advantages of Multilevel Inverters

- Modular - lower manufacturing costs
- Redundant levels for increased reliability
- Possible connections: single-phase, multi-phase, three phase wye or delta
- Fundamental frequency switching technique yields very low switching losses and high converter efficiency
- Possible control strategies
  - Fundamental Frequency Switching
  - Multilevel PWM

Disadvantages of Multilevel Inverters

- High device count, but with lower voltage ratings.
- Complex control for variable DC sources as in this case because DC sources need to be monitored.
- Higher low order harmonics, but harmonic reduction techniques are available.





Conclusions

- ORNL has extensive experience in power electronics for utility applications and addressing interface issues.
- Five power electronics interfaces were presented for integrating multiple distributed generators.
- More research is required to quantitatively comparing each configuration with others.