

Advanced Power Electronics Interfaces for Distributed Energy Workshop Summary

August 24, 2006
Sacramento, California

B. Treanton and J. Palomo
California Energy Commission

B. Kroposki and H. Thomas
National Renewable Energy Laboratory

Workshop Summary

NREL/BK-581-40480

October 2006

NREL is operated by Midwest Research Institute • Battelle Contract No. DE-AC36-99-GO10337



Advanced Power Electronics Interfaces for Distributed Energy Workshop Summary

August 24, 2006
Sacramento, California

B. Treanton and J. Palomo
California Energy Commission

B. Kroposki and H. Thomas
National Renewable Energy Laboratory

Prepared under Task No. WW88.2005

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
303-275-3000 • www.nrel.gov

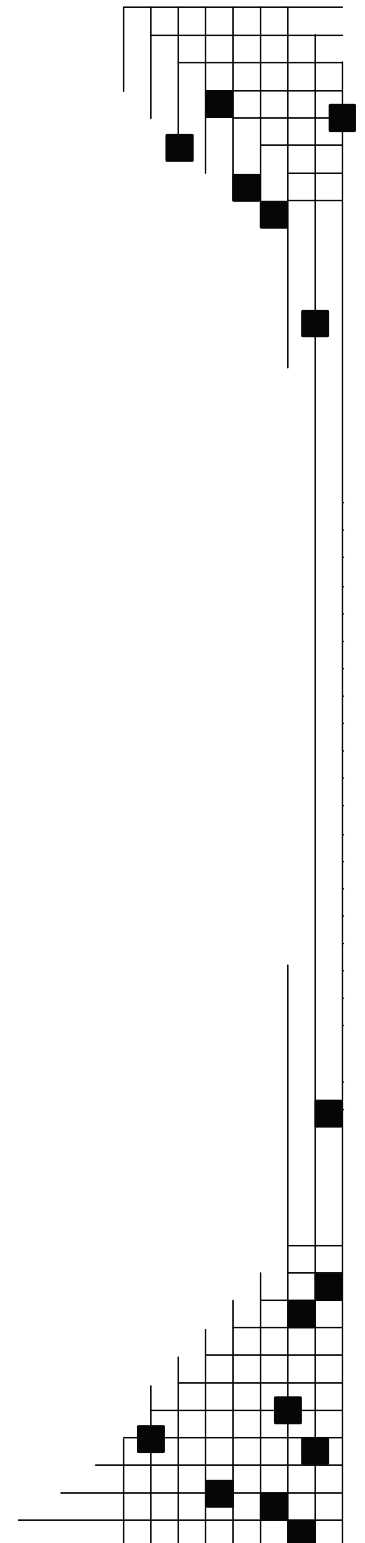
Operated for the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
by Midwest Research Institute • Battelle

Contract No. DE-AC36-99-GO10337

Workshop Summary

NREL/BK-581-40480

October 2006



LEGAL NOTICE

The National Renewable Energy Laboratory is a national laboratory of the U.S. Department of Energy (DOE) managed by Midwest Research Institute for the U.S. Department of Energy under Contract Number DE-AC36-99GO10337. This report was prepared as an account of work sponsored by the California Energy Commission and pursuant to a M&O Contract with the United States Department of Energy (DOE). Neither Midwest Research Institute, nor the DOE, nor the California Energy Commission, nor any of their employees, contractors, or subcontractors, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by Midwest Research Institute, or the DOE, or the California Energy Commission. The views and opinions of authors expressed herein do not necessarily state or reflect those of Midwest Research Institute, the DOE, or the California Energy Commission, or any of their employees, or the United States Government, or any agency thereof, or the State of California. This report has not been approved or disapproved by Midwest Research Institute, the DOE, or the California Energy Commission, nor has Midwest Research Institute, the DOE, or the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

DISCLAIMER

The government and the facility operator make no express or implied warranty as to the conditions of the research or any intellectual property, generated information, or product made or developed under this agreement, or the ownership, merchantability, or fitness for a particular purpose of the research or resulting product; that the goods, services, materials, products, processes, information, or data to be furnished hereunder will accomplish intended results or are safe for any purpose including the intended purpose; or that any of the above will not interfere with privately owned rights of others. Neither the government nor the facility operator shall be liable for special, consequential, or incidental damages attributed to such research or resulting product, intellectual property, generated information, or product made or delivered under this agreement.

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available electronically at <http://www.osti.gov/bridge>

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: <mailto:reports@adonis.osti.gov>

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: <http://www.ntis.gov/ordering.htm>



Printed on paper containing 100% postconsumer waste

Executive Summary

The Advanced Power Electronics Interfaces for Distributed Energy Workshop, sponsored by the California Energy Commission Public Interest Energy Research (PIER) program and organized by the National Renewable Energy Laboratory, was held Aug. 24, 2006, in Sacramento, Calif.

The workshop provided a forum for industry stakeholders to share their knowledge and experience about technologies, manufacturing approaches, markets, and issues in power electronics for a range of distributed energy resources. It focused on the development of advanced power electronic interfaces for distributed energy applications and included discussions of modular power electronics, component manufacturing, and power electronic applications.

The workshop was organized into four sessions:

- Experience With Modular Power Electronics
- Advanced Concepts and Components
- Modular Power Electronics
- Power Electronics for Distributed Energy Applications.

Each session included multiple presentations, and subsequent discussion periods allowed attendees to ask questions and share thoughts on power electronics issues.

The presentation and discussion sessions revealed several themes:

- The need for a standardized interface for power electronics
- The importance of scalability in power electronics
- The importance of modularity in power electronics
- The need for power electronics to perform with high reliability and mean time between failure
- The need to reduce the cost of power electronics components and address the increasing cost of current designs
- The reluctance of industry to forfeit proprietary designs for a standardized interface and the threat/opportunity of commoditization
- The need for longer warranties for power electronics products
- The need for improved certification scenarios and lower-cost certification methods
- The need to plan for power electronics early in system designs to reduce cost and increase effectiveness.
- The recognition that power electronics interface manufacturing will compete in a global market.

The information collected from this workshop is a resource for organizations that plan to submit proposals in response to an upcoming California Energy Commission PIER request for proposals for an advanced power electronic interface.

Information about the workshop was posted on the California Energy Commission PIER Web site (see http://www.energy.ca.gov/pier/notices/2006-08-24_workshop_power_elect.html). Forty-one people—representing industry, state and federal government, and national laboratories—attended.

Acronyms

APEI	Advanced Power Electronics Interface
CBEMA	Computer Business Equipment Manufacturers Association
CPES	Center for Power Electronics Systems
DER	distributed energy resources
EPS	electric power system
ETO	emitter turn-off
IEEE	Institute of Electrical and Electronics Engineers
NREL	National Renewable Energy Laboratory
ONR	Office of Naval Research
PEBB	Power Electronics Building Block
PIER	Public Interest Energy Research
PV	photovoltaics
R&D	research and development
UL	Underwriters Laboratories
UPS	uninterruptible power system

Definitions

Distributed energy resources (DER): DER are electric power sources located at or near the point of use or load center. DER include distributed generation, distributed energy storage, and demand response efforts. The energy generation resources include a range of technologies, such as photovoltaics, wind turbines, fuel cells, microturbines, combustion turbines, reciprocating engines, gas- and steam-powered turbines, Stirling engines, biomass systems, and solar thermal systems. Related systems and supporting technologies include integrated storage systems, power electronics, and control technologies.

Plug and play: An approach in which hardware and software work together to automatically configure devices and assign resources. This allows hardware changes and additions without large-scale adjustments or modifications. The goal is to be able to plug in a new device and immediately use it, without complicated or significant setup modifications or adjustments.

STATCOM: An abbreviation for “static compensator.” This device is a shunt-connected voltage controller typically used to limit reactive power fluctuations or harmonic content. It does not contain energy storage but can actively inject or draw reactive power.

Table of Contents

1	Introduction	1
1.1	Workshop Sponsor.....	1
1.2	Workshop Structure	2
2	Workshop Introduction	3
2.1	“Power Electronics for Utility Applications at the Department of Energy,” Imre Gyuk, Department of Energy	3
2.2	“Power Electronics Research Assessment,” Forrest Small, Navigant.....	4
2.3	Workshop Introduction Discussion.....	5
3	Session 1: Experience With Modular Power Electronics	6
3.1	“Power Electronic Building Blocks: Office of Naval Research Experience and Observations,” Terry Ericson, Office of Naval Research	6
3.2	“Integrated Power Electronics Building Block Modules, Converters, and Systems,” Fred Wang, Virginia Tech	7
3.3	“Bricks and Buses,” Giri Venkataramanan, University of Wisconsin.....	8
3.4	Session 1 Discussion.....	9
4	Session 2: Advanced Concepts and Components.....	12
4.1	“Advanced Topologies for Distributed Energy Interface,” Ned Mohan, University of Minnesota	12
4.2	“Integrated Modules Simplify Systems Design,” John Mookken, SEMIKRON Inc.....	12
4.3	“Distributed Energy Advanced Power Electronic Interfaces,” Ben Kroposki, National Renewable Energy Laboratory.....	13
4.4	Session 2 Discussion.....	15
5	Session 3: Modular Power Electronics Distributed Energy Applications	17
5.1	“Modular and Scalable Power Converters in the Uninterruptible Power Supply Industry,” Ian Wallace, Eaton.....	17
5.2	“Distributed Energy Applications Leverage High-Volume, Modular Power Converters,” Perry Schugart, American Semiconductor	18
5.3	“Modular Inverters for Distributed Generation,” Matt Zolot, UQM	19
5.4	Session 3 Discussion.....	20
6	Session 4: Power Electronics for Distributed Energy Applications.....	21
6.1	“Power Electronics Conversion for Distributed Energy Applications,” Alex Levran, Magnetek Inc.	21
6.2	“Xantrex Power Electronics for Renewable Energy System Applications,” Ray Hudson, Xantrex.....	21
6.3	“Power Electronics for DER and Renewable Applications,” Jonathan Lynch, Northern Power Systems	22
6.4	“SMA America: Advanced Power Electronic Interfaces Workshop,” Kent Sheldon, SMA.....	23
6.5	Session 4 Discussion.....	24

7	Conclusions	26
	Appendix A: Agenda	27
	Appendix B. List of Attendees	29
	Appendix C. Speaker Biographies.....	33
	Appendix D. Workshop Presentations	36
	Appendix E. Additional Resources	221

1 Introduction

The Advanced Power Electronics Interfaces for Distributed Energy Workshop, sponsored by the California Energy Commission Public Interest Energy Research (PIER) program and organized by the National Renewable Energy Laboratory (NREL), was held Aug. 24, 2006, in Sacramento, California.

The purpose of the workshop was to create a forum for a diverse range of distributed energy resource (DER) industry stakeholders to learn about experiences and related technologies and explore the issues and options for DER power electronics. It focused on the development of advanced power electronic interfaces for distributed energy applications and included discussions of modular power electronics, component manufacturing, and power electronic applications.

1.1 Workshop Sponsor

The California Energy Commission, California's energy policy and planning agency, forecasts energy needs, keeps historical energy data, licenses thermal power plants, promotes energy efficiency, develops energy technologies and renewable energy, and plans for and responds to energy emergencies. In 1996, the Electric Utility Industry Restructuring Act of 1996 expanded the commission's responsibilities by establishing the PIER Program. The act required that at least \$62.5 million be collected each year from investor-owned utility ratepayers to fund public interest energy research.

The PIER Program partners with individuals, businesses, utilities, and public and private research institutions to conduct research on promising technologies, products, and services. It focuses on:

- Buildings end-use energy efficiency
- Energy innovations small grant program
- Energy-related environmental research
- Energy systems integration
- Environmentally preferred advanced generation
- Industrial/agricultural/water end-use energy efficiency
- Renewable energy technologies.

Power electronics fall within the purview of the PIER Energy Systems Integration group. This group takes a systems engineering approach to the electricity delivery system and focuses on transmission research, distribution research, and the integration of DER into the power system. A significant part of this group's \$42 million research portfolio is committed to demonstrating the benefits of DER integration for utilities, regulators, and ratepayers. Power electronics, a key technology in this area, can reduce the costs of interconnection and improve the integration of DER technologies.

Toward this end, PIER has partnered with the NREL to address power electronics issues. Called the Advanced Power Electronics Interface (APEI) Initiative, this six-year, \$20-million-plus effort is a coordinated plan to develop a modular architecture for standardized, highly integrated power electronics interconnection technologies that will come as close as possible to “plug-and-play” for DER platforms.

The goal of the APEI Initiative is to develop power electronics technology that improves and accelerates the use of DER systems. The objective is to reduce costs for DER and interconnections by developing standardized, high-production-volume power electronic modules.

NREL is the U.S. Department of Energy’s premier research facility for renewable energy and energy efficiency research. As part of its mission, NREL has established a Distributed Energy Systems Integration group to facilitate the interconnection of DER with the electric power system (EPS). The Distributed Energy Systems Integration group focuses on testing and certification, standards and codes, technology development, DER applications, and regulatory issues.

1.2 Workshop Structure

The workshop provided a status update on DER power electronics designs, manufacturing approaches, and issues. PIER will use the information gathered to determine issues its research could address and strategies for the APEI Initiative. The information will also be used to develop a future California Energy Commission PIER request for proposals for an advanced power electronic interface.

The workshop was organized into four sessions:

- Experience With Modular Power Electronics
- Advanced Concepts and Components
- Modular Power Electronics
- Power Electronics for Distributed Energy Applications.

Sections 3 through 6 provide summaries of the workshop presentations. The full presentations are included in Appendix D. As an additional resource, a presentation by Dr. Alfred Engler, Institut für Solare Energieversorgungstechnik, is included in Appendix E.

2 Workshop Introduction

Mark Rawson, program lead of the PIER Energy Systems Integration team, opened the workshop by welcoming participants and providing background information about the APEI Initiative.

The PIER Energy Systems Integration team uses a systems engineering approach in its work to integrate energy efficiency, demand response, DER, renewable energy, and energy storage into the EPS. It focuses on science and technology advancements in sensors and monitoring, power electronics, communications and controls, intelligent automated systems, and real-time operations.

Two of PIER's seven strategic objectives are addressed by the advancement of power electronics:

- Enable optimal integration of renewables, distributed generation, demand response, and storage to the power system.
- Improve cost and functionality of components to integrate demand response, distributed generation, and electricity storage into the system.

The APEI Initiative, under the direction of PIER Energy Systems Integration and NREL, will facilitate the advancement of the power electronics industry by enabling the production of more cost-effective products.

2.1 “Power Electronics for Utility Applications at the Department of Energy,” Imre Gyuk, Department of Energy

Power quality is critically important to today's digital economy. In fact, common nominal power quality events cost the nation about \$52 billion each year. To address power quality issues, the Energy Storage program within the Department of Energy's Office of Electricity Delivery and Energy Reliability has researched a number of advancements in energy storage technologies and power electronics, including a large-scale uninterrupted power system (UPS) that could be factory-integrated, tested, and used in plug-and-play installations.

Based on CBEMA curves (which were developed by the Computer and Business Equipment Manufacturers Association to simplify the modeling of system response and evaluate all factors in voltage deviations from the norm) from the Electric Power Research Institute, researchers determined that a system that could provide power for 15–30 seconds would cover 95% of all outages. A mobile, 2-MW, 15-second battery system was designed to meet these requirements. This system won an R&D 100 award and is now used throughout the country. A later generation, which provides 10 MW for 30 seconds, is now in service in a microchip plant in Arizona. Another, which uses a sodium sulfur battery rather than a lead acid array, provides peak shaving at a substation.

Other areas of research have included optically isolated inverters; advanced heat exchangers; low-cost, modular, highly-reliable inverters; emitter turnoff switches; and transmission stabilization devices.

The emitter turn-off (ETO) switch, developed by Virginia Tech and North Carolina State, was conceived from the need for a faster, more powerful, and cheaper switch. The resulting product is 15–20 times faster than a gate turnoff thyristor and has three times the power of the more-expensive insulated gate bipolar transistor. This technology also was awarded an R&D 100.

The transformerless STATCOM with energy storage was created through a collaboration of organizations with the goal of providing four quarter control with both real and reactive power. Although two-thirds of an example trailer-mounted installation employed supercapacitors, one-third made use of the ETO.

Finally, a more recent project has addressed the power quality issues associated with a 48-MW Bonneville Power Administration wind farm. Customer complaints and variable voltage led the administration to seek solutions. A trailer-mounted ETO STATCOM couple with grid power was one suggestion. The group is currently pursuing this option.

Projects such as these are showing the potential of power electronics. In fact, a recent meeting that brought together representatives of the national laboratories, renewable and electricity research groups, and the Office of Science determined that power electronics and energy storage should be priority areas for investment.

Future research plans include work with advanced materials, ETO deployment, thermal management systems, novel materials, silicon carbide switches, high-temperature materials, ionic fluids for electrolytes, advanced wideband gap system deployment, nano-structured materials, and diamond switches.

2.2 “Power Electronics Research Assessment,” Forrest Small, Navigant

In 2004, Navigant Consulting Inc. worked with PIER’s Energy Systems Integration team on research assessment and planning for power electronics. The goal was to identify research activities the commission could support to increase the penetration of DER in California.

To do so, Navigant first surveyed stakeholders to identify their key business needs. It found that the expense of power electronics—as much as 40% of DER system cost—has inhibited the use of DER. It also found that the current performance of power electronics was lacking and hindering long-term commercial application.

Navigant then analyzed the technology challenges related to these needs. It found:

- A lack of standardization and inter- and intra-operability of power electronic systems, components, and the grid
- A need for power electronic devices that are modular and scalable
- A need for improvements in power electronic system packages.

Navigant next identified 10 potential research initiatives to address the technology challenges. It ranked the initiatives based on their relative impact to DER systems, their relevance to the public interest, and the existing gap between current and necessary research. Based on the rankings, it identified three key initiatives:

- Standardize the interface between power electronics systems and the grid.
- Standardize and improve the interoperability of power electronics components and systems.
- Improve the scalability/modularity of power electronic systems and components.

Navigant believes these initiatives offer the greatest potential to affect future development and recommended that the PIER team pursue them with a systems approach. These findings were the basis for the California Energy Commission to proceed with the APEI Initiative.

2.3 Workshop Introduction Discussion

- *Who manufactures the ETOs in Dr. Gyuk's projects?*

The ETO is not being commercially manufactured. At this time, it is made only at the university. However, there is some interest, and manufacturers are being pursued.

- *It was mentioned that power electronics correspond to up to 40% of the cost of DER systems. Does that include motors and generators as part of power electronics?*

Navigant performed a round buildup of the cost of a representative DER system to determine what percentage of the cost would belong to power electronics components. Forrest Small, of Navigant, believes this counted only inverter and control systems.

3 Session 1: Experience With Modular Power Electronics

3.1 “Power Electronic Building Blocks: Office of Naval Research Experience and Observations,” Terry Ericson, Office of Naval Research

In 1994, the Office of Naval Research (ONR) instituted the Power Electronics Building Blocks (PEBB) program, an effort to develop a universal power processor capable of changing any electrical power input into any voltage, current, and frequency output. The goal was to create a product that would enable high-volume production of small power electronics to reduce their cost and development time. The resulting PEBB is envisioned to be software-reconfigurable, multi-purpose, “smart,” and universal (i.e., it replaces specialized devices such as power conditioners, inverters, and circuit breakers). However, numerous advances are still necessary.

The ONR has identified several challenges to its overall ship design process. These include rule-based design, standard parts, increasing complexity, specifications and documents, and small sample statistics.

However, there are other, more general, challenges as well. One example is the role of simulation. Today, as in the past, simulations are developed as an analysis tool. They are based on models of a real product to study variations in design. However, simulations can play a synthesis role in the process. In the future, simulations should be based on specifications and performed in the early stages of design to determine the final real product.

Another example is the effect of the design cycle—or the lack of one. Because power electronics do not function in a vacuum, they should be developed in an iterative design cycle in which requirements influence products and vice versa. It was noted that the use of general models in the design process is more productive than the use of specific ones because they help developers avoid overly constrained problems.

Then there is complexity. Complexity is a result of emergence. That is, complex systems display a behavior that cannot be predicted based on the behaviors of their individual parts. Complexity is not a product of the number of parts. Complex systems can be simplified through physics-based partitioning, the addition of intelligent active devices, and the creation of controlled and predictable system states at physics-based partitions. However, reducing complexity increases the detail, size, weight, and cost of the power electronics. Therefore, these traits must be reduced to enable practical application and overall simplification of complex systems.

Three recent innovations will influence the future development of power electronics: (1) increased computing power; (2) the development of high-speed, low-cost controllers; and (3) system-simplifying concepts. These are important innovations that will touch on multiple aspects of development and enable new advances.

An additional problem relates to investor influence. Up to a point, if money is invested into a development process, the final cost of the product will decrease and performance will improve. Obviously, at some point, more money must be invested to extract diminishing performance returns. Between these is an optimal point, at which the balance between investment and performance is ideal. For investors, their influence is very high early in the development process, when their investments garner big returns on performance. But as progress is made, changes become more difficult, and investor influence weakens. Therefore, for effective development and maximum influence, investors must become involved early in the process, and developers must employ modeling and simulation to guide the process.

All of these issues have influenced the vision and development of PEBBs. Other important influences include the concepts of partitioning, concurrent engineering, early validation, and universal, or “plug and play” components.

Today, a working group headed by Narain Hingorani is developing an IEEE standard using the PEBB concept for electrical power systems. There are also some examples of PEBBs already in use. Three to five megawatts have been installed for a variety of applications.

Finally, future needs also include modeling standards, benchmark models, a library of models, and a body of international volunteer experts for these efforts.

3.2 “Integrated Power Electronics Building Block Modules, Converters, and Systems,” Fred Wang, Virginia Tech

The Center for Power Electronics Systems (CPES), a National Science Foundation engineering research center, is focused on the development of integrated power electronics modules. Its vision is to follow the example of micro-electronics by achieving integrated functionality, a standardized interface, and a versatile product suitable for mass production.

Power electronics interfaces are a key enabling technology for DER. They offer the potential of lower costs, higher reliability, and improved performance. To achieve this, other organizations are pursuing the conventional approach of improving the components, devices, and circuits of power electronics. CPES, however, has adopted an alternative approach of modularization, standardization, and integration to achieve economies of scale. It also emphasizes a system perspective in its work.

CPES’ specific approaches include integrated load converters (including motor-converter integration and microprocessor-converter integration), power distribution converters, and integrated source converters. For each, CPES begins with basic research on the devices, materials, and technology and then moves to developing enabling technologies and, finally, engineered systems. Already, through research funded by ONR’s PEBB program and other sponsors, CPES has developed numerous integrated power electronics modules ranging from 10 W to 10 MW. CPES researchers are now addressing the issues of a building block approach, architecture and partitioning, and interface characterization.

CPES starts at the bottom with a topology and builds from that foundation up to application layer control in a hierarchical structure. This requires the correct control architecture and communication protocols.

Finally, CPES has realized additional benefits to integrated power converter functionality. These include power flow control; power management; power quality control; monitoring, diagnosis, and online mitigation; and protection.

3.3 “Bricks and Buses,” Giri Venkataramanan, University of Wisconsin

The largest markets for power electronics today are in relatively large-volume areas such as motor drives, power supplies, UPSs, and compact fluorescents. However, these are segmented markets, and it is unclear if DER can establish itself as a new market segment.

To create a new market segment, DER power electronics must overcome challenges. For example, a typical inverter is a complicated piece of equipment. The power electronic, filter, transformer, and controller components form a jungle of wires and electronics. Because of this, power electronics applications are assembled by hand—even in mass production scenarios. This production process is expensive and inhibits cost reductions. If significant cost reductions are to be realized, automated assembly, fabrication, and compilation are necessary. Other constraints include low reliability, custom designs, and long design cycles. Therefore, the future of power electronics must include standardized input, output, and functionality; “compilable” cabinets; and fail-safe and plug-and-play capabilities as well as units compatible with multiple geometries.

Modular systems are in production. Eaton has developed a molded case circuit breaker board into which input and output breakers, transient voltage surge suppressor modules, and card and voltage sensors can be plugged. Therefore, minimum assembly is involved. Rockwell has introduced a product line of several drives that are pre-engineered to work together. These incorporate control and communication cables interfaced through a bus and a line interface module that is pre-engineered for ease of integration. These are models for DER market development.

Several years ago, with support from the California Energy Commission and other sources, the University of Wisconsin – Madison began to develop a “bricks and buses” converter. This work involved demonstrating a concept prototype with electrical performance comparable to that of classically designed products, increased power density, modular packaging, and improved manufacturability.

One result of this work was a 3.2-kW, single-phase inverter. The inverter integrates the switch gear, rectifier module, capacitor, inductor, and output. On the bottom, mechanical, power, and control buses are positioned for “brick” interconnection. Each of its modules is independently thermally managed. However, other models are also possible.

The “bricks and buses” example offers standard depth and height dimensions but varied widths. In addition, it has variable volume, proportional scaling of the surface area, a decoupled power bus and signal bus, and a contained interconnect electromagnetic interference.

However, there are still challenges. The cost, size, and lack of modularity of the many components are major barriers. For example, the prices of copper and steel, which are used for the magnetic elements, have increased substantially over the past 5 years. Many of these components can be produced with less expensive materials and in more modular structures.

Such advances could make possible alternatives. An example is a system that could include a switch, throw capacitance, pole magnetics, and thermal management. These cells can be combined to increase power rating and number of phases. Other advanced concepts include air- and liquid-cooled designs and bus-centered assemblies.

3.4 Session 1 Discussion

- *The initial PEBB program focused on Navy ship power systems. For that program, how many eventual manufacturers are there? And are their products compatible with one another's, or are they just compatible within each company?*

The Navy is not a mass buyer, and it does not buy these types of systems frequently. So it is not an industry. To create an industry and bring down costs for the Navy, utilities and others must be involved. ONR has employed a spin-on/spin-off strategy to spin off its investments to companies such as ABB and Rockwell. So far, several PEBBs—including one aboard a GLIB, or Great Lakes Icebreaker—have been put into use through this arrangement.

Manufacturers have an incentive to adopt the PEBB process because of economies of up to five- to ten-time reductions in engineering costs. ONR's next development will be plug-and-play units. At that point, it is expected that costs will start to be driven from the customer side. The question remains of how to provide incentives for this step.

- *How realistic is it that PEBBs can accommodate distributed generation and storage in increasingly large power classes? More specifically, is the PEBB approach one that focuses within classes, or can it be used to cross classes of power electronics packages?*

The idea is to do both. In fact, as the various markets and industries progress, they are becoming more similar. For example, they are losing fuses and breakers as solid state becomes more common. The ABB SCS 5000, a medium-voltage system for ship drives, is a 20-MW system with no fuses or breakers.

However, this may be a challenge for utilities that want to visually check switch gear and relays. In the ship system, this is not an issue because there are no uncontrolled generation sources and so no reason to employ fuses and breakers to protect the system from such threats.

- *The business paradigm also must change, and it is. In the past, the manufacturers have associated themselves with a particular application segment (e.g., drives or wind generation). But with converter modules or PEBBs, they must associate with a line based on power level rather than application.*

Eventually, this will mean original equipment manufacturers will be able to offer application solutions within short time frames, much like the computer industry. This is a difficult move for industry, but it is beginning to happen.

- *If there is a failure in a module, is there some type of diagnostic to identify which module needs attention? Can that module be replaced, or must the entire block be discarded?*

At this point, this is not possible. However, it is the intent for the future. Upon failure, the module would shut itself off and electrically isolate itself from the other units. The long-term goal is modules that are “hot swappable,” meaning that they can be replaced without shutting the system down.

This type of functionality will require a definition of an architecture, and the IEEE working group is working on one now. Another idea for such functionality uses “agents” located inside each PEBB. When the system is activated, the agents would communicate with one another to determine the incorporated functions and operate appropriately. This could lead to the development of dynamically reconfigurable systems.

- *What are the biggest barriers to industry adoption of a bricks and buses approach?*

In approximately 2003, Dr. Venkataramanan held a workshop of power electronics industry representatives in Madison, Wisconsin. The feedback he received revealed hesitations to dismantle practices and systems designed for established industries (e.g., power supplies or motor drives).

However, there has been change since that time, and some of the new thinking is being incorporated into new designs. Further, this workshop is focused on power electronics for DER, which is a new industry. It will likely be easier to work with all the players early on, before they are entrenched in practices and systems.

4 Session 2: Advanced Concepts and Components

4.1 “Advanced Topologies for Distributed Energy Interface,” Ned Mohan, University of Minnesota

The University of Minnesota has performed power electronics research at the detailed level of topologies. This work has included an ultra-compact, high-efficiency, hybrid converter for photovoltaics (PV) and fuel cells and a multi-port DC-DC converter. The multi-port DC-DC converter is a compact unit that works as an interface between two or more energy sources and a load. It allows power flow from different energy sources to a load and bidirectional flow for all sources (e.g., for a battery). The converter is intended for use in hybrid vehicles and residential homes/buildings.

More recently, the university has been working to simplify the control of matrix converters to control motors and generators. It has found that silicon carbide-based converters, which can operate at very high temperatures, are particularly promising.

The voltage-link power electronic system is common, but there are problems with its storage capacitor—and particularly with weight, cost, and reliability. In addition, the capacitor has problems with in-rush current, and it is difficult to integrate with motors.

Matrix converters, however, have no energy storage element. They operate AC-AC and offer bidirectional power flow. The university used ideal transformers to simplify how switching signals are generated and therefore simplify matrix converter control.

The university’s study then pushed the technology by incorporating an AC machine to improve its performance. It found it could almost double it. By taking an AC machine’s Wye-connection and opening it up and feeding it from matrix converters from both sides, it found it could eliminate bearing currents, deal with isolated voltages, reduce slab insulation, control input power factor, and increase power capability. In addition, because the converters take advantage of the new silicon carbide materials, they have the potential for reduced costs because they do not require expensive copper and steel. And finally, functionally, they are PEBBs. They eliminate the need for bulky storage capacitors.

Future research on matrix converters will analyze the efficiency of the system, explore how to make the current ripple smaller, and determine ways to operate at lower frequencies.

4.2 “Integrated Modules Simplify Systems Design,” John Mookken, SEMIKRON Inc.

Power modules have evolved significantly since their introduction in the 1960s. Each generation has introduced improved power densities and new components, and each generation has evolved to integrate more components into the modules. Today, power modules integrate diodes, switching devices, gate drives, current sensors, voltage sensors, and temperature sensors.

The trend toward integration has several drivers, including a shorter time to market, easier system design and assembly, improved economics, and a reduced number of components. In addition, integration offers benefits such as customized solutions for regular prices, standard interfaces, and standard platforms.

At SEMIKRON, the latest design is the SKAI, which also includes the digital signal processor controller, a move toward intelligence in the module. (However, the module is not yet fully “intelligent” because the software is not included.) This programmable module was developed with U.S. Department of Energy funding over a 3-year period that began in 1999. It is an advanced design that begins to blur the boundary between power modules and motor drives.

The SKAI consists of a core platform (which consists of the semiconductors and capacitor) and customizable components (i.e., the insulated gate bipolar transistors, digital signal processor, controller, power supply, gate driver, protection, and heat sink). SEMIKRON designed the module to work with various applications but incorporated flexibility into the design based on its customer experience. It found that its customers liked the product, but, because of its general design, it was not optimized for their needs. The customizable components offer them the flexibility to build an optimized solution while taking advantage of the benefits of standardization. Today, only about 5% of SKAI sales are for unmodified units.

The SKAI can be configured using 600 V or 1,200 V insulated gate bipolar transistors with continuous AC output currents of 400 A rms or 300 A rms, respectfully. The module includes either a liquid-cooled or air-cooled heat sink. It is about the size of shoebox and can be manufactured in large quantities. All customizations are additions to the manufactured unit, so they do not affect manufacturing costs. The SKAI can be used for a variety of applications, depending on the customer’s need and software.

SEMIKRON has experienced varying reactions to the standardized platform. It has generally found that its customers like the standardization concept—for their own product ranges. But most do not want outside products to be able to plug into their architecture. However, this is the general growth pattern in the industry and is likely to be overcome. For example, earlier power module designs from one company were eventually adopted by others so they could serve the replacement market. Customers especially like this situation because it results in competition. However, it makes the product a commodity, and power module manufacturers have incentives to resist this situation.

4.3 “Distributed Energy Advanced Power Electronic Interfaces,” Ben Kroposki, National Renewable Energy Laboratory

Distributed energy applications include wind turbines, PV arrays, fuel cells, microturbines, and reciprocating engines. Although they are not new technologies, they are receiving increased attention today because of their ability to provide combined heat power, peak power and demand reduction, backup power, improved power quality, and ancillary services to the power grid.

One concern with distributed energy applications is their interconnection with the grid. Interconnection technologies have the potential to simplify this issue by performing the integration for all DC generation technologies as well as for generators. However, in addition to the basic integration, they can provide broader functions. Many small distributed energy systems already incorporate these functionalities in their inverter technology. Larger systems, however, generally incorporate these functions through separate pieces of equipment.

Power electronics have the potential to improve the interconnection of distributed energy applications and the power grid. In one scenario, they are used as an interface between the DER unit and the grid. In another, they are used to facilitate the creation of “islands” or “microgrids” by replacing circuit breakers.

Such applications can have many benefits. For example, the use of power electronics to interconnect DER can improve operating efficiencies, improve power quality, provide Var support and voltage regulation, reduce distributed energy fault currents, allow interoperability of multiple sources, and provide for standardization and modularity.

Key to the interconnection of distributed energy applications are the ongoing efforts of the IEEE 1547 working groups. These groups are developing a series of standards to address the technical requirements interconnection. IEEE 1547 Standard for Interconnecting Distributed Resources With Electric Power Systems, the first of the series, was approved in 2003, and 1547.1 Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources With Electric Power Systems was approved in 2005. These standards provide a foundation for efforts to develop power electronics-based interconnection equipment. Five more standards in the series are under development and will provide more guidance. In the future, a possible standard may address power electronics interface specifications. NREL, through support from the Department of Energy Office of Energy Research, is leading these efforts.

Further, the tests outlined in IEEE 1547.1 to ensure proper interconnection have been incorporated into Underwriters Laboratories (UL) 1741 Inverters, Converters, Controllers, and Interconnection System Equipment for Use With Distributed Energy Resources. This provides manufacturers of power electronics or other interconnection equipment with a consistent set of testing requirements for their products. UL 1741 was updated to include these requirements last November, and manufacturers have 18 months from that date to comply.

NREL also performs testing and evaluation of DER systems and components at its Distributed Energy Resources Test Facility in Golden, Colo. This facility will be used for testing and evaluation of equipment developed as a result of the upcoming PIER Advanced Power Electronics Initiative solicitation.

4.4 Session 2 Discussion

- *Presentations in the first session focused on the different functional modules in the PEBB concept and their standardization, but John Mookken focused on standardizing only the power module. What cost savings can be realized from standardizing only that piece?*

The standard power module includes the driver and controller, but both can be replaced, if the customer desires. The biggest cost contributors are the capacitor, the current sensor, and the silicon.

- *Five percent of SEMIKRON's orders for the SKAI were for off-the-shelf units. What is the cost increase for changes to those units?*

Because no manufacturing modifications are necessary to accommodate the changes, the cost on a per-unit basis is virtually insignificant. The only changes that significantly affect cost are adding more capacitance into the module or scaling up the power level.

- *Does the SKAI come with a warranty, and if so, do customizations affect the warranty?*

SEMIKRON offers a 2-year warranty for the SKAI. Customized models are also covered.

- *First, manufacturers have until May 2007 to comply with the requirements of 1547.1 and UL 1741, and UL is not yet prepared to certify to 1547. However, utilities are beginning to require 1547.1 certification. This is, in effect, locking the manufacturers out of some utility districts. Second, 1547.1 introduced new requirements that resulted in manufacturers having to redesign and recertify their equipment. This is a very expensive process. Will the other standards in the 1547 series have similar effects?*

IEEE 1547 and IEEE 1547.1 are actual standards, but the rest of the series consists of guides and recommended practices. Therefore, few or no requirements should be developed as part of their introduction (with the possible exception P1547.6 and operation on distribution secondary networks). Unfortunately, for the 1547 and 1547.1 requirements, meeting them is a cost of doing business in the DER market. UL1741 provides a way to certify products to those standards.

- *There has been a lot of discussion of standards. Are the future PEBB standards for consumers or application suppliers?*

The consumer likely has the most to gain from a standard. As mentioned earlier, this would eventually result in a commodity product and lower prices. This is why some manufacturers resist the concept of standards.

- *There is resistance to standardization, but there are benefits also. The market increases with commoditization because of lower costs and standardization.*

However, it can also work the other way. Consumers want the lowest possible price. In some instances, they may want a custom solution (e.g., they do not need a standard part) to further lower costs.

- *Have the matrix converters discussed by Dr. Mohan been tested to confirm the doubling of power?*

Not yet. The idea is only in the conceptual and analytical stages at this point.

- *Is the NREL test facility able to implement and test microgrid configurations?*

The facility is flexible and includes a variety of distributed generation sources. It can be used for low-voltage configurations of less than 600 V. Additional equipment would be necessary for medium-voltage configurations.

- *Are there problems with the 60-Hz harmonics in the matrix converter because there aren't any passives?*

No. Matrix converters can synthesize any frequency desired at the output. In the past, a drawback was that the output voltage was only 86% of the input voltage. The new configuration achieves 186%. It also allows control of the input power factor. However, this is all analytical at this time. It has only been simulated through software.

- *One problem with matrix converters is their lack of fault tolerance. How will this be addressed for interconnection applications?*

There must be protection against spikes, but matrix converters are in some ways more benign than others.

- *What is the IEEE standard for microgrids and intentional islanding?*

IEEE P1547.4 Guide for Design, Operation, and Integration of Distributed Resource Island Systems With EPS is currently under development. It is not a full standard but rather a guide of how to intentionally island parts of the power system correctly and safely.

5 Session 3: Modular Power Electronics Distributed Energy Applications

5.1 “Modular and Scalable Power Converters in the Uninterruptible Power Supply Industry,” Ian Wallace, Eaton

Sensitive (e.g., data centers, servers, and clinical laboratory equipment) and critical (e.g., broadcast transmitters, industrial process, and government facilities) power applications require high quality. Even brief interruptions in power supply or quality can severely affect function and profits.

The EPS typically provides 99.9%, or three “nines,” reliability to its users, which is equivalent to roughly 9 hours of outage per year. However, for mission-critical applications, this is often not sufficient. These applications require “high nines” reliability, or reliability on the order of 99.9999% or more.

To achieve “high nine” reliability, most of these systems rely on two elements. The first is multi-source power, or the use of some combination of utility power, generators, batteries, flywheels, ultracapacitors, etc. The second is a UPS, located between the power sources and the load. In the event of a power quality or availability problem, the UPS switches the load’s source to avoid a power outage or equipment damage.

To be effective, UPSs must employ parallel redundancy to ensure availability and avoid single-point failures. They must be easily expanded to accommodate increased capacity and growth, and they must have a low mean time for repairs.

Today, the UPS market is growing. It is projected the industry will achieve 10% growth in revenue per year and a 4% reduction in UPS price. In the market, the drivers for UPS technology and market growth include:

- Low installation cost
- Low operating cost
- High power quality utility interface
- High power density
- Serviceability
- Multi-source compatibility
- Monitoring, diagnostics, and prognostics
- Maintenance services.

Past UPSs were positioned to meet these needs, but they faced two technical hurdles: the control of two or more paralleled AC power sources and the elimination of all systems-level single points of failure. These systems were limited to six “nines” or less.

Today, Eaton uses Hot Sync technology, a communicationless parallel system, to achieve seven “nines.” The elimination of communications enables the use of multiple units connected together and eliminates single points of failure. The identical modules operate together as peers to share and balance the power. This modular system provides flexibility and scalability to Eaton’s UPS systems.

Based on this technology, Eaton has developed product lines that can be expanded incrementally for capacity, redundancy, and volume. In one approach, the control contains overhead to accommodate the incorporation of future modules, and the modules are standardized “bricks.” In another, full modular products are hot-swapped on a standard rack.

5.2 “Distributed Energy Applications Leverage High-Volume, Modular Power Converters,” Perry Schugart, American Semiconductor

Regardless of the size of the system, power electronics are often the last component to be designed. Frequently, the power electronics designers are forced to accommodate the rest of the system by squeezing their product into whatever space is left. Often, however, there are significant benefits to planning for the power electronics early in the design process.

American Superconductor has developed a PEBB with support from the ONR. The PM1000 is a programmable building block power converter designed for high-volume production and rapid development. Each module is fully contained with controls and power supplies. The PM1000 uses a power pole architecture and can be air- or liquid-cooled. It is designed to accommodate customer special needs without converter board modifications. The PM1000 offers two digital signal processors and four operating programs as well as a configurable graphical user interface.

The modularity of the PM1000 allows rapid development of power converters and power conversion systems. In addition, its standard power pole enables high-volume production, low cost, and increased reliability. The use of the PM1000 allows developers to avoid the time and cost of design, development, iteration, integration, and production. American Superconductor estimates this saves developers 1 year of development time and approximately \$2 million.

Another product offered by American Superconductor is a developer kit, which includes a PM1000, a converter interface, a graphical user interface, a software package, and fiber optic cable with a connector. The software can be changed out to change functionality. For example, a unit may first be used as an active rectifier but later switched to a DC-DC converter. No hardware changes are required.

These developer kits cut time to operation even more. For example, a fuel cell manufacturer bought two of these kits to demonstrate a new concept for providing power to the grid. The demonstration was operational in less than a week.

A related development kit is designed for multiple-converter systems and can use any converter type (e.g., three-pole or six-pole). This system also allows the use of proprietary control algorithms. This kit is particularly applicable to DER applications. American Superconductor also offers the PM2000, a higher-power version of the PM1000.

5.3 “Modular Inverters for Distributed Generation,” Matt Zolot, UQM

UQM’s focus is on high-performance, power-dense, energy-efficient motors and power electronics for vehicle electrification. Over the past few years, interest has increased in the potential to connect hybrid vehicles to the power grid. These vehicles could conceivably provide peak-shaving power or other grid support and charge themselves from grid power to achieve true electric hybrid status.

However, the automotive industry has different requirements for DG converters if they are to be packaged within vehicles. To be successful, the converters would need to be high-voltage, high-density, lightweight, rugged, and low-cost.

UQM’s general specifications for a grid-connect inverter include an input voltage of 150–360 V, a power output of up to 5 kW, 90% or more efficiency, galvanic isolation, and a grid and standalone operation of 50/60 Hz. In addition, the unit must meet appropriate UL and IEEE standards.

UQM uses a Mathworks autocoding setup that takes advantage of existing in-house capabilities to simplify the control design process. This approach also allows researchers to perform simulations to test the code before it is downloaded to hardware. This setup will be used for the DER work to allow for advanced signal processing, true sine wave generation, and various phase operations.

After analyzing the trade-offs between the performance, cost, and packaging of higher-integration modules and discrete component and the benefits of component-, board-, and package-level modularity, UQM chose to pursue smaller modular products.

The UQM modular inverter allows incremental additions of 1.7 kW to a 1.7-kW base, up to 5 kW. There is also a package design in which the modularity comes from components added to a board. A DC front end provides 5 kW and interfaces with the inverters. The whole system can then be duplicated and multiple systems coupled together. The output voltage can be configured in various ways.

The goal of a modular system is to prevent redesign to enable high-volume production and reduce costs. However, to reach this goal, some challenges must be overcome. One challenge is the actual interconnection. To be truly useful, it must be simple enough for non-specialists to accomplish. Another involves communication between modules and packages. IEEE standards do not currently address this, so there is no standard for communication between different products. Another challenge is anti-islanding. Although it is not a challenge for the DER industry, it is a new concept for the automotive industry and must be considered. Finally, there must be a market. At this point, it is unclear if or how the market for such applications may develop.

5.4 Session 3 Discussion

- *Why are the automotive units only 5 kW?*

For light-duty vehicles, this is about right. Traction and heavier-duty uses would require more.

- *Approximately what volumes of the PM1000 are being produced?*

American Superconductor is producing hundreds of the converter per year.

- *What sort of list price, in dollars per watt, does the PM1000 have? And what is smallest power increment?*

Currently, there is essentially one power size. The three-phase unit is 175 kilowatts. The six-pole is about twice that.

The developer kit, which is for three-pole configuration, is just less than \$20,000. However, a volume purchase of the three-pole converter would garner a lower price per unit. The developer kit is intended for small volumes. Overall, however, the biggest cost savings come from the avoidance of development costs.

- *Do these products have warranties, and if so, what is the length?*

The Eaton UPS products carry warranties of 1–2 years. The American Superconductor products come with base warranties of 1 year and offer the option of an extended warranty. The UQM product is still under development.

- *It seems 1–5 years seem to be the lifespan of warranties. What components are failing?*

Electrolytic capacitors and fans often have the shortest lifetimes, but warranties are not necessarily indicative of lifespan. In addition, service contracts are an important offering to extend performance.

Another consideration is the trade-off between lifespan and cost. Longer life spans will require increased costs. There is a balance that must be determined.

6 Session 4: Power Electronics for Distributed Energy Applications

6.1 “Power Electronics Conversion for Distributed Energy Applications,” Alex Levran, Magnetek Inc.

Magnetek is a power electronics company that develops products for various applications, including DER. Its DER products serve wind turbines, PV arrays, energy storage, fuel cells, variable speed generation, and microturbines. Magnetek serves both residential and commercial markets.

DER applications have specific requirements that must be considered in the design of power electronics. For example, they must meet grid connection and anti-islanding standards and technical requirements. They must achieve high efficiencies in both power conversion and energy harvesting, and they must have compact designs. In addition, power electronics for DER must be reliable and cost-competitive, and they must be capable of communications and remote monitoring.

Magnetek’s strategy is to lead the power electronic interface market for alternative energy systems. Its approach employs a common platform and building blocks into a scalable, modular, compact design that can be used for multiple DER sources. It uses high-efficiency, reliable converters; primary energy source control; high power densities; and system-level control.

Magnetek anticipates several trends in the future of DER technologies. For inverters, new topologies and improved control algorithms will improve performance. Improvements will also be realized in thermal management devices, driver and sensing circuits, and capacitors and magnetic devices. In addition, silicon will be used for more components, and medium voltage will become more common. Magnetek also predicts the expansion of modular designs and more flexibility, scalability, and cross-technology platforms.

6.2 “Xantrex Power Electronics for Renewable Energy System Applications,” Ray Hudson, Xantrex

Xantrex is a power electronics company that is focused on the renewable power, portable and mobile power, and programmable power markets. It offers products for the solar, wind, and backup power areas of DER.

For solar, the function of the power electronics is to convert the DC source power to AC power for use by loads or the electricity grid. The solar grid-tied inverters do not include backup power capability; they only allow the provision of PV power to the electricity grid. Off-grid inverters, in contrast, can provide backup power or primary power in locations without access to the grid. Xantrex offers battery-based, single-phase grid-tied, and three-phase grid tied inverter lines. It also offers a charge controller product.

These inverters are crucial elements of solar array systems. They provide the user interface and key safety features. However, they are also very complicated and are often perceived as a weak link in the overall system because of past reliability issues. For example, solar array panels come with 20–30 year warranties; inverters come with 5–10 years.

Xantrex's key requirements for solar application inverters include high efficiency, advanced communication capabilities, low weight and part count, a sealed design, and standards compliancy.

For wind applications, the role of power electronics is to convert the variable frequency and voltage AC power from the turbine(s) into grid-compatible AC power. Unlike PV systems, wind-based generation must meet Federal Energy Regulatory Commission ride-through requirements. Xantrex offers products for both the commercial and residential scales.

In addition, Xantrex has developed power electronics for other DER technologies, including fuel cells, microturbines, advanced energy storage systems, and hybrid systems. However, this work has been relatively small-volume.

In the future, Xantrex forecasts that power electronics manufacturers will move toward optimal system design that includes the balance-of-system components. The market will also see improved performance, with higher reliability, higher efficiency, longer life spans, lower costs, and simplified installation. For DER, Xantrex anticipates higher penetration levels on the EPS and a merger between the conflicting requirements for grid-tied wind turbine and PV applications. It also projects a “feed in” tariff incentive to reward the delivery of electricity and encourage the optimization of all DER system components.

6.3 “Power Electronics for DER and Renewable Applications,” Jonathan Lynch, Northern Power Systems

Northern Power Systems works on systems integration and engineering procurement, but it is steadily expanding its products and services, including those for renewable DER applications.

Through market observation and experience gained from its own installations, Northern recognized a need for power electronics. It also recognized that power electronics were often the last part of the system to be considered and that this hindered performance. It saw opportunities for advanced power electronics to enable simpler interconnections, advanced power system architectures, utility distribution system support, increased DER ancillary support, and increased DER penetration.

Based on these observations, Northern determined its power electronics focus. The company works primarily on applications of 500 kW or more and uses its PowerRouter control system to enable advanced power system architectures. It is also developing a line of products to support these systems.

Northern's FlexPhase power converter platform is a modular converter system that accommodates applications from 500 kW to multiple megawatts. It is available in 480 V and 690 V and contains configurable, rack-in power modules. The modules can be quickly replaced, and they contain intelligence. A system controller provides overall coordination.

The benefits of the FlexPhase platform include its modularity, performance, size, and cost. The modular design of the system enables a low mean time to repair, which is particularly important in remote applications. It also allows serial production, which decreases manufacturing costs, and standard sizing.

Northern is now using power electronics with conventional DER to standardize the grid interface, eliminate fault current contributions, add variable speed capability, and enable advanced architectures. Other recent efforts include the Power Distributor, which uses a power converter to provide distributed generation to multiple services; a DER utility interface switch, and the SmartView DER management system.

6.4 "SMA America: Advanced Power Electronic Interfaces Workshop," Kent Sheldon, SMA

SMA America focuses on solar technology but also has product areas in communications and control, railway technology, and advanced energy systems. Within the solar division, about 80%–85% percent of SMA's business is for grid-tied units. SMA's product line includes residential PV, small wind, and hydro; commercial PV; and backup power and off-grid inverters.

SMA believes that inverters are becoming a commodity, much like solar panels have. Maximum achievable efficiencies of 97%–98% are being reached, so cost is the only area for development and improvement. However, products can be differentiated based on strengths. At SMA, the strength is communications and control.

SMA offers a Web box communication hub and system logger. This product logs every inverter on a system and stores the information in data files for customer use. This technology will be especially useful as renewable energy credit trading becomes more common, and it enables services such as performance analysis and system alarms.

Another SMA differentiation is its use of AC coupling. In the United States, most off-grid and backup power systems are connected through battery storage. In AC coupling, SMA connects the system through an inverter that controls power quality to the load. This design provides an adaptable system and achieves 96% efficiency to loads.

Recent innovations in SMA power electronics include optic-cooled forced air cooling, an integrated aluminum enclosure and heat sink, Ethernet communication, and a load-break rated DC fused disconnect. SMA has also introduced a transformerless, 8-kW grid-tied PV inverter in Europe that has achieved 98% peak efficiency. Future products include a power balancer to correct imbalance of multiple inverters on three-phase systems.

SMA identified several challenges in today's power electronics market. These include pressure to further reduce prices, high competition, high certification costs, and increasing material costs. However, it also sees promising developments for the future. For future success, SMA believes there must be a shift to performance-based incentives, an acceptance of transformerless inverter technologies, and easing of regulatory and certification requirements.

6.5 Session 4 Discussion

- *Are the megawatt-scale inverters for the large wind projects UL-listed? Do they conform to UL 1741, or are there other requirements that they must meet?*

They do not go through UL, and there is not a specific standard for them other than safety requirements. Generally, at these sizes, the turbines are “behind the fence” of the utility and are not subject to UL authority.

- *What is the longest warranty offered on the DER-type inverters?*

The standard warranty is 5 years, although some companies also offer extended warranties for a fee. The 5-year standard was influenced by California Energy Commission requirements.

- *There was a reference to ride-through in wind installations versus anti-islanding in PV installations. Is the PV is on the distribution system and the wind on the transmission system?*

Yes, that is a difference. Because these systems interconnect at different levels of the EPS, they may have different interconnection rules.

- *Is there any standard to qualify digital signal processor software?*

Yes, UL 1998.

For a utility application, is there any standard requirement for validation of the code?

No attendees were aware of any such requirements.

Are there standards for electromagnetic compatibility of internal components of digital signal processor chips or power electronics?

There are no standards, but there are techniques that can be used to check for this.

- *Where do you think price points can be on megawatts-size power electronics if you produce 100 MW per year?*

Price points are variable and depend on the product and its specifications.

- *Have the inverter companies considered their future business plans? Perhaps the commoditization of inverters will not be a bad thing if it is approached correctly.*

Not everyone agrees that inverters will become a commodity. However, much of the future will depend on the degree that the industry moves to vertical integration, the level of competition and the number of competitors, and the variations allowed in the products while meeting standards requirements.

It is difficult for companies in this industry to create long-range plans because the market environment is very fluid. The regulatory climate and incentives change frequently, and so do material prices. One option to avoid all of these challenges may be pre-competitive cooperation, but this is not the way the industry is currently headed.

- *What could increase the reliability of your product lines?*

Several things could and do help, including improvements in installation and installer knowledge, inverter technology maturation, the use of proven reliability techniques, improved simulation, and service contracts.

- *Other than cost, is there anything about the semiconductors that limit inverter performance?*

Yes, the actual losses in the power electronics. They can be about 3%–4%.

- *Can inverters be designed in such a way that testing costs can be reduced?*

The UL requirements are not yet known, and how the tests will be performed is not known. Easier test points can be added, but the standards must be known first.

In addition, IEEE 1547.1 addresses testing of the black box, the whole package. Even if individual components of the unit have passed testing individually, it requires that they be tested again as part of the full system.

7 Conclusions

The Advanced Power Electronics Interfaces for Distributed Energy Workshop was organized to gather information about the status of power electronics technologies. Through workshop presentations and discussion, several important themes emerged. These included:

- The need for a standardized interface for power electronics
- The importance of scalability in power electronics
- The importance of modularity in power electronics
- The need for power electronics to perform with high reliability and mean time between failure
- The need to reduce the cost of power electronics components and address the increasing cost of current materials
- The reluctance of industry to forfeit proprietary designs for a standardized interface and the threat/opportunity of commoditization
- The need for longer warranties for power electronics products
- The need for improved certification scenarios and lower-cost certification methods
- The need to plan for power electronics early in the system design processes to reduce cost and increase effectiveness
- The recognition that power electronics interface manufacturing will compete in a global market.

PIER will use the information gathered to determine issues its research could address and strategies for the APEI Initiative. The information will also be used to develop a future California Energy Commission PIER request for proposals for an advanced power electronic interface.

Appendix A: Agenda

Agenda

Advanced Power Electronics Interfaces for DE Workshop

Thursday, August 24, 2006

Sponsor: California Energy Commission

Location: 1516 9th Street Sacramento, CA

A WORKSHOP TO FOCUS ON THE STATUS OF DEVELOPMENT OF ADVANCED POWER ELECTRONIC INTERFACES FOR DISTRIBUTED ENERGY APPLICATIONS AND A DISCUSSION OF MODULAR POWER ELECTRONICS, COMPONENT MANUFACTURING, AND POWER ELECTRONIC APPLICATIONS

8:00 - 8:10 Welcome and Introductory Remarks, *Mark Rawson, California Energy Commission*

8:10 - 8:25 Power Electronics for Utility Applications at the Department of Energy, *Imre Gyuk, DOE*

8:25 - 8:40 Power Electronics Research Assessment, *Forrest Small, Navigant*

Session 1: Experience with Modular Power Electronics - Chair: Bernard Trenton, CEC

EXPERIENCE WITH MODULAR POWER ELECTRONICS FROM THE POWER ELECTRONICS BUILDING BLOCK PROGRAM, INTEGRATED POWER ELECTRONICS MODULES AND BRICKS AND BUSES APPROACH

8:40 - 9:00 PEBB Program Experience, *Terry Ericson, Office of Naval Research*

9:00 - 9:20 Integrated PEBB Modules, Converters, and Systems, *Fred Wang, Virginia Tech*

9:20 - 9:40 Bricks and Buses, *Giri Venkataramanan, University of Wisconsin*

9:40 - 10:00 **General Discussion**

10:00 - 10:30 BREAK

Session 2: Advanced Concepts and Components - Chair: Dick DeBlasio, NREL

ADVANCED CONCEPTS FOR POWER ELECTRONICS CONVERTER DESIGNS INCLUDING MATRIX AND MULTI-PORT CONVERTER, MANUFACTURING POWER ELECTRONIC COMPONENTS AND ADVANCED FUNCTIONALITY FOR DISTRIBUTED ENERGY APPLICATIONS.

10:30 - 10:50 Advanced Topologies, *Ned Mohan, University of Minnesota*

10:50 - 11:10 Integrated Modules Simplify Systems Design, *John Mookken, SEMIKRON Inc.*

11:10 - 11:30 Power Electronic Interfaces, *Ben Kroposki, NREL*

11:30 - 12:00 **General Discussion**

12:00 – 1:00 Lunch (on your own)

Session 3: Modular Power Electronics Distributed Energy Applications - Chair: Jose Palomo, CEC

HIGH VOLUME POWER ELECTRONICS DESIGN AND MANUFACTURING CHALLENGES AS WELL AS CURRENT DISTRIBUTED ENERGY APPLICATIONS THAT USE THE MODULAR APPROACH

1:00 – 1:20 Modular and Scalable Power Converters in the UPS Industry, *Ian Wallace, Eaton*

1:20 – 1:40 Distributed Energy Applications Leverage High Volume, Modular Power Converters- *Perry Schugart - American Superconductor*

1:40 – 2:00 Modular Inverters for Distributed Generation, *Matt Zolot, UQM*

2:00 – 2:30 **General Discussion**

2:30 – 3:00 BREAK

Session 4: Chair: Power Electronics for Distributed Energy Applications - Chair: Holly Thomas, NREL

CURRENT POWER ELECTRONICS IN THE RENEWABLE AND DISTRIBUTED ENERGY MARKETS

3:00 – 3:20 Magnetek Power Electronics - *Alex Levran, Magnetek, Inc.*

3:20 – 3:40 Xantrex Power Electronics for Renewable Energy System Applications – *Ray Hudson, Xantrex*

3:40 – 4:00 Power Electronics for DER & Renewable Applications, *Jonathan Lynch, Northern Power Systems*

4:00 – 4:20 SMA Power Electronics – *Kent Sheldon, SMA*

4:20 – 5:00 **Wrap-up for the day and general discussion**

Appendix B. List of Attendees

Allen, Jennifer

California Energy Commission
1516 9th St., MS 43
Sacramento, CA 95814-5512
(916) 653-0291
jallen@energy.state.ca.us

Alvarez, Manuel

Southern California Edison
(916) 441-2369
alvarem@sce.com

Balog, Robert

Smart Spark Energy Systems
60 Hazelwood Drive
Champaign, IL 61820
(217) 344-6044
R.Balog@SmartSparkEnergy.com

Basso, Thomas

NREL
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 275-3753
thomas_basso@nrel.gov

Briere, Michael

International Rectifier
1521 E. Grand Ave.
El Segundo, CA 90245
(310) 252-7124
mbrierel@irf.com

DeBlasio, Richard

NREL
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 275-4333
dick_deblasio@nrel.gov

Erickson, Robert

University of Colorado – Boulder
Engineering Center, OT 356 425 UCB
Boulder, CO 80309-0425
(303) 492-7003
rwe@colorado.edu

Ericson, Terry

ONR
875 North Randolph St., Suite 1425
Arlington, VA 22203-1995

Gyuk, Imre

Department of Energy – Office of
Electricity Delivery & Energy Reliability
1000 Independence, OE-10
Washington, DC 20586
(202) 586-1492
Imre.Gyuk@hq.doe.gov

Hingorani, Narain

26480 Weston Drive
Los Altos Hills, CA 94022,
(650) 941-5240
nhingorani@aol.com

Hudson, Raymond

Xantrex Technology Inc.
161-G South Vasco Road
Livermore, CA 94551
(925) 245-5421
ray.hudson@xantrex.com

Johnson, Robert

Cal Poly, San Luis Obispo
1228 Bordeaux St.
Livermore, CA 94550
(805) 550-7535
rhoberto@gmail.com

Kramer, Bill

NREL
1617 Cole Blvd.
Golden, CO 80401
(303) 275-3844
bill_kramer@nrel.gov

Kroposki, Benjamin

NREL
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 275-2979
benjamin_kroposki@nrel.gov

Kulkarni, Pramod

California Energy Commission
1516 9th St., MS 43
Sacramento, CA 95814-5512
(916) 654-4637
pkulkarn@energy.stare.ca.us

Levran, Alexander

Magnetek
8966 Mason Ave.
Chatsworth, CA 91311
(818) 727-2216
alevran@magnetek.com

Lutz, Jon

UQM Technologies Inc.
7501 Miller Drive, P.O. Box 439
Frederick, CO 80530
(303) 278-2002
jlutz@uqm.com

Lynch, Jonathan

Northern Power
182 Mad River Park
Waitsfield, VT 05673
(802) 583-7224
jlynch@northernpower.com

Mohan, Ned

University of Minnesota Twin Cities
Campus - Department of Electrical and
Computer Engineering
200 Union St. S.E.
Minneapolis, MN 55455
(612) 625-3362
mohan@ece.umn.edu

Mookken, John

SEMIKRON Inc.
11 Executive Drive
Hudson, NH 03051
(603) 883-8102 Ext. 145
john.mookken@semikron.com

Nichols, David

Rolls-Royce Fuel Cell Systems
13030 Heatherstone Circle
Pickerington, OH 43147
(614) 755-2768
david.nichols@rolls-royce.com

Palomo, Jose

California Energy Commission
1516 9th St., MS 43
Sacramento, CA 95814-5504
(916) 654-4388
jpalomo@energy.state.ca.us

Pink, Christopher

NREL
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 275-3758
chris_pink@nrel.gov

Rawson, Mark

California Energy Commission
1516 9th St., MS 43
Sacramento, CA 95814-5504
(916) 654-4671
mrawson@energy.state.ca.us

Schugart, Perry

American Superconductor
15775 W. Schaefer Court
New Berlin, WI 53151
(262) 901-6036
psehugart@amsuper.com

Sheldon, Kent

SMA America
P.O. Box 5049
Livermore CA 94551-5049
(530) 273-4895
ksheldon@sma-america.com

Small, Forrest

Navigant Consulting
77 South Bedford St., Suite 400
I Burlington, MA 01803
(781) 270-8455
fsmall@navigantconsulting.com

Smedley, Gregory

One-Cycle Control Inc.
13844 Alton Parkway, Suite 137
Irvine, CA 92618
(949) 275-0581
gsmedley@onecyclecontrol.com

Soinski, Art

California Energy Commission
1516 9th St., MS 43
Sacramento, CA 95814-5504
(916) 654-4674
asoinski@energy.state.ca.us

Steeley, William

EPRI Research Institute
3420 Hillview Ave.
Palo Alto, CA 94304-1395
(650) 855-2203
wsteeley@epri.com

Thomas, Holly

NREL
1617 Cole Blvd.
Golden, CO 80401-3393
(303) 275-3755
holly_thomas@nrel.gov

Thompson, Chris

Xantrex Technology Inc.
8999 Nelson Way
Burnaby, BC Canada V5A 4B5
(604) 422-2500
chris.thompson@xantrex.com

Treanton, Bernard

California Energy Commission
1516 9th St., MS 43
Sacramento, CA 95814-5504
(916) 654-4512
btreanto@energy.state.ca.us

Vartanian, Charlie

Southern California Edison
1000 Portero Grande
Monterey Park, CA 91755
(323) 889-5516
charles.vartanian@sce.com

Vaughn, Amy

NREL
1617 Cole Blvd.
Golden, CO 80401
(303) 275-3863
amy_vaughn@nrel.gov

Venkataramanan, Giri

University of Wisconsin
1415 Engineering Drive
Madison, WI 53706
(608) 262-4479
giri@engr.wisc.edu

Wallace, Ian

Eaton Corp., Innovation Center
4201 North 27th St.
Milwaukee, WI 53216-1897
(414) 449-6238
iantwallace@eaton.com

Wang, Warren

Navigant Consulting
One California Plaza, 300 S. Grand Ave.
29th Floor
Los Angeles, CA 90071
(213) 670-3248
wwang@navigantconsulting.com

Wang, Fred

Virginia Tech
645 Whittemore Hall (Mail Code 0179)
Blacksburg, VA 240612
(540) 231-8915
fred.wang@vt.edu

Zolot, Matthew

UQM Technologies Inc.
7501 Miller Drive
Frederick, CO 80530
(303) 278-2002 x1153
mzolot@uqm.com

Appendix C. Speaker Biographies

Imre Gyuk, U.S. Department of Energy

Dr. Imre Gyuk is program manager of the U.S. Department of Energy's Energy Storage and Power Electronics Research Program in the Office of Electricity Distribution and Energy Reliability. The program funds work on a variety of technologies, such as advanced batteries, flywheels, supercapacitors, and power electronics. The program works with California Energy Commission on a joint \$9.6 million energy storage initiative.

Forrest Small, Navigant

Forrest Small is an associate director in the Energy Practice of Navigant Consulting. His professional focus is on the development and implementation of technology-based solutions for electric power delivery through work with utilities, equipment suppliers, and public sector agencies. Mr. Small has more than 15 years of experience in the electric power industry and has worked in consulting, open access transmission operations, transmission and distribution planning, and advanced power system engineering.

Terry Ericson, Office of Naval Research

Terry Ericson is the program manager for the ONR. He has led the development of the Power Electronic Building Block Program for the office.

Fred Wang, Virginia Tech

Dr. Fred Wang is an associate professor and the technical director at CPES, Virginia Tech. Prior to joining CPES five years ago, he worked for GE for 10 years as a power systems application engineer, a motor drive design engineer, and a power electronics R&D manager. His interests are power converters, power systems, and motor drives.

Giri Venkataramanan, University of Wisconsin

Giri Venkataramanan studied electrical engineering at Government College of Technology, Coimbatore, India; Caltech; and the University of Wisconsin, Madison. After teaching electrical engineering at Montana State University, Bozeman, he returned to the University of Wisconsin, Madison, as a faculty member in 1999, where he continues to direct research in various areas of electronic power conversion as an associate director of the Wisconsin Electric Machines and Power Electronics Consortium. He holds five U.S. patents and has co-authored more than a hundred technical publications. His interests are in the areas of microgrids, wind energy, power converter topologies, dynamics and control, and community engineering projects.

Ned Mohan, University of Minnesota

Ned Mohan is Oscar A. Schott Professor of Power Electronics at the University of Minnesota in Minneapolis, Minnesota, where he has been teaching for the past 31 years. He has numerous patents and publications in the fields of power electronics, electric machines and drives, and power systems, in which he has written five books.

John Mookken, SEMIKRON Inc.

John Mookken's career in power electronics began in 1999 as an applications and test engineer working on a U.S. Department of Energy-funded automotive power electronics program. In 2004, he joined SEMIKRON USA as a product manager for advanced integrated power modules. He is also the project director of the U.S. Department of Energy-funded AIPM program at SEMIKRON. He completed his MS in electrical engineering at the University of South Carolina.

Ben Kroposki, NREL

Ben Kroposki is the Distributed Energy Systems Integration supervisor at NREL. His expertise is in the design and testing of renewable and distributed power systems, and he has produced more than 40 publications in this area. Kroposki received his BS and MS in electrical engineering from Virginia Tech and is pursuing his Ph.D. in electrical engineering at Colorado School of Mines. He is a senior member of the IEEE and a registered professional engineer in Colorado.

Ian Wallace, Eaton

Ian Wallace is a senior specialist at Eaton Corp.'s Innovation Center, a research and development center in Milwaukee, Wisconsin. He has 16 years experience in electric power conversion designing and developing power electronics and control systems for industrial, aerospace, and power quality markets.

Perry Schugart, American Superconductor

Perry Schugart joined American Superconductor in December 2000 as director of Sales and Marketing of the company's Power Electronics Business Unit. In this position, Schugart is responsible for the development, marketing, sales, and distribution of the company's power electronic converter products. Prior to joining American Superconductor, Schugart held increasingly senior positions with International Rectifier, most recently as director of Sales Development. An Illinois native, Schugart holds a bachelor's of science degree in physics from the University of California, Santa Barbara.

Matt Zolot, UQM

Matt Zolot is a power electronics engineer at UQM, where he works on the development of modular inverter designs. Prior to working at UQM, Matt was with NREL, where he worked on power electronics for the transportation sector. Matt graduated from Georgia Tech with a BS in electrical engineering and is currently pursuing a master's degree in electrical engineering at the Colorado School of Mines.

Alex Levran, Magnetek Inc.

Alex Levran is the executive vice president and chief technology officer for Magnetek. He manages engineering activities in the design of power supplies, generators and motors, military and commercial power conversion, and alternative energy products. He also coordinates engineering activities in Europe and the United States, creates technology roadmaps, and engages in acquisitions. Prior to his work at Magnetek, he worked for Marlin Gernin and Teledyne. Levran has also been a visiting professor at the University of California, Los Angeles, and is currently on the board of directors for the Power Sources Manufacturers Association.

Ray Hudson, Xantrex

Ray Hudson is the vice president of Advanced Technology for Xantrex.

Jonathan Lynch, Northern Power Systems

In his role as chief technology officer of Northern Power, Mr. Lynch manages R&D and new product development efforts. Lynch is responsible for the identification and development of new technology and products to aid Northern's growth across its business areas, which include products and services for remote industrial, onsite generation, and renewable-based power systems. Prior to joining Northern, Lynch was employed as a design engineer at Carrier Corp., where he modeled and designed high-performance refrigeration systems and controls for transportation applications. Lynch graduated from Stevens Institute of Technology with a BSME degree with honor.

Kent Sheldon, SMA America

Kent Sheldon has been involved in the renewable energy industry for 10 years with Kenetech Windpower, Trace Technologies, Xantrex Technologies, and SMA America. During this time, he has worked as a project engineer for a variety of three-phase, grid-tied photovoltaic and large hybrid power centers; an engineering manager for the PV Series inverter family; and, currently, as a sales support manager.

Appendix D. Workshop Presentations





**Advanced Power Electronics Interfaces
for
Distributed Energy Workshop**

August 24, 2006

**Energy Systems Integration Research Program
California Energy Commission
and
National Renewable Energy Laboratory**

 Mark Rawson
 Energy Systems Integration Research Program
 California Energy Commission




California's PIER Program

- **Public Interest Energy Research (PIER)**
 - Established in 1996 as part of deregulation of electric utilities
 - At least \$62.5M collected annually from investor-owned utility ratepayers for "public interest" energy R&D
 - Focuses on R&D not adequately provided by competitive and regulated markets
- **Comprised of 7 research areas**
 - Environmentally Preferred Advanced Generation
 - Renewable Generation
 - Building End Use Efficiency
 - Industrial, Agricultural and Water End Use Efficiency
 - Environmental
 - Transportation
 - **Energy Systems Integration**
- **New, complementary natural gas public interest program established in 2005 that is expected to grow to \$24M by 2009**

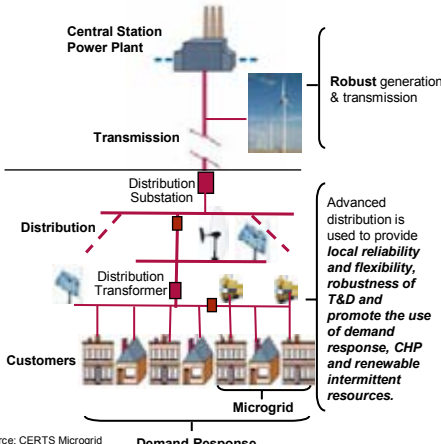
2



ESI Approach



ESI uses systems engineering approach that requires looking at the big picture in a holistic fashion.



Source: CERTS Microgrid

- Addressing T&D and load growth issues necessitates a coordinated effort
 - Integrate EE, DR, DG-CHP, renewables (large and DG), and storage into local energy system designs
 - Demonstrate the benefit to utilities, regulators and ratepayers
 - Optimize integration strategies to target peak load and grid utilization
- Advances in the T&D system and on the load side can get us to this new vision for the future
 - Sensors and monitoring
 - Power electronics
 - Communication and controls
 - Intelligent automated systems
 - Real time operations of the T&D system

Science and technology can transform the 19th century electricity system into the 21st century information age if we dare to make it happen.

3



ESI Strategic Objectives Aligned with Policy Drivers



IEPR, EAP, California Solar Initiative, RPS all identify needs that ESI is focused on finding solutions for.

Integrated Electricity System that is Reliable and Secure

PIER Strategic Objectives	1. Enable optimal integration of renewables, distributed generation, demand response, and storage to the power system. 2. Improve capacity, utilization, and performance of transmission and distribution system. 3. Improve cost and functionality of components to integrate demand response, distributed generation, and electricity storage into the system. 4. Improve security and reliability of electricity system. 5. Support improvement of tariffs and regulations for demand response, distributed generation, storage, and renewables. 6. Facilitate transmission siting process. 7. Develop knowledge base for future decision-making and informed delivery, integration, and infrastructure policy relative to electricity.
----------------------------------	--

Source: PIER 2007-2011 Electricity Research Investment Plan

Our comprehensive portfolio of T, D, DR, DER Integration, Storage and Security research projects is supporting these strategic objectives.

4



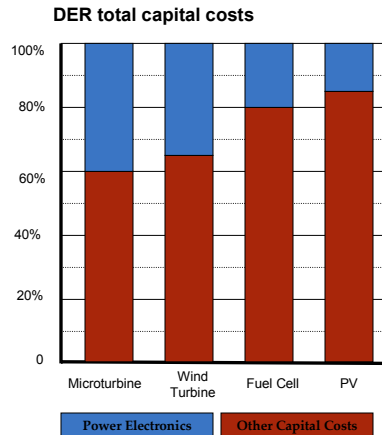
Cost of Power Electronics



Power electronics are part of key DER technologies, and represent a significant portion of the capital costs.

DER Type	DER Capital Cost \$/kW	Power Electronics % of DER cost
Microturbine	\$900 - \$1,800	35% - 45%
Wind Turbine	\$1,000 - \$4000	25% - 40%
Fuel Cell	\$3,000 - \$6,000	10% - 30%
Photovoltaics	\$6,000 - \$10,000	10% - 25%

Cost reductions in power electronics will reduce the overall cost of DER.



5



APEI Initiative Timeline



APEI Initiative is anticipated to be a collaborative ~\$20M, 6 years effort.

Project	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Generation 1 Advanced Power Electronics Interface	Build Prototype Version	Build Commercial Version	Small Demo	Evaluate Performance	Large Demo	Evaluate Performance
	Solicitation #1					
Generation 2 Advanced Power Electronics Interface		Topical Workshop on advanced components	Design of Generation 2	Build Prototype Version	Build Commercial Version	Demo
			Solicitation #2			

6



Purpose and Focus of Workshop



Purpose

- To provide industry stakeholders with an update of the status of technologies and issues in power electronics

Focus

- Development of advanced power electronic interfaces for Distributed Energy Applications

Results from this workshop will help PIER and NREL structure our strategies for the upcoming APEI Initiative.

Power Electronics for Utility Applications at the Department of Energy

IMRE GYUK, PROGRAM MANAGER
ENERGY STORAGE AND POWER ELECTRONICS
RESEARCH, DOE

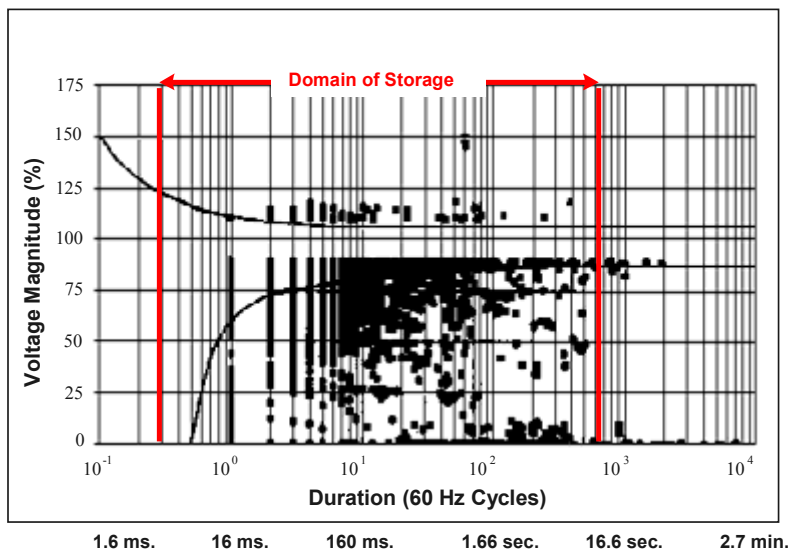
CEC-PE 8-24-06

Office of Electricity Distribution and Energy Reliability DOE

Utility Power Electronics funded
through the Energy Storage Program
but relevant for all Distributed Generation.

THE PQ PROBLEM:

- The Digital Economy is vulnerable to Power Quality (PQ) events such as micro-outages of a few milli-seconds and voltage sags of a few percent
- PQ events are common and cost the U.S. economy an estimated \$52 billion
- System should be factory integrated and tested and allow plug and play installation



CBEMA Magnitude - Duration Scatter Plot (EPRI Data)

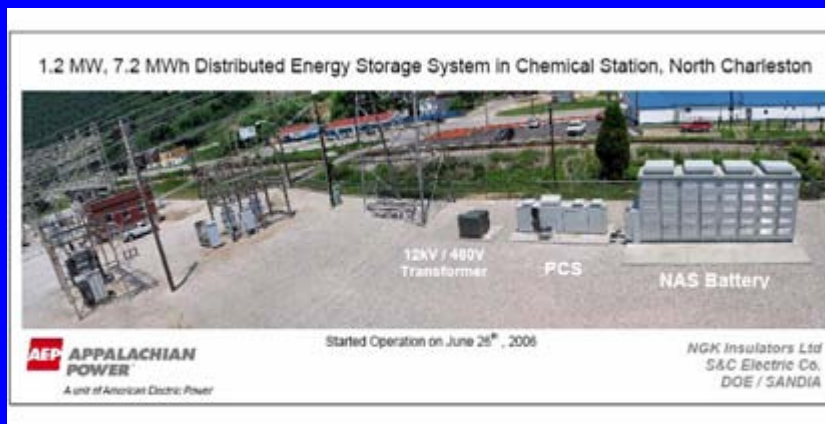
- Full power must be available in 4 milliseconds = 1/4 cycle for seamless power supply
- Energy should last for 15 -30 sec to cover 95% of outages and allow backup generation to ramp up
- Required development of a compact 250kW inverter (Omnion, S&C)
- Testing at PG&E facility. [R&D 100](#)



2 MW – 15 sec Mobile Battery System



10 MW - 30 sec System at AZ Microchip Plant



**S&C Power Conditioning System for a
1.2 MW – 6 hour NaS System for Peak Shaving**

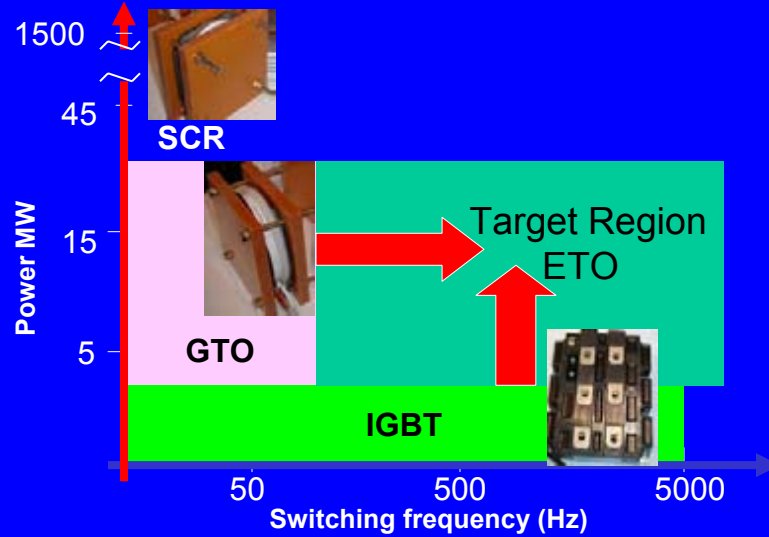
SBIR Projects :

- Optically Isolated Inverter, (ONR co-funding)
R&D 100 Award
- High Current Inverter with Advanced Heat Exchanger
- Low Cost Modular Highly Reliable Inverter

Development of Emitter Turn-off (ETO) Switch

**Need for a Switch that is
Faster, More Powerful,
and Cheaper than
Conventional Switches**

CURRENT HIGH-POWER SWITCH TECHNOLOGY



16 MW ETO Switch

- Developed at Virginia Tech – NC State
- 15-20 times faster than GTO
- 3 times the power and less expensive than IGBT
- Development of Transmission Stabilization Device Planned with TVA

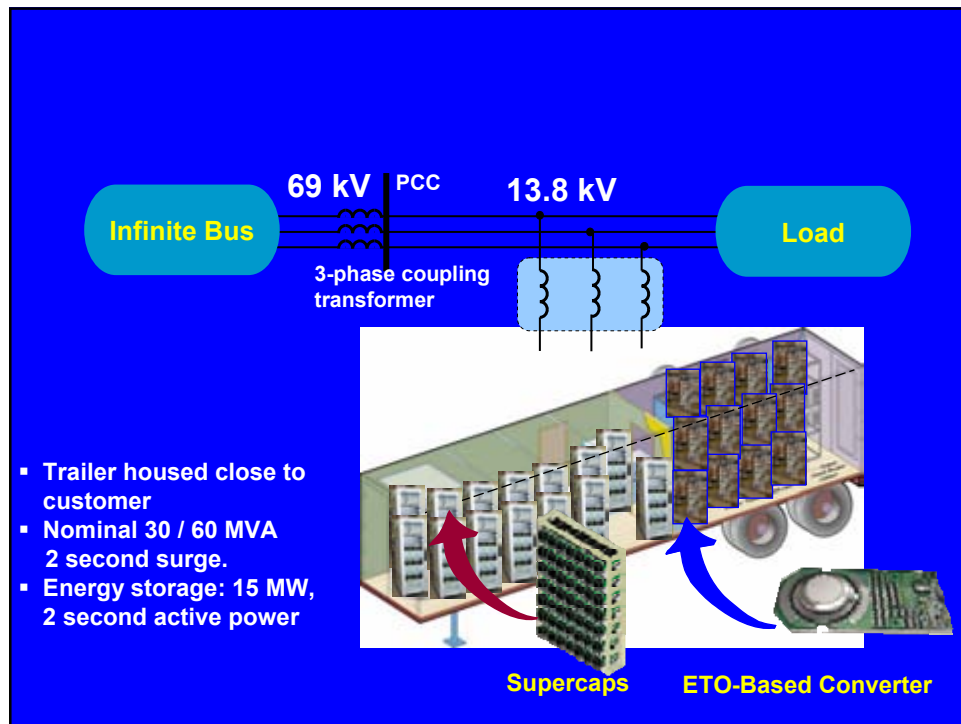


Emitter Turn Off Thyristor R&D 100 Award Winner

Transformerless STATCOM with Energy Storage

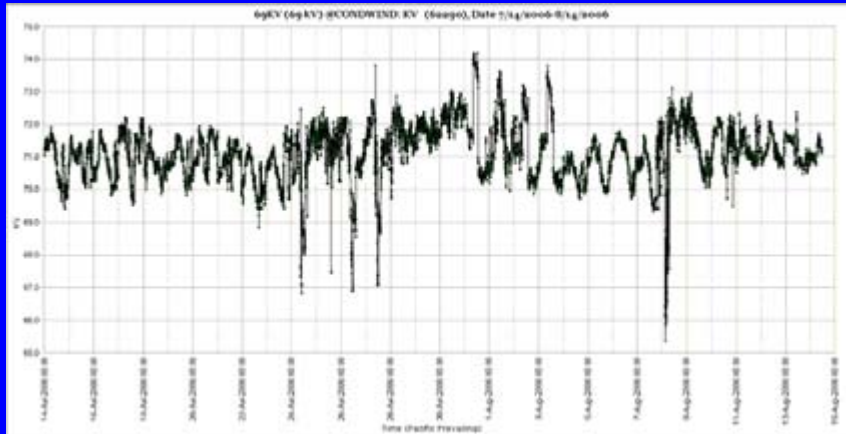
DOE, TVA, NC State University,
EPRI, EPRI-Solutions, Sandia

To provide 4-quarter control with Real and
Reactive Power

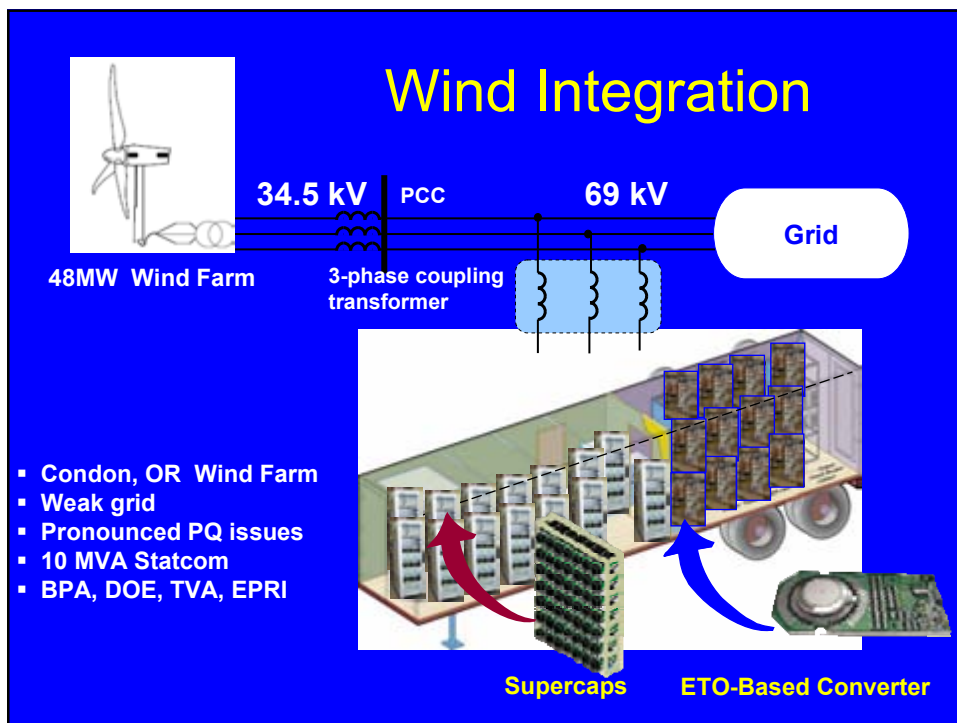


The BPA Wind Project:

- A 48 MW Wind Farm on the BPA Grid
- Extensive Complaints by other Customers about poor PQ
- Proposed Solution by ETO Statcom



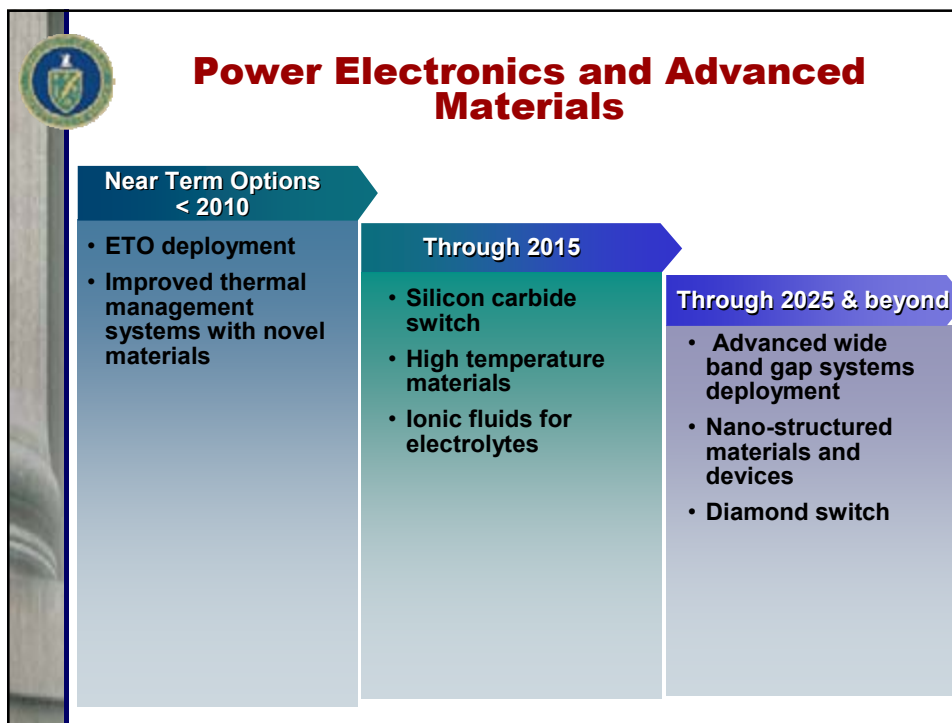
Condon Wind Voltage, July 14-Aug.14
5 minute samples



FY 2008 Science, Technology, and Environment Briefing

Specific Areas for Investment and Management Attention – Plus ups

- **Electricity storage**
- Carbon capture & storage
- Unconventional fossil
- Bioenergy
- Adaptive grid controls
- **Power electronics**
- Superconductivity
- Solar energy utilization
- Buildings systems
- Complex systems assessment



SBIR Projects :

- High Power Density (100 kW) Silicon Carbide (SiC) Three Phase Inverters, Arkansas Power Electronics (FY06)
- Advanced Power Converter System Using High Temperature, High Power Density SiC Devices, Aegis Technology (FY06)
- Wide Band Gap, High Voltage, High Frequency Switches (FY07)

Energy Storage and Power Electronics
Program Peer Review

Nov. 2 – 3, 2006, Washington, DC

<http://www.sandia.gov/ess/>



DER Integration Research Program

Power Electronics Research Assessment Executive Summary

**Advanced Power Electronics Interfaces for DE Workshop
August 24, 2006**

**Public Interest Energy Research Program
California Energy Commission**



Research Assessment Scope

In 2004, the CEC asked NCI to provide input into the Distributed Energy Resources Integration research agenda for power electronics.

- **Objective**
 - To identify gaps in the research programs being conducted by government organizations and private industry in order to provide guidance to the PIER DER Integration Research Program as it develops its research agenda in the area of Power Electronics technologies used in DER applications.
- **Scope**
 - Included the identification and assessment of research gaps in Power Electronics technologies used in DER applications. The analysis focused on Power Electronics technologies used in distributed generation systems (e.g., fuel cells, PV and microturbines) and distributed energy applications (e.g., inverters, uninterruptible power supplies and energy storage).
 - Included recommendations for specific research initiatives and approaches.

NCI recommended that the CEC support three research initiatives and act as a catalyst for a systems approach to power electronics.

High Priority Research Initiatives

- Standardize the interface between power electronics systems and the grid
- Standardize and improve the interoperability of power electronics components and systems
- Improve the scalability and modularity of power electronic systems and components

Catalyst for Systems Approach

CEC should drive for a systems approach:

- Large projects should include all stakeholders that develop the various components and systems rather than just the final integrator/packager of the technologies.
- Smaller projects should be encouraged to exchange research needs ideas and results. These projects should be coordinated to effect the larger PE systems.
- CEC should begin by supporting the development of a forum to encourage a dialogue between different stakeholders. The initial topic could discuss how to move toward common standards and modularity.

The key business needs for DER power electronics are reducing costs and improving reliability. To support these an effective R&D program must address three technology challenges.

Key Business Needs

- Reduce costs – power electronics can account for up to 40% of the costs of a DER system
- Improve reliability – current level of performance may prevent the long term commercial penetration of DER using power electronics

Technology Challenges

- Lack of standardization and the inter- and intra-operability of power electronic systems, components and the grid
- Need power electronic devices that are modular and scalable
- Need for improvements (R&D) in power electronic system packages

Key Research Initiatives



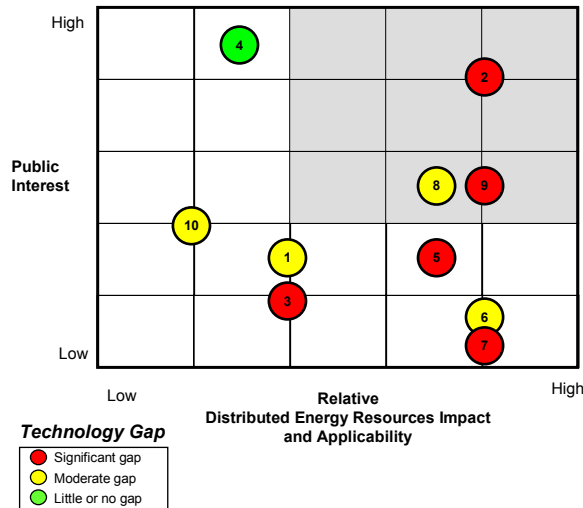
The technology challenges can be overcome by supporting ten key research initiatives.

1. Increase the efficiency of power electronic systems
2. Standardize the interface between power electronics systems and the grid
3. Improve the thermal management characteristics of power electronic systems
4. Minimize the harmonic distortions of power electronic systems
5. Improve the durability of power electronic systems and components
6. Reduce the complexity of power electronic systems
7. Improve the manufacturability of power electronic systems and components
8. Standardize and improve the interoperability of power electronics components and systems
9. Improve the scalability / modularity of power electronic systems and components
10. Minimize the system package size of power electronics

Initiative Mapping



Initiatives that the CEC should consider are those that have a large technology gap, high public benefit and high DER applicability.



Research Initiatives

1. Increase the efficiency of power electronic systems
2. Standardize the interface between power electronics systems and the grid
3. Improve the thermal management characteristics of power electronic systems
4. Minimize the harmonic distortions of power electronic systems
5. Improve the durability of power electronic systems and components
6. Reduce the complexity of power electronic systems
7. Improve the manufacturability of power electronic systems and components
8. Standardize and improve the interoperability of power electronics components and systems
9. Improve the scalability / modularity of power electronic systems and components
10. Minimize the system package size of power electronics

Top Three Initiatives for the CEC



Of the ten research initiatives identified, three are the most attractive for the CEC:

- 2 Standardize the interface between power electronics systems and the grid**
 - A significant research and funding gap exists
 - This initiative is very important for both DER and Public Benefit
 - PIER could play an instrumental role in bringing together the key stakeholders to develop necessary and acceptable interface standards for DER power electronics
- 8 Standardize and improve the interoperability of power electronics components and systems**
 - A moderate research and funding gap exists, and this was raised as a critical issue for power electronics
 - Private industry would likely have great difficulty organizing itself to address this challenge
 - PIER could facilitate the bringing together of key stakeholders to develop interoperable components and systems
- 9 Improve the scalability / modularity of power electronic systems and components**
 - A significant research and funding gap exists
 - This initiative is very important for DER and moderately so for increasing public benefit
 - The impact of this research initiative is cross-cutting as increased scalability and modularity should lead to improvements in the reliability and cost of DER power electronics

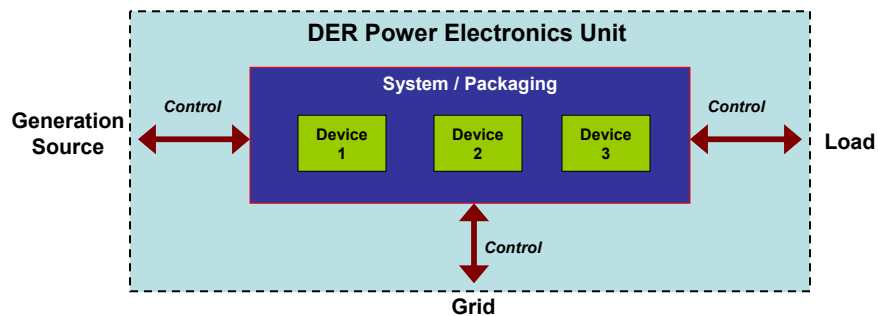
Power Electronics Research Assessment Executive Summary, 08/24/2006

7

End of Executive Summary

NAVIGANT
CONSULTING

A DER power electronics unit is a system that incorporates packaged devices and controls. The level of complexity depends on the application.



9

The power electronics activity can be classified into three fundamental areas: Devices, System / Packaging, and Controls.

	Devices	System / Packaging	Controls
Description	- The discrete switching devices themselves - Current technology is silicon-based, with silicon-carbide technology the most likely successor in the coming years.	- The arrangement of devices - Devices can be used individually or in combinations depending on the application	Hardware and software to manage the power electronics system as well as monitor and respond to changing conditions
Examples	- Metal Oxide Semiconductor Field Effect Transistor (MOSFET) - Insulated Gate Bipolar Transistor (IGBT) - Gate Turn-Off Thyristor (GTO)	- Rectifier - Inverter - Converter	- Sensors - Processors - Communications - Software
Current R&D	Devices: - IGCT switch - Super GTO switch - ETO switch Materials - Silicon Carbide - Diamond	- ETO - Advanced topologies utilizing higher voltage/capacity devices - Thermal management - Packaging	- Plug and play interconnection of DER - Autonomous control - Peer to peer communications

10



The degree to which individual research initiatives are currently being pursued was categorized based on comments and feedback.

- **Significant gap:** Few companies or entities are adequately pursuing this strategy at a level that will likely ensure the strategy has a reasonable chance of success to help resolve the issue it is addressing. This could indicate an area that has been overlooked or just emerging as a viable strategy.
- **Moderate gap:** There are several companies and/or entities pursuing this strategy. Continued *and* additional activity is likely required to ensure the strategy has a reasonable chance of success to help resolve the issues it is addressing. Strategies were also given a moderate gap rating if it is deemed a strategy that is not appropriate or feasible to pursue at this time.
- **Little or no gap:** There are many companies and/or entities pursuing this strategy. The current level of activity is likely appropriate to ensure the strategy has a reasonable chance of success to help resolve the issue it is addressing. *Little* additional work beyond what is currently funded is needed.



Research Initiative 1	
1	Increase the efficiency of power electronic systems
Increasing the efficiency of power electronic systems is a key concern given its impact on the effectiveness of power electronics solutions, and there are multiple projects currently underway that are addressing this issue. Nevertheless, given the fundamental importance of this top, additional support may be warranted.	
Public benefit: This initiative could provide a competitive advantage, but benefits are primarily to the manufacturer.	2
Relative DER Applicability: This initiative is a crosscutting issue, but there is little room left for economic or reliability improvements to occur as a result of increased efficiency.	2.5
Estimated Total Funding Needed	\$20 M
Estimated Current Public Support	\$1.9 M
Research Projects That Address Initiative	
A	Optically Isolated 5MW Inverter. Improve reliability by developing a new, highly efficient (99%+) inverter design that utilizes optical sensing and control, DSP control algorithms and HVIGBT devices.
J	High Reliability Inverter Development. Reduce the cost and improve reliability by developing an inverter that operates like a convention hard-switched inverter with no limitations on switching timings or additional control complexity.
C	Compact Diode-Clamped Multilevel Converter. Improve reliability and efficiency by developing a diode-clamped multilevel inverter that share a common DC bus
L	Digital Control of PWM Converters. Improve reliability by minimizing the power dissipation of the converter by dynamically adjusting parameters such as the synchronous rectification dead time and the current sharing in multi-phase converters.
H	Silicon Carbide Power Electronics for Utility Application. Improve the reliability of power electronics by researching the benefits and applications of SiC.
O	Diamond Tip Emitters. Improve the reliability and efficiency of power electronics through the use of diamond tipped emitters



Research Gap Analysis Research Initiative 2

Research Initiative 2

2	Standardize the interface between power electronics systems and the grid	
Standardization of a power electronic grid interface for DER is critical to increasing the penetration of DER. Several projects are developing technology that will support this initiative, but only one project directly addresses the issue of standardization. Moreover, the current public support is a small fraction of the estimated total funding required.		
Public benefit: Very limited incentives, and all classes of stakeholder (including ratepayers) will benefit.		4.5
Relative DER Applicability: This initiative is unique to DER and there could be a significant impact to DER through reduced installation costs and improved reliability.		4.5
Estimated Total Funding Needed \$15 M		Estimated Current Public Support \$1.5 M

Research Projects That Address Initiative	
C	<i>Compact Diode-Clamped Multilevel Converter.</i> Improve reliability by developing a diode-clamped multilevel inverter that share a common DC bus Their unique structure allows them to span high voltage without the use of transformers and with no voltage sharing problems.
G	<i>Distributed Energy Interface.</i> Improve the reliability of power electronics by improving the power flow between energy resources and the grid through the use of power electronic interfaces.
J	<i>High Reliability Inverter Development.</i> Reduce the cost and improve reliability by developing an inverter that operates like a conventional hard-switched inverter with no limitations on switching timings or additional control complexity.
N	<i>ETO Thyristor Development.</i> Reduce cost and improve reliability by utilizing integrated power electronic modules composed of standardized components (instead of custom designed systems) in the development of ETO Thyristors.
V	<i>Static Inverter Type Testing.</i> Improve reliability by developing a procedure type and verification testing of static inverter.

● Significant gap
 ● Moderate gap
 ● Little or no gap

13



Research Gap Analysis Research Initiative 3

Research Initiative 3

3	Improve the thermal management characteristics of power electronic systems	
There are only a few projects addressing the thermal management issue, yet this is a major issue surrounding power electronics. Several of the people interviewed raised this topic as an area requiring further research. Thermal management can be controlled or improved through both material and mechanical advances and should increase both performance and reliability.		
Public benefit: This initiative is more of a product attribute, and the benefits are not widespread.		1.5
Relative DER Applicability: This initiative could reduce package size and manufacturing costs. Reliability is increased through the reduction in failures associated with poor thermal management.		2.5
Estimated Total Funding Needed \$10 M		Estimated Current Public Support \$2 M

Research Projects That Address Initiative	
H	<i>Silicon Carbide Power Electronics for Utility Application.</i> Improve the reliability of power electronics by researching the benefits and applications of SiC.
R	<i>Thermal Management for Power Electronics.</i> Increase the reliability of power electronics by improving the thermal characteristics with a combination of high-temperature materials and advanced cooling strategies
O	<i>Diamond Tip Emitters.</i> Improve the reliability and efficiency of power electronics through the use of diamond tipped emitters

● Significant gap
 ● Moderate gap
 ● Little or no gap

14



Research Gap Analysis
Research Initiative 4

Research Initiative 4

4

Minimize the harmonic distortions of power electronic systems

There was only one project identified that is focusing on reducing the harmonic distortions of power electronics, yet a significant amount of research has been done in this area in the past. Industry standards already exist to address this issue.

<u>Public benefit:</u> There is significant public interest and multiple stakeholder classes will benefit.	5
<u>Relative DER Applicability:</u> There is minimal impact on DER applications.	2

Estimated Total Funding Needed

\$2 M

Estimated Current Public Support

\$0.5 M

Research Projects That Address Initiative	
D	<i>Multilevel Universal Power Conditioner:</i> Improve the reliability of power electronics through the development of a multilevel universal power conditioner.
I	<i>Harmonic Elimination Technique and Multilevel Converters:</i> Control a multilevel inverter in such a way that it is an efficient, low total harmonic distortion (THD) inverter that can be used to interface distributed dc energy sources to a main ac grid.

● Significant gap
 ● Moderate gap
 ● Little or no gap

15



Research Gap Analysis
Research Initiative 5

Research Initiative 5

5

Improve the durability of power electronic systems and components

A significant research gap exists as relatively few projects are actively concentrating on increasing the durability of power electronic components and systems. While power electronics system manufacturers are likely to be actively conducting internal research to improve the reliability of their products, a more systemic approach with public funding support may yield benefits that can be shared industry-wide.

<u>Public benefit:</u> This initiative benefits primarily manufacturer and customer.	2
<u>Relative DER Applicability:</u> This initiative has high applicability to DER, and improves reliability.	4

Estimated Total Funding Needed

\$20 M

Estimated Current Public Support

<\$0.5 M

Research Projects That Address Initiative	
	None

● Significant gap
 ● Moderate gap
 ● Little or no gap

16




Research Gap Analysis Research Initiative 6

Research Initiative 6

6	Reduce the complexity of power electronic systems		
The DOE is funding several research projects to reduce the complexity of power electronics, but many comments were raised about the significance of this issue. This is a cross-cutting issue that will help reduce costs, ease manufacturing, and facilitate standardization.			
Public benefit: Commercial incentives already exist, and this initiative primarily benefits the manufacturer.			
1			
Relative DER Applicability: This initiative is very applicable to DER and significant cost reductions could occur.			
4.5			
Estimated Total Funding Needed \$10 M Estimated Current Public Support \$2.0 M			
Research Projects That Address Initiative			
F	<i>Soft Switching Snubber Inverter.</i> Reduce the cost and improve reliability through the development of advanced inverter designs that utilize fewer components and modular electronics.	N	<i>ETO Thyristor Development.</i> Reduce cost and improve reliability by utilizing integrated power electronic modules composed of standardized components (instead of custom designed systems) in the development of ETO Thyristors.
J	<i>High Reliability Inverter Development.</i> Reduce the cost and improve reliability by developing an inverter that operates like a convention hard-switched inverter with no limitations on switching timings or additional control complexity.	O	<i>Diamond Tip Emitters.</i> Improve the reliability and efficiency of power electronics through the use of diamond tipped emitters
M	<i>PV Inverter Products Manufacturing and Design Improvement.</i> Design a large number of products based on small number of functional modules to achieve high manufacturing efficiencies and enhanced product reliability	P	<i>Standard Power Electronic Interfaces.</i> Reduce the cost and improve the reliability of power electronics by developing standardized approaches for integrating power converter components.

● Significant gap
● Moderate gap
● Little or no gap

17




Research Gap Analysis Research Initiative 7

Research Initiative 7

7	Improve the manufacturability of power electronic systems and components
There is a need for additional research to improve ease of manufacturing. Although the DOE is supporting projects focused on reducing manufacturing costs, there is still a great deal of research needed. Manufacturing costs are a major part of total power electronic system costs, and so improving the ease of which a component is manufactured could have a substantial impact on the attractiveness of power electronics based DER.	
Public benefit: Commercial incentives exist, and this initiative primarily benefits the manufacturer.	
1	
Relative DER Applicability: This initiative is very applicable to DER and significant manufacturing cost reductions could occur.	
4.5	
Estimated Total Funding Needed \$15 M Estimated Current Public Support \$1.2 M	
Research Projects That Address Initiative	
B	<i>Cascade Multilevel Inverter for Utility Applications.</i> Reduce the manufacturing cost and improve reliability and efficiency of multilevel inverter through the utilization of modular and compact circuit topology
J	<i>High Reliability Inverter Development.</i> Reduce the cost and improve reliability by developing an inverter that operates like a convention hard-switched inverter with no limitations on switching timings or additional control complexity.
M	<i>PV Inverter Products Manufacturing and Design Improvement.</i> Design a large number of products based on small number of functional modules to achieve high manufacturing efficiencies and enhanced product reliability
N	<i>ETO Thyristor Development.</i> Reduce cost and improve reliability by utilizing integrated power electronic modules composed of standardized components (instead of custom designed systems) in the development of ETO Thyristors.
P	<i>Standard Power Electronic Interfaces.</i> Reduce the cost and improve the reliability of power electronics by developing standardized approaches for integrating power converter components.

● Significant gap
● Moderate gap
● Little or no gap

18

Research Gap Analysis Research Initiative 8



Research Initiative 8

8	Standardize and improve the interoperability of power electronics components and systems
Standardization of interfaces was identified as a significant barrier surrounding power electronics. There are public and privately funded projects addressing the standardization / interoperability issue, but research is still needed.	
<u>Public benefit:</u> Limited incentives exist, and this initiative could benefit multiple stakeholders.	
3	
<u>Relative DER Applicability:</u> This is a crosscutting initiative that could yield significant cost and reliability benefits.	
4	
Estimated Total Funding Needed	\$5 M
Estimated Current Public Support	\$1.0 M
Research Projects That Address Initiative	
C	<i>Compact Diode-Clamped Multilevel Converter.</i> Improve reliability by developing a diode-clamped multilevel inverter that share a common DC bus Their unique structure allows them to span high voltage without the use of transformers and with no voltage sharing problems.
J	<i>High Reliability Inverter Development.</i> Reduce the cost and improve reliability by developing an inverter that operates like a conventional hard-switched inverter with no limitations on switching timings or additional control complexity.
N	<i>ETO Thyristor Development.</i> Reduce cost and improve reliability by utilizing integrated power electronic modules composed of standardized components (instead of custom designed systems) in the development of ETO Thyristors.

● Significant gap
● Moderate gap
● Little or no gap

19

Research Gap Analysis Research Initiative 9



Research Initiative 9

9	Improve the modularity / scalability of power electronic systems and components
Scalability and modularity were identified as major barriers to improved adoption of power electronics based systems due to the potential impact on flexibility and cost. There are few projects addressing these issues and significant research is still needed.	
<u>Public benefit:</u> Limited incentives exist, and this initiative could benefit multiple stakeholders.	
3	
<u>Relative DER Applicability:</u> This initiative is highly applicable to DER and could yield significant cost benefits.	
4.5	
Estimated Total Funding Needed	\$10 M
Estimated Current Public Support	\$1.3 M
Research Projects That Address Initiative	
J	<i>High Reliability Inverter Development.</i> Reduce the cost and improve reliability by developing an inverter that operates like a convention hard-switched inverter with no limitations on switching timings or additional control complexity.
P	<i>Standard Power Electronic Interfaces.</i> Reduce the cost and improve the reliability of power electronics by developing standardized approaches for integrating power converter components.
Q	<i>New Power Electronic Technologies.</i> Reduce costs and improve reliability by developing power electronics products using cutting edge technology.

● Significant gap
● Moderate gap
● Little or no gap

20

Research Gap Analysis

Research Initiative 10



Research Initiative 10

10	Minimize the system package size of power electronics
A moderate research gap exists as several projects identified are trying to minimize the system footprint, and this topic of obvious concern to manufacturers. The size of the power electronics package impacts the attractiveness of DER technologies and the ease of integration.	
Public benefit: Limited incentives exist, yet this initiative benefits the manufacturer and customer only.	
2.5	
Relative DER Applicability: This initiative has limited applicability to DER and could actually increase costs.	
1.5	
Estimated Total Funding Needed \$5 M Estimated Current Public Support \$0.8 M	
Research Projects That Address Initiative	
A	<i>Optically Isolated 5MW Inverter.</i> Improve reliability by developing a new, highly efficient (99%+) inverter design that utilizes optical sensing and control, DSP control algorithms and HVIGBT devices.
B	<i>Cascade Multilevel Inverter for Utility Applications.</i> Reduce the manufacturing cost and improve reliability and efficiency of multilevel inverter through the utilization of modular and compact circuit topology

NOTE ON MANUFACTURERS: Given that many of the research initiatives are manufacturing or packaging related, it is likely that many DER power electronics equipment suppliers are actively pursuing internally-funded research supporting many of the research initiatives identified well beyond research activities co-funded by public sector entities. However, due to competitive nature of the business, very little is known about these internal research activities.

● Significant gap
 ● Moderate gap
 ● Little or no gap

21

Literature Search and Interviews



Literature Search and Interviews

The first stage of this project was to conduct literature searches and telephone interviews with research stakeholders.

- Literature search of projects and activities by various stakeholders
 - DOE and National Labs
 - State based R&D funding entities (e.g., CEC, NYSERDA, etc.)
 - Universities
 - Manufacturers
 - Industry organizations and standards bodies
- Telephone interviews with stakeholders and researchers such as:

- Alex Huang of Virginia Tech
 - Giri Venkataramanan of University of Wisconsin
 - Keith White and Richard Zhang of GE
 - Leon Tolbert of Oak Ridge National Laboratory and the University of Tennessee
 - Matt Lazarewicz of Beacon Power
 - Nag Patibandla of NYSERDA
 - Stan Atcity of Sandia National Laboratory
 - Tim Zgonena of UL

- Bill Erdman of DUA
 - Ben Koproski of NREL
 - Bob Panora of Tecogen
 - Greg Ball of PowerLight
 - Ian Wallace of Eaton
 - Jim Davidson of Vanderbilt University
 - Perry Schugart of American Superconductor
 - Scott Samuelsen of UCI
 - Syed Ahmed of Southern California Edison

22



Advanced Electric
Power Systems Thrust

Power Electronic Building Blocks, PEBB ONR Experience and Observations

Terry S Ericson
Program Office for Electrical Science and Technology
Office of Naval Research
ericset@onr.navy.mil



Advanced Electric
Power Systems Thrust

Recent Innovations

- Computing Power Increase
- High-Speed and Low-Cost Controllers
- System Simplifying Concepts



Advanced Electric
Power Systems Thrust

“System of Systems” Design Challenges

Today

- Rule Based Design
- Standard Parts
- Increasing Complexity
- Specifications, Documents
- Small Samples Statistics

Tomorrow

- Relational Based Design
- Standard Processes
- Increasing Detail
- Model is the Specification
- Physics Based Analysis
- Statistics from All of Industry



Advanced Electric
Power Systems Thrust

The Changing Role of Simulation

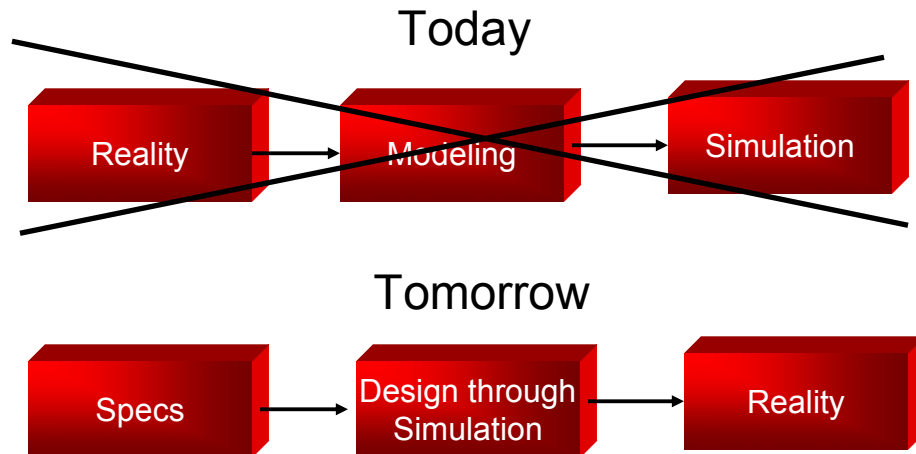
- **Today**, simulation is used for evaluation -- **Analysis**.
 - Simulation programs require detailed design information
 - Circuit parameters are entered before simulation begins.
 - Variations in design can be analyzed
- **Tomorrow**, simulation will become part of the design process -- **Synthesis**.

The Model Will Be The Specification



Advanced Electric
Power Systems Thrust

Future Design Process

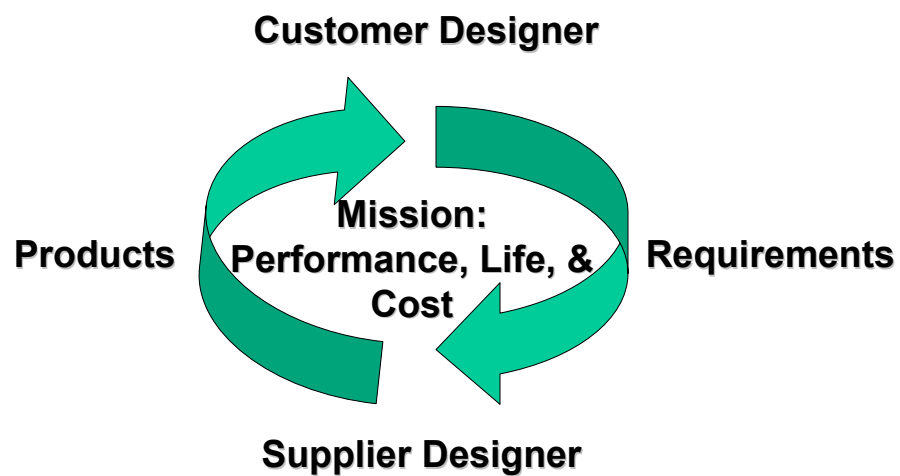


Roger Dougal & Antonello Monti, University of South Carolina



Advanced Electric
Power Systems Thrust

The Design Cycle





Advanced Electric
Power Systems Thrust

Changing World of Models -- Dynamics

- Model is the Specification
- Model is the Control
- Model is the Machine



Advanced Electric
Power Systems Thrust

Physics-Based Models are Required

- Product models must be specific
- Requirement models can be general
 - In fact, requirement models with very specific details, in the design phase, can lead to an overly constrained problem.



Advanced Electric
Power Systems Thrust

Complexity

(From “Modeling and Simulation in System Engineering: Whither Simulation Based Acquisition?” By Andrew P. Sage and Stephen R. Olson, George Mason University)

- The more identical that a model must be to the actual system to yield predictable results, the more complex the system is.
- Complex systems “...have emergence ... the behavior of a system is different from the aggregate behavior of the parts and knowledge of the behavior of the parts will not allow us to predict the behavior of the whole system.”
- “In systems that are ‘complex,’ structure and control emanate or grow from the bottom up.”
- A system may have an enormous number of parts, but if these parts “interact only in a known, designed, and structured fashion, the system is not complex, although it may be big.”
- Although a physical system maybe not be complex, if humans are a part of the system, it becomes complex



Advanced Electric
Power Systems Thrust

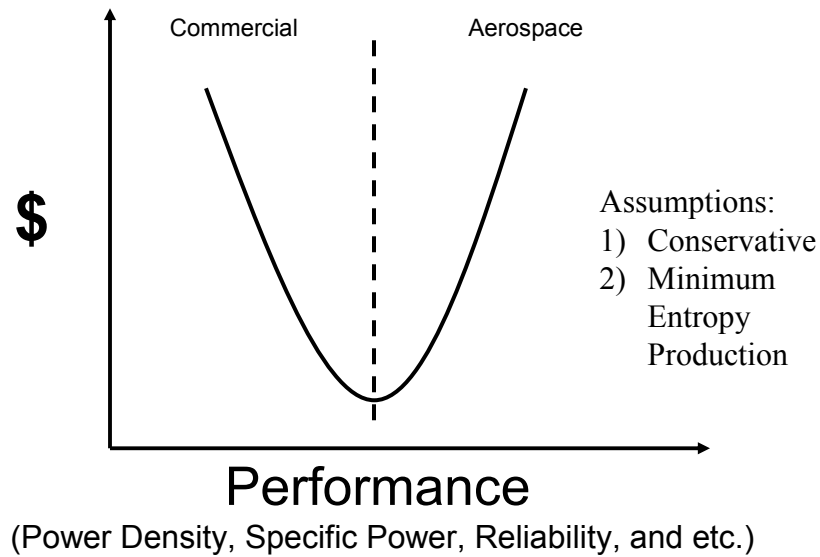
Complexity and Simplification

- Complex systems can be simplified by:
 - Physics-based partitioning
 - Based on the nature of the materials, components, and manufacturing methods
 - Adding intelligent active devices
 - Creating controlled and predictable system-states at physics-based partitions
- All of this increases detail, size, weight, and cost.
- Therefore:
 - The size, weight, and cost of these technologies have to be reduced to enable practical application and simplification.
 - Computational abilities and new modeling and simulation tools are needed to allow for design with increased detail.



Advanced Electric
Power Systems Thrust

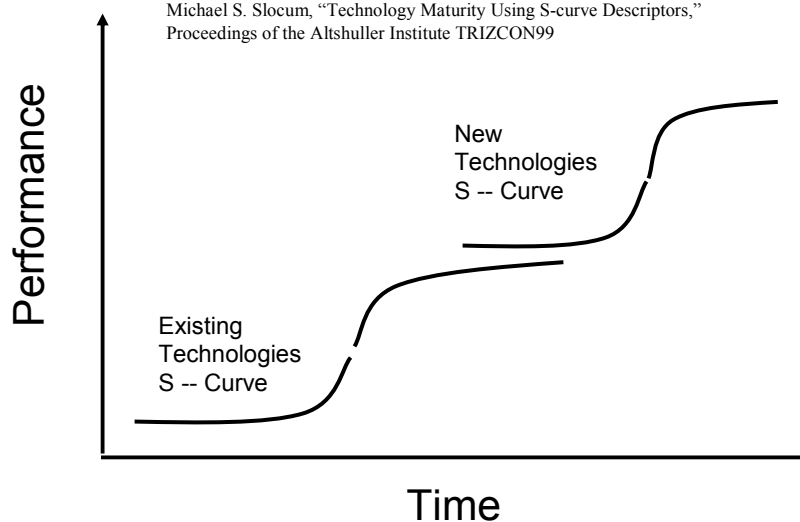
Development Processes



Advanced Electric
Power Systems Thrust

Technology Maturity Based on the Micro-Evolution of Biological Systems

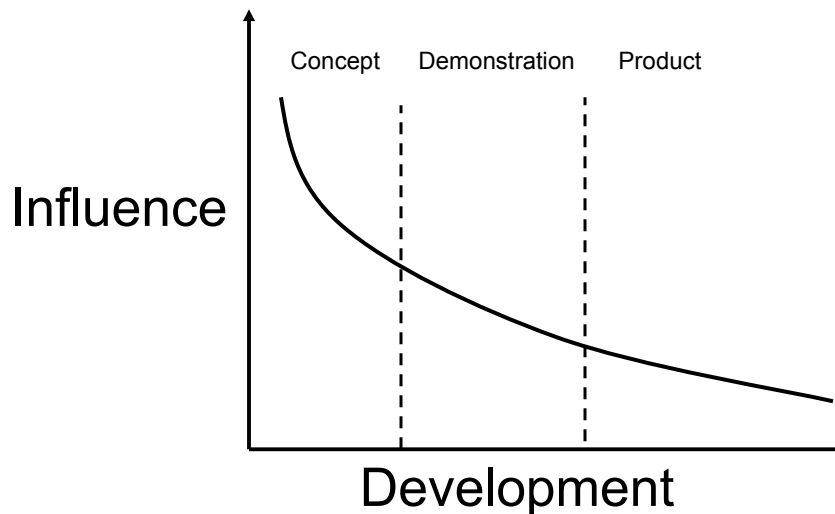
Michael S. Slocum, "Technology Maturity Using S-curve Descriptors,"
Proceedings of the Altshuller Institute TRIZCON99





Advanced Electric
Power Systems Thrust

Management Influences



Modeling and Simulation as Early as Possible in a Project



Advanced Electric
Power Systems Thrust

Example: The Electrical System and The Power Electronics Thesis

- Present electrical power systems are complex.
 - At equilibrium, 60Hz. Supplies power to 60Hz loads the system is stable and predictable.
 - If perturbed, the system can become unstable and unpredictable – bifurcation can occur.
 - Humans are needed to operate the system
- Future PEBB based power electronic systems will not be complex.
 - Automation is possible -- reduced operating costs
 - Progressive integration -- reduced system costs
 - Higher availability due to physics-based health prediction – reduced maintenance costs
 - Increased reliability and life by controlling overstresses

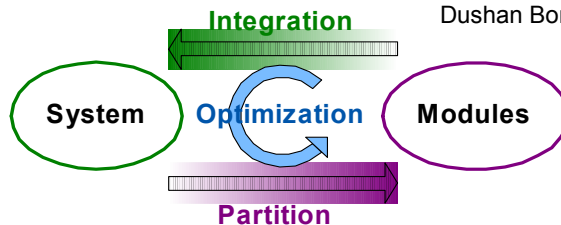


Advanced Electric
Power Systems Thrust

Modularization/Integration Process: CPES Example



Dushan Boroyevich, VA Tech



Partition

- Optimization techniques
- Spatial and functional, then temporal
- Facilitate manufacturing, achieve volume

Integration

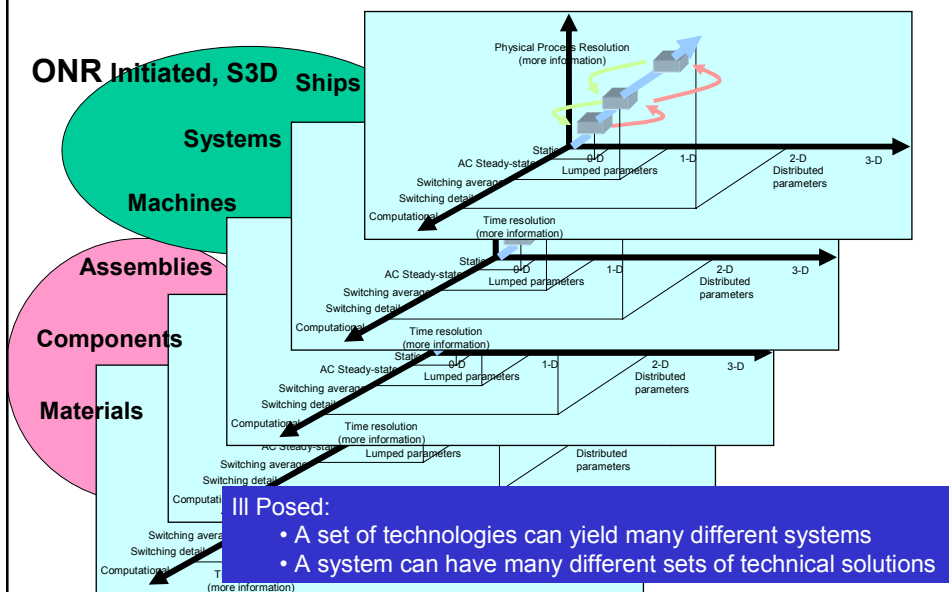
- Interaction of components: energy, control
- Spatial, then temporal and functional
- Manufacturing volume

Non-desired interactions are non-desired, non-useful, energy exchanges among system components



Advanced Electric
Power Systems Thrust

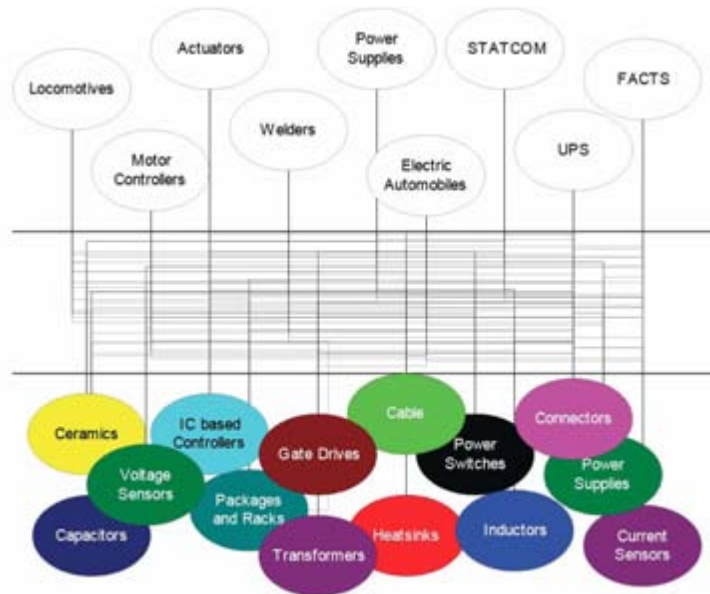
Design Challenges, Partitions and Standard Interfaces





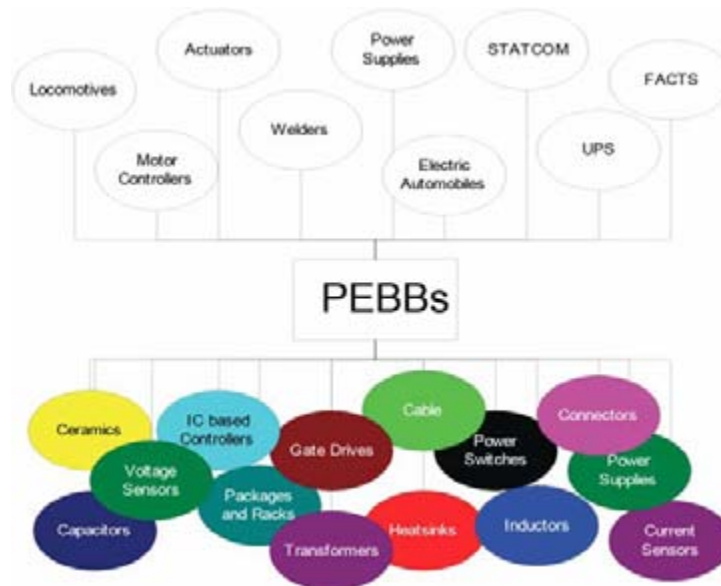
Advanced Electric
Power Systems Thrust

Traditional Power Electronics Industry



Advanced Electric
Power Systems Thrust

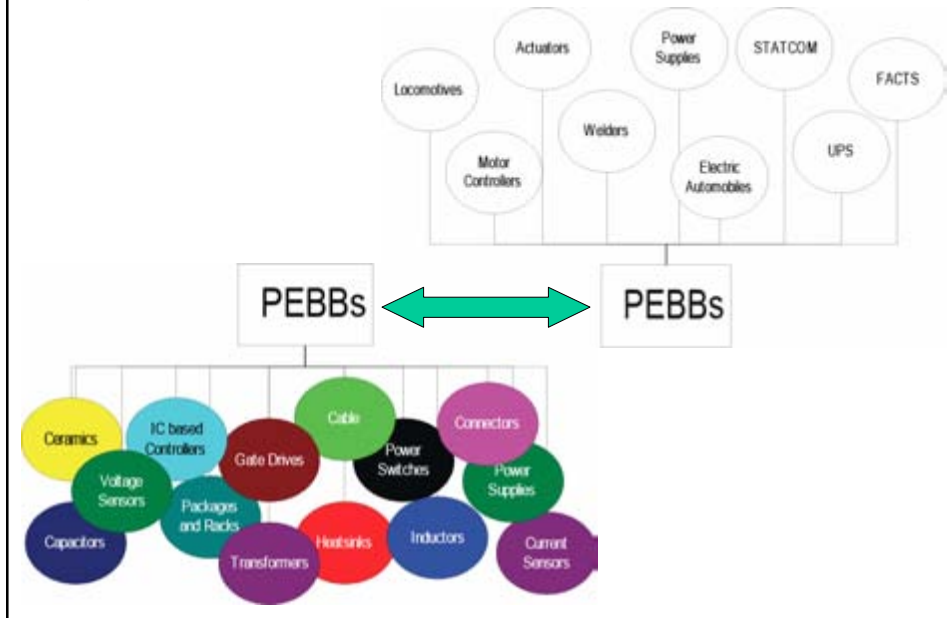
PEBB Based Power Electronics Industry





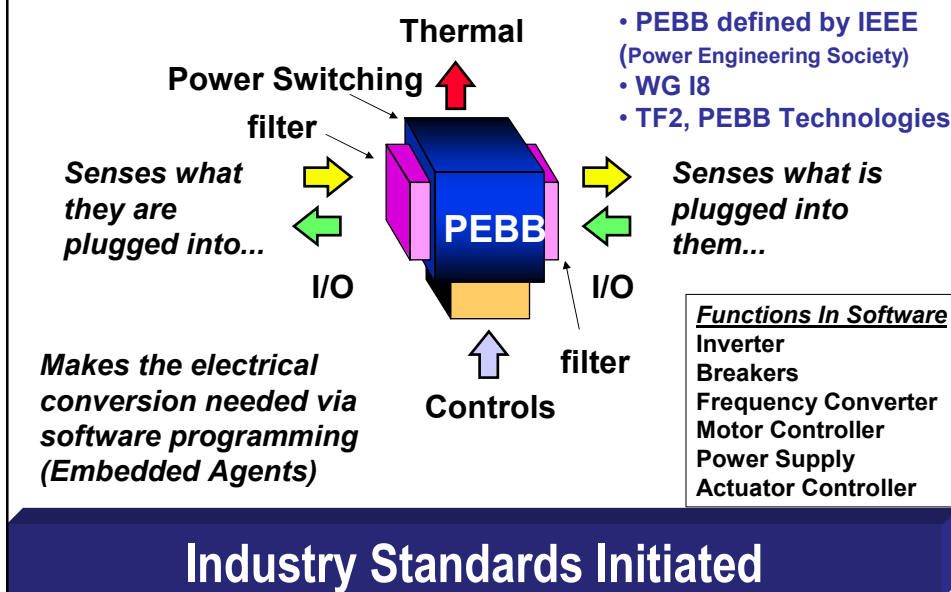
Advanced Electric
Power Systems Thrust

Asynchronous Processes for Multiplicative Product Development -- Concurrent Engineering



Advanced Electric
Power Systems Thrust

PEBB -- A Simple Set of Blocks for Power System Development (Functional)

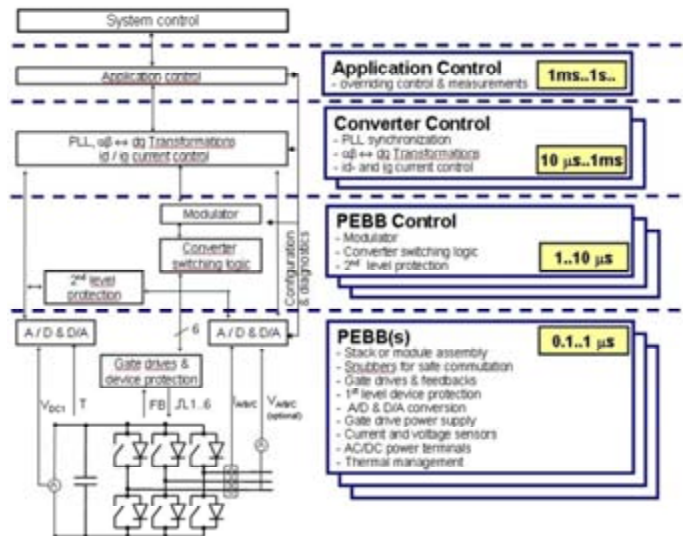




Advanced Electric
Power Systems Thrust

Universal Control Architecture for Control Interfaces (temporal) , IEEE Guide Initiated

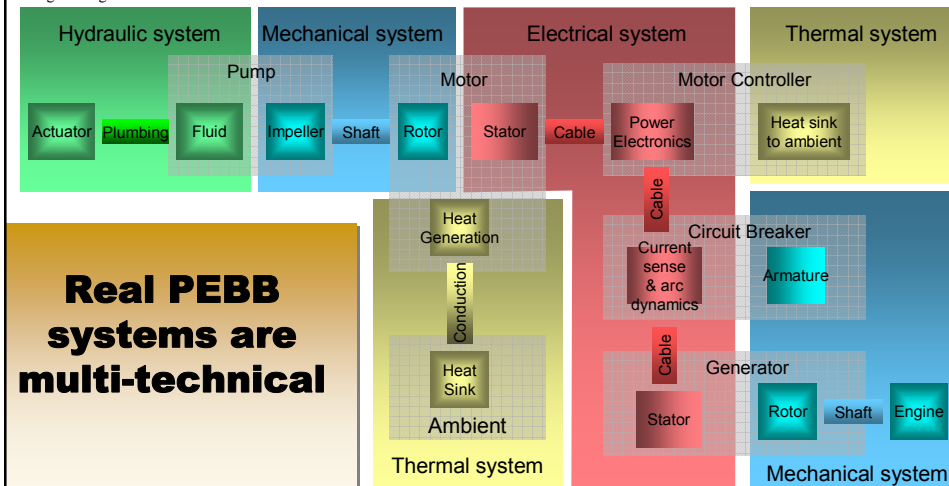
PEBB Concept for Power Electronics



Advanced Electric
Power Systems Thrust

VTB Simulation Environment

Roger Dougal



UNIVERSITY OF SOUTH CAROLINA



Advanced Electric
Power Systems Thrust

Validation, Emulation, and Incremental Prototyping

- Validation of models
 - Controller In the Loop
 - Processor In the Loop
 - Hardware In the Loop
- Real-time simulation is needed for real hardware
- High speed real-time simulation is need for high-speed controllers
- Multi-rate simulation for distributed simulation environments

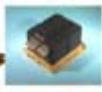


Advanced Electric
Power Systems Thrust

PEBB Examples

Experimental PEBB (blocks)

- Low Power, < 50kW



Satcon,
~600 kW/m²

- Medium Power, 50kW - 1MW



CONSWC/SPCO,
60 - 80 kW/m²



VPEC,
50-100 kW/m²

- High Power, > 1MW



A/C Switch



SPCO

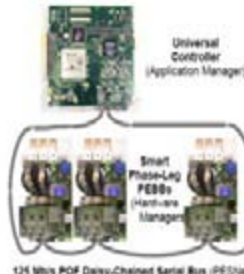


ABB Lopak5 IGBT based
PEBB with 12 capacitor DC
bank



ABB ANPC IGBT PEBB
(16 MVA PowerStack)

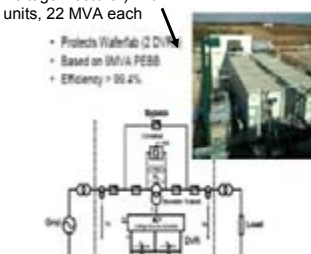
Virginia Tech Universal
Controller



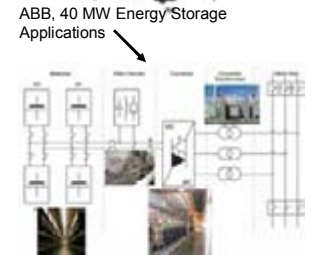
Advanced Electric Power Systems Thrust

ABB DVR (Dynamic Voltage Restorer) Two units, 22 MVA each

- Protects Voltage (2 DVA)
- Based on IGBT/PEBB
- Efficiency > 99.4%

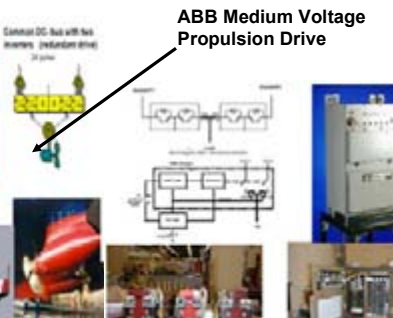


ABB, 40 MW Energy Storage Applications



PEBB Applications

ABB Medium Voltage Propulsion Drive

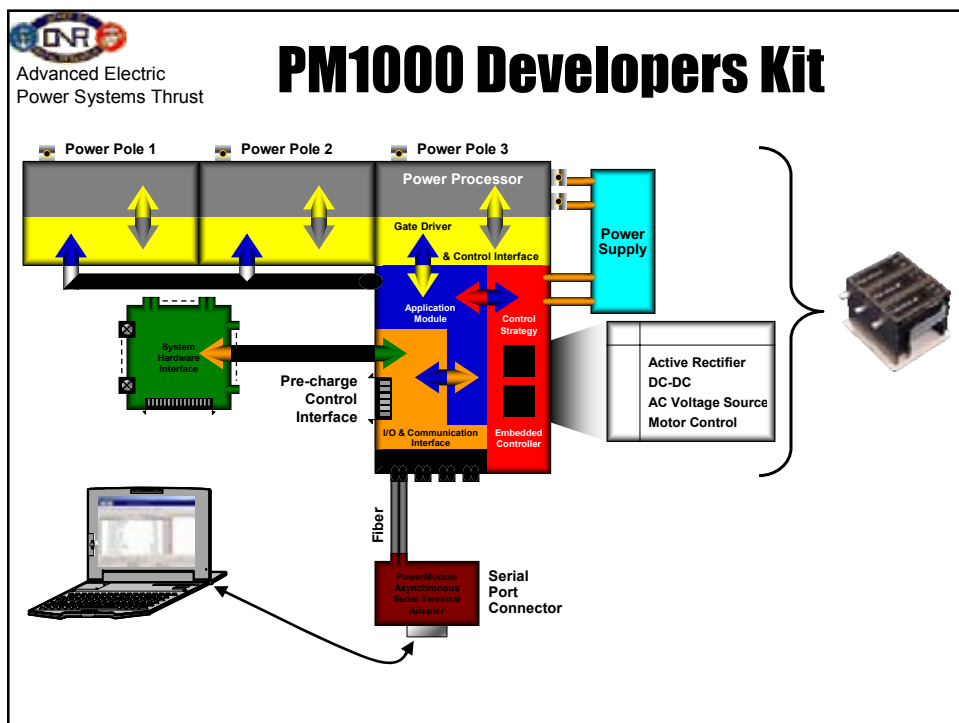


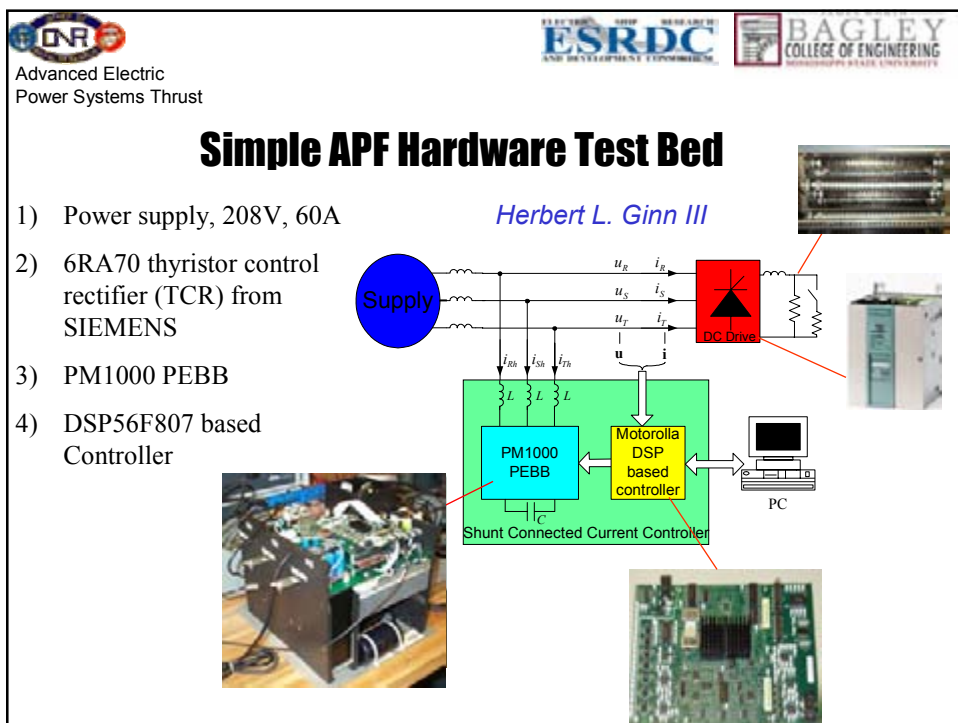
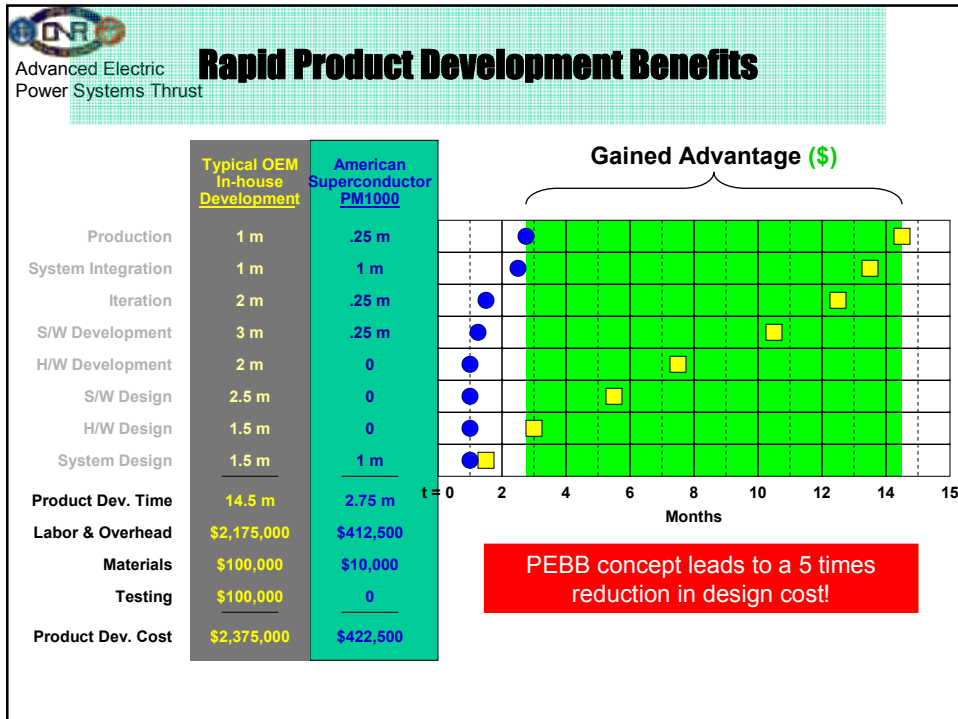
Solid State Transfer Switches and Current Interrupters by L-3 Power Paragon Inc.



American Superconductor PEBB products

Wind Turbine	Generator Set	Fuel Cell
PEBB provides active force control of the wind turbine's output.	PEBB provides converter for the generator set applications.	PEBB used to provide a regulated output voltage from the fuel cell.
		







Advanced Electric
Power Systems Thrust

Shunt Current Controller Applications

Herbert L. Ginn III



Converter System Description	Function	Power Electronics Type	Simple One-line Diagram
Active Filter	Cancel harmonic currents by injecting appropriate current into the node	Bi-directional voltage source converter	
Static Synchronous Compensator (STATCOM)	Provide desired reactive current for VAR compensation, voltage regulation and stability enhancement	Bi-directional voltage source converter	
Mini-HVDC	Provide interconnection between two ac nodes for active and reactive power flow control	Bi-directional voltage source converter	
Energy Storage System	Provide active power for load leveling or UPS function	Bi-directional voltage source converter and DC/DC converter	
Active Front End for Motor Drives	Provide active and reactive power for motor VSD	Bi-directional voltage source converters	



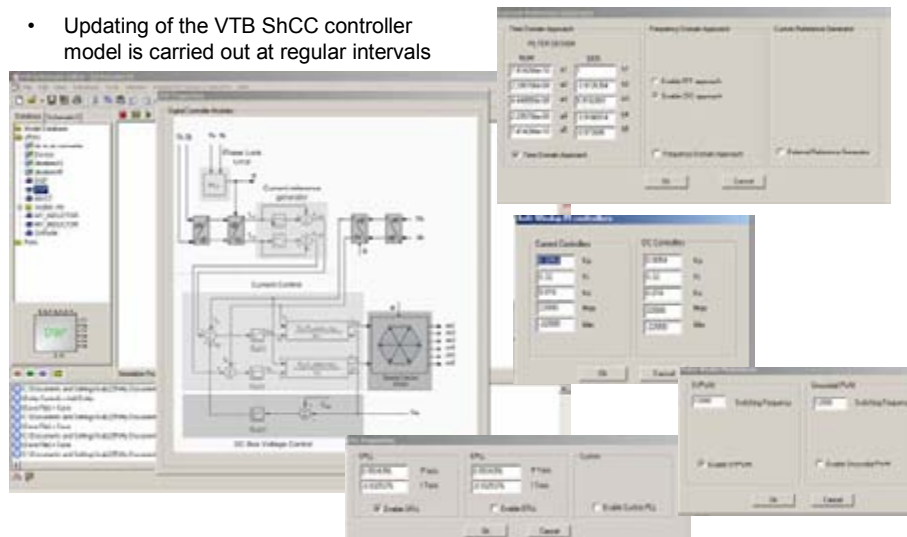
Advanced Electric
Power Systems Thrust

Herbert L. Ginn III



Generalization of ShCC Digital Controller Model in VTB

- Updating of the VTB ShCC controller model is carried out at regular intervals



Vehicle Power Problem

$$p = \varepsilon \frac{dw}{dt}$$

W = energy which is equal to the ceiling amount of the installed generation capacity (may increase over time with technology – fractionally)

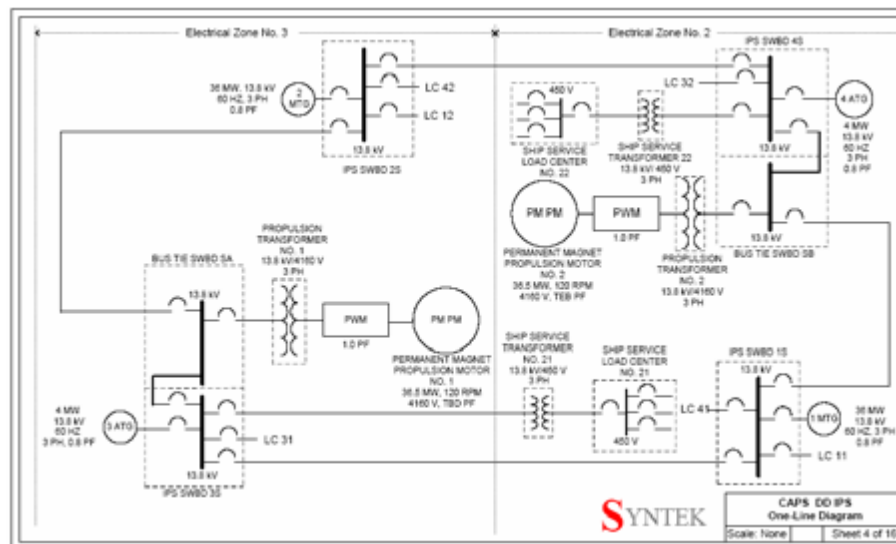
p, power requirements are increasing multiplicatively by 10x to 100x

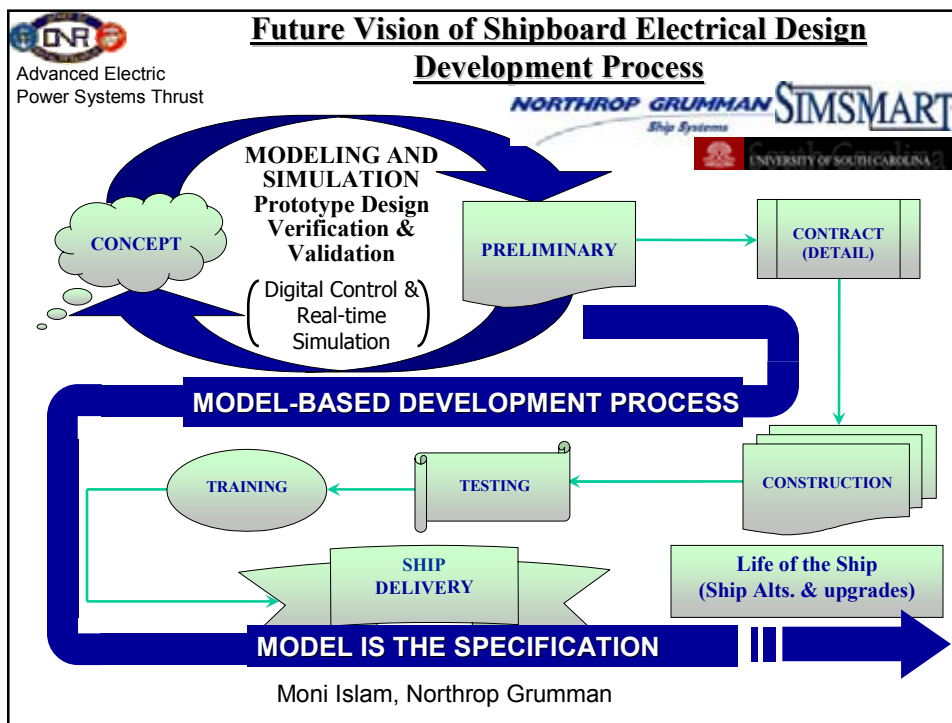
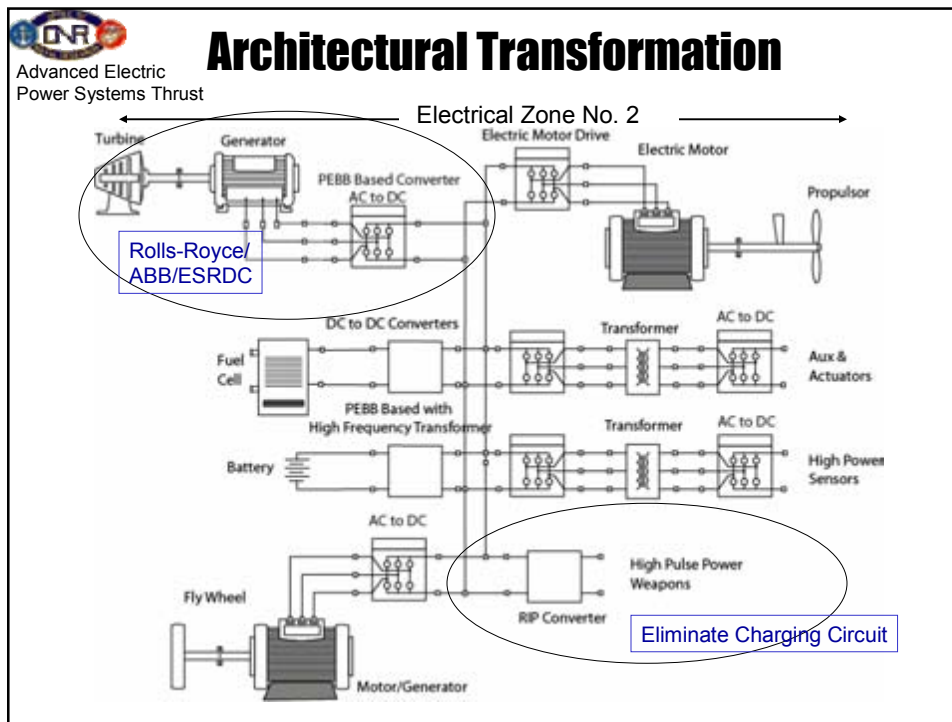
 $\varepsilon = \text{efficiency}$

Conditions:

- 1) Size, weight, cost stay the same or decrease
- 2) Open architecture, plug and play

Notional Integrated Power System (IPS)







Advanced Electric
Power Systems Thrust

Needs Continued – Social Structure

- Modeling Standards
- Benchmark Models
- Public Library of Models
- A body of international volunteer experts for all of the above
- And ...



Center for Power Electronics Systems

A National Science Foundation Engineering Research Center

Virginia Tech, University of Wisconsin - Madison, Rensselaer Polytechnic Institute
North Carolina A&T State University, University of Puerto Rico - Mayaguez

Integrated Power Electronics Building Block Modules, Converters, and Systems

Fred Wang
Virginia Tech, Blacksburg, VA
fred.wang@vt.edu

Advanced Power Electronics Interfaces for DE Workshop
Sacramento, CA, USA

August 24, 2006



Distributed Energy Resources

- Wind
- Bio
- Microturbines
- Others
- Solar
- Fuel cells
- Energy storage

Power Electronics Interface a Key Enabling Technology

- ***Lower cost***
- ***Higher reliability***
- ***Better performance***

August 24, 2006

1



Improving DE Power Electronics Interfaces

- **Conventional approach**
 - components, circuits, control, processes, design optimization
- **Modular building blocks**
 - high volume, standardization
- **Integration**
 - reliability, performance, manufacturing
- **System**
 - added functionality and values

CPES focus on IPEMs and IPEM building blocks based systems

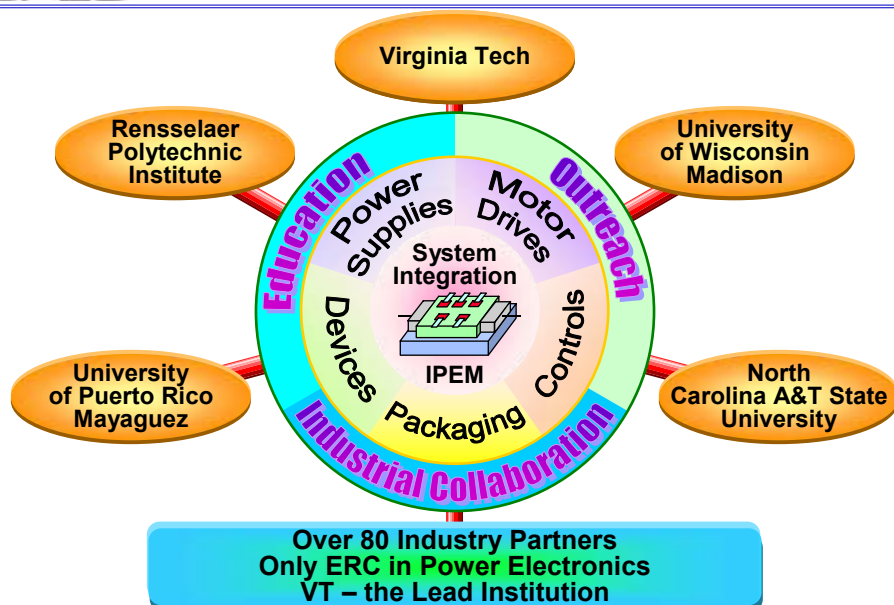
August 24, 2006

2



Center for Power Electronics Systems

A National Science Foundation Engineering Research Center



August 24, 2006

3

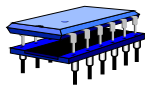


CPES Research Vision and Objectives

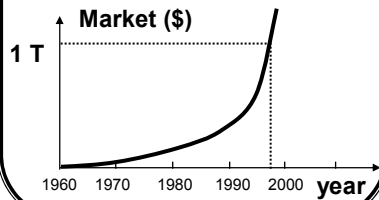
– Power electronics to follow microelectronics –

Moore's Law Prevails

- Standardization
- Manufacturability
- Volume production
- Cost reduction

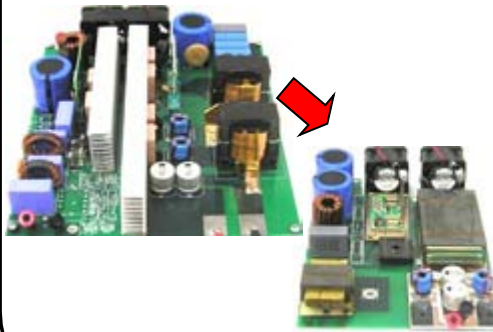


Signal
Processing
IC



August 24, 2006

- Integrated Power Electronics Modules (Standardized building blocks)
- Reduce labor content
- Low cost



Power Processing IPEM

4



Vision and Focus

Enable dramatic improvements in the performance, reliability, and cost-effectiveness of energy processing systems by developing an integrated system approach via Integrated Power Electronics Modules (IPEMs).

IPEM Concept:

A concept for design of electronic energy processing systems with improved performance, reliability, manufacturability, and reduced cost, based on the integration of a set of building blocks with:

- Integrated functionality,
- Standardized interfaces,
- Suitability for mass production, and
- Application versatility.

August 24, 2006

5

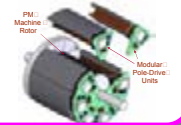


Different Approaches to Integration

• Integrated Load Converters:

- Low-cost, “intelligent motors”
 - motor as output filter
- Fast power delivery to microprocessors
 - minimum distance to load

Motor and Converter Integration



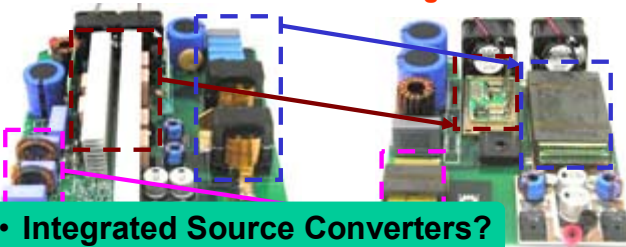
Microprocessor and Converter Integration



• Power Distribution Converters:

Discrete converter

Integrated converter



• Integrated Source Converters?

Standard-Cell IPEMs:

- Active IPEM
- Passive IPEM
- EMI Filter IPEM

August 24, 2006

6



CPES Research Thrusts

Engineered Systems

IPEM-Based Power Conversion Systems (IPEM-PCS)
D. Boroyevich, VT

Enabling Technology

Electro-Magneto-Thermo-Mechanical Integration Technology (EMTMIT)

T. M. Jahns, UW-M

Microprocessor and Converter Integration

Standard-Cell Active IPEMs

Standard-Cell Passive and Filter IPEMs

Motor and Converter Integration

Fundamental Knowledge

Advanced Power Semiconductors (APS)
T. P. Chow, RPI

Integratable Materials (IM)
G. Q. Lu, VT

High-Density Integration (HDI)
J. D. van Wyk, VT

Thermo-Mechanical Integration (TMI)
E. P. Scott, VT

Control & Sensor Integration (CSI)
R.D. Lorenz, UW-M

August 24, 2006

7



Promoting IPEMs

For Different Power Ranges and Applications

10-100 W IPEMs



IR iPOWER™



TI SWIFT™



Philips PIP20x



CPES Monolithic VRM

IR, Philips, On Semi, Intersil, Linear Tech, TI, Renesas, NSC, Power One, Infineon, ST, Maxim, Micrel, Volterra, Primarion, Fairchild, Analog

1-10 kW IPEMs



Semikron IPM



CPES Integrated EMI Filter



CPES Flip-Chip-On-Flex Phase-Leg



CPES Transmission Line Filter



CPES Active IPEM



CPES Passive IPEM

ABB, Hitachi, IXYS, Toshiba, Semikron, Fuji, Infineon, Eupec, Powerex

10 kW - 10 MW IPEMs



CPES 800 V, 40 A ZVZCT phase-leg



1.8 kV, 60 A, 3-level ZVZCT phase-leg



CPES 4.5 kV, 4 kA ETO

ONR, DOE, NSWC, Thales, Northrop Grumman, Rockwell Automation, General Dynamics, ABB, Bettis, Alstom, ACI, PEMCO, TVA

August 24, 2006

CPES industry consortium members or research sponsors

8



Issues for IPEM Building Block Approach

- **Basic building blocks**
 - “A minimum set of building blocks with integrated functionality, standardized interfaces, suitability for mass production, and application versatility.”
- **Architecture & Partitioning**
 - How to build a power system application with application-independent PE modules?
- **Interface Characterization**
 - What are interface characteristics and requirements for a selected architecture?

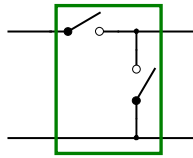
August 24, 2006

9

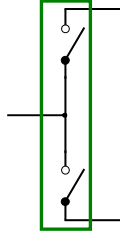


Topologies Based on Totem-pole Phase-leg Modules

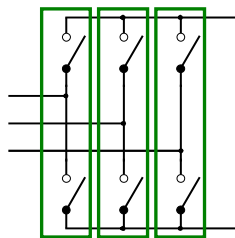
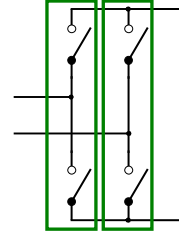
Single-Ended



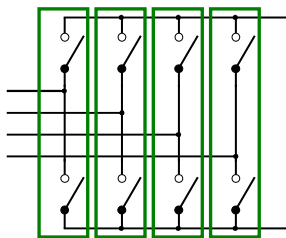
Half-Bridge



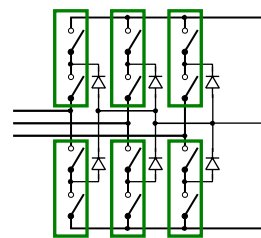
Full-Bridge



Three-Phase



Multi-Phase



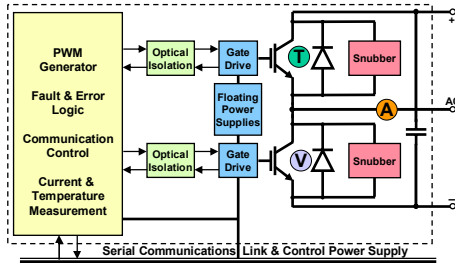
Multi-Level

August 24, 2006

10



Integrated Phase-leg PEBB + “Plug & Play” Control Architecture

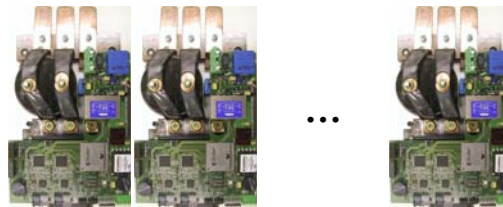


35 kVA, 800 V, 20 kHz

Universal Controller
(Application Manager)



Smart Phase-Leg PEBBs (Hardware Managers)



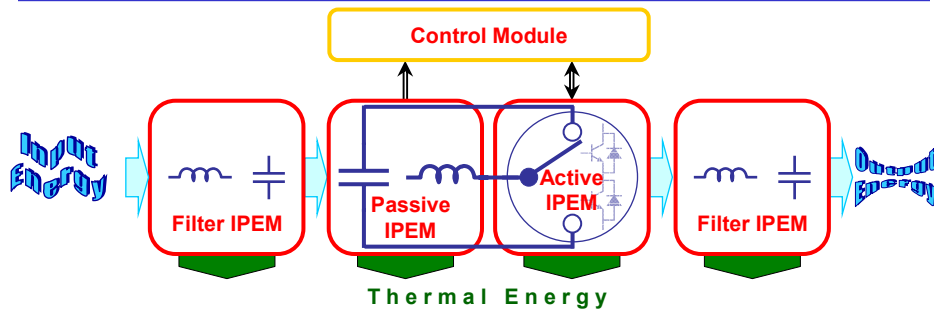
125 Mb/s POF Daisy-Chain Serial Bus (PESNet)

August 24, 2006

11



Passives and Filters Need to be Integral Part of the Converter



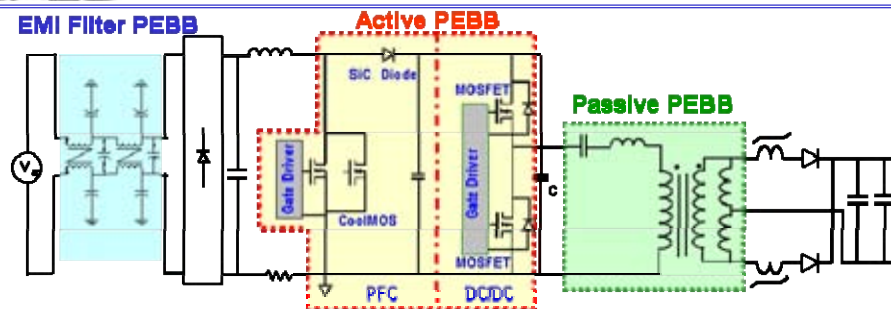
- **Active IPEM**
Controls the energy flow (switching)
- **Control Module**
- **Passive IPEM**
Absorbs high-frequency energy (temporary storage)
Size reduces with increasing switching frequency
- **Filter IPEM**
Blocks high-frequency energy (size independent of switching frequency)

August 24, 2006

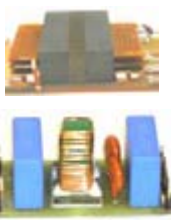
12



1 kVA, 1-AC (90-260 V) to DC (48 V) Isolated Converter



EMI Filter PEBB

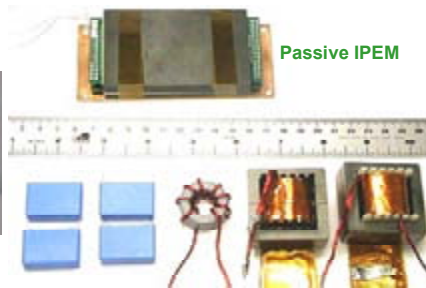


Discrete EMI Filter

Active IPEM



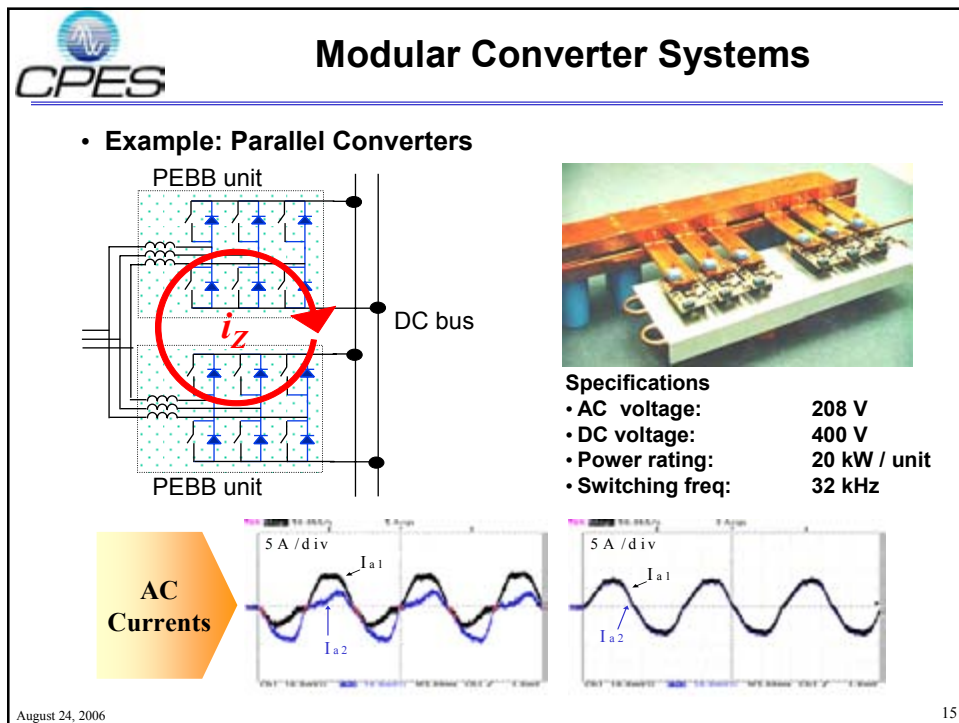
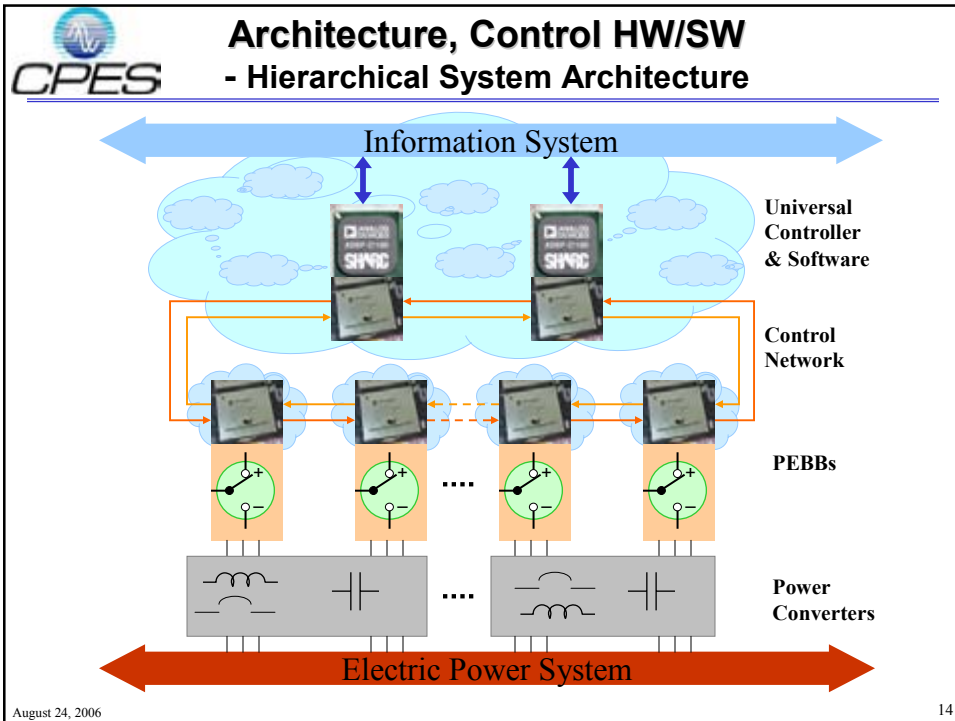
Passive IPEM



Discrete Components

August 24, 2006

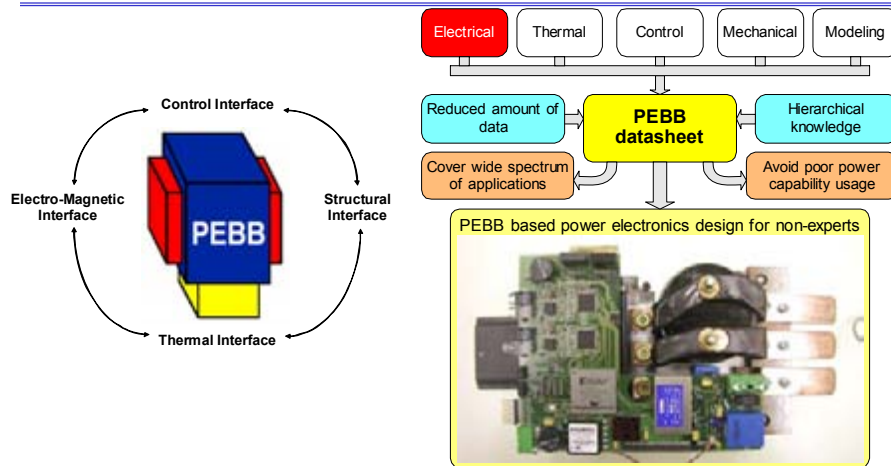
13





Modeling and Characterization

CPES - Standard cell interface characterization



PEBB modules with standardized interfaces

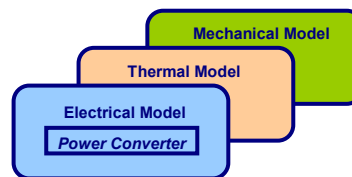
August 24, 2006

16



Modeling and Simulation as Partition Evaluation Methodology

- Physics-based modeling
 - Takes into account (within and without)
 - Energy fields
 - Materials
 - Assembly
- Enables system-level evaluation
 - Terminal models of subsystems
 - Power: v, i
 - Control: u
 - Thermal: θ, p
 - Structural (mechanical)
- Explicit relationships between terminal variables, while indirectly capturing internal physics
- Hierarchical reduction of modeling detail



August 24, 2006

17



PCS with Integrated Functionality

- **With active control and built-in intelligence, power converters can change the dynamics of the sources and loads to:**
 - Reduce system complexity by decoupling the dynamics (benefits in design & operation)
 - Reduce the oversize margin for sources and loads
 - Replace/eliminate bulky passive filters
- **Functionalities:**
 - Power flow control
 - Power management (continuous)
 - PQ control, active filtering
 - Monitoring, diagnosis, and on-line mitigation
 - Protection

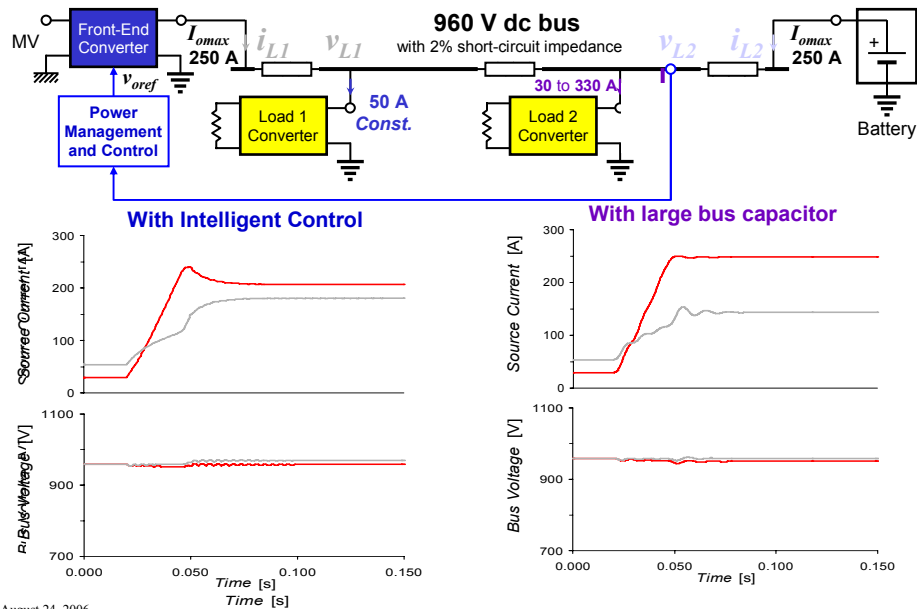
August 24, 2006

18



Subsystem Interaction Example

– models with input & output impedances –



August 24, 2006

19



Summary

- CPES promotes an integrated system approach via Integrated Power Electronics Modules (IPEM) concept to improve performance, reliability, and cost-effectiveness of power converters
- IPEM building blocks need passive and filter modules in addition to active modules
- Benefits can be achieved, and researches are needed at module, converter, and system levels
- There is a strong need for consistent, physics-based, system architecture analysis and evaluation methodology

August 24, 2006

20



Acknowledgement

The work and contributions are result of many CPES faculty, students, and staff.



This work was supported primarily by ERC Program of the National Science Foundation under Award Number ECC-9731677 and by Office of Naval Research over the years

Many other US government and industrial sponsors of CPES research are gratefully acknowledged.

August 24, 2006

21



Bricks and Buses

Giri Venkataramanan
University of Wisconsin-Madison
Giri@engr.wisc.edu
Ph: 608-262-4479

24th Aug 2006
California Energy Commission
Sacramento, CA

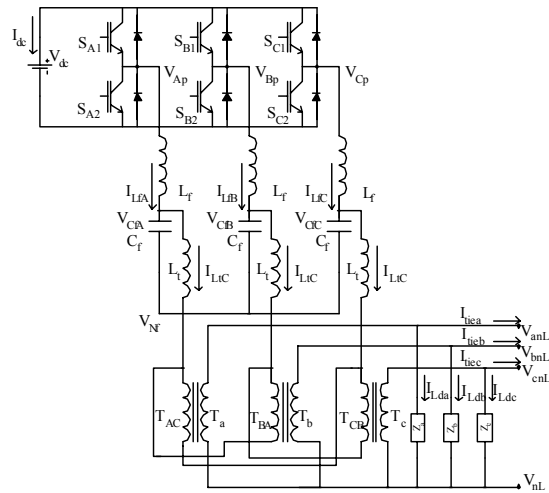


Power Electronics Applications

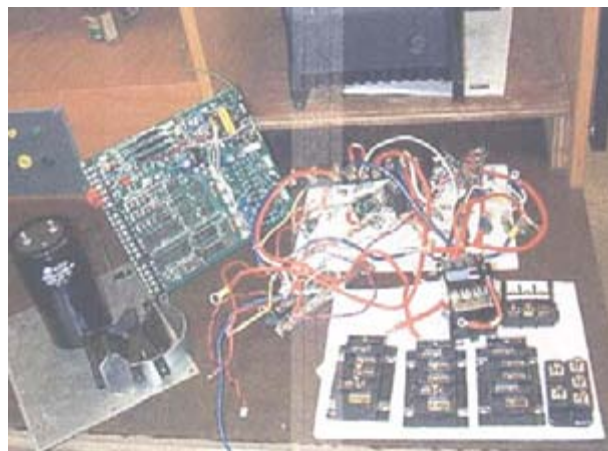
- Motor drives 1 h.p. – 5000 h.p.
- Power supplies 10W – 5 kW (and >)
- UPS systems 100W – 100kW
- Compact fluorescents 5W – 50W

- Segmented markets
- DG as a new market segment?

Typical schematic



State of the art





Power Electronics Assembly



CEC, 24th Aug 2006

GV -5



Restrains

- Barriers to growth
 - High cost
 - Low reliability
 - High complexity
 - Custom design
 - Long design cycle
 - High manufacturing cost
 - Low volume
 - Custom interfaces
 - Lack of scalability
 - Multi-geometric assembly

CEC, 24th Aug 2006

GV -6



Desirable scenario

- Standardized input, output, functionality
- 'Compatible' cabinets
- Fault tolerant, fail safe capability
- Plug and play
- Geometries for:
 - Thermal
 - Electrical & Magnetic
 - Mechanical & Industrial design

CEC, 24th Aug 2006

GV -7



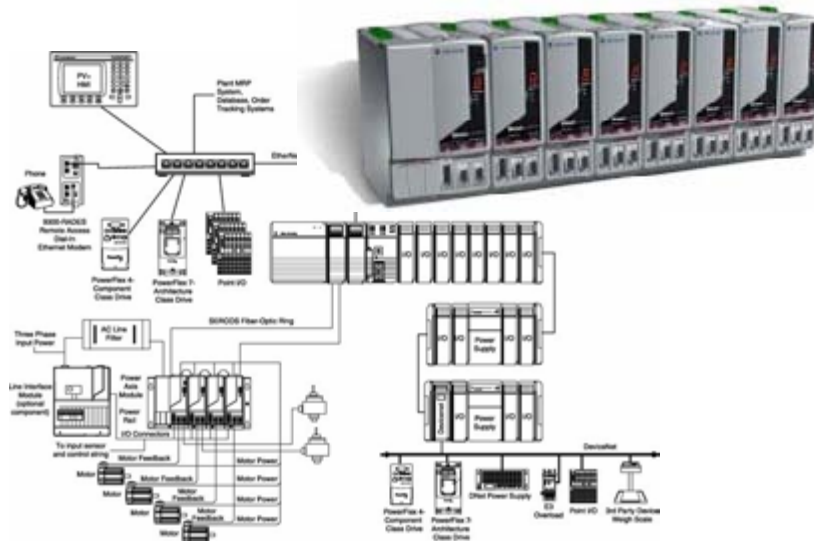
MCCB Panel Boards (EATON)



CEC, 24th Aug 2006

GV -8

Modular servo drives (Rockwell)

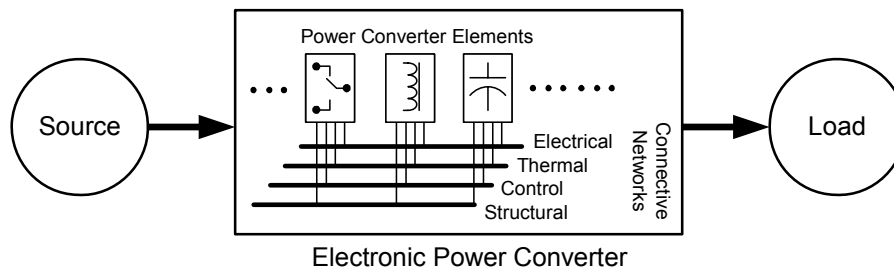


CEC, 24th Aug 2006

GV -9



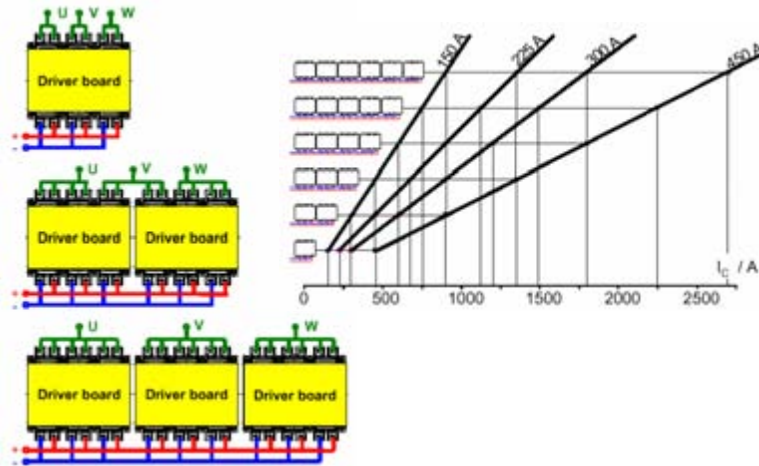
Components



CEC, 24th Aug 2006

GV -10

Silicon scaling

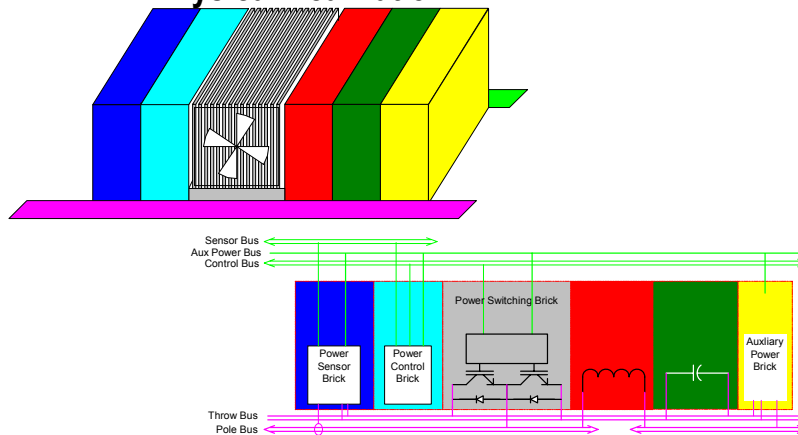


CEC, 24th Aug 2006

GV -11

Bricks & Buses Concept

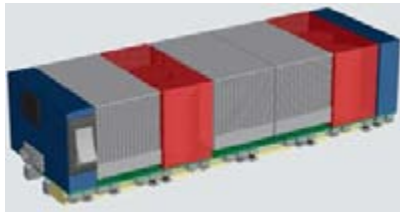
Physical Realization



CEC, 24th Aug 2006

GV -12

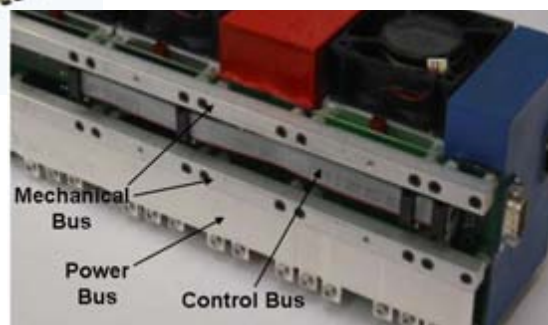
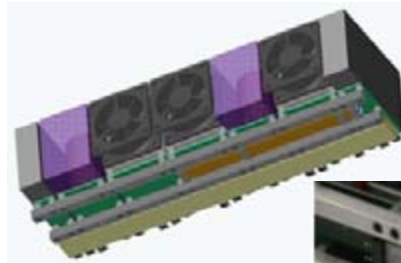
Bricks and Buses Converter



CEC, 24th Aug 2006

GV -13

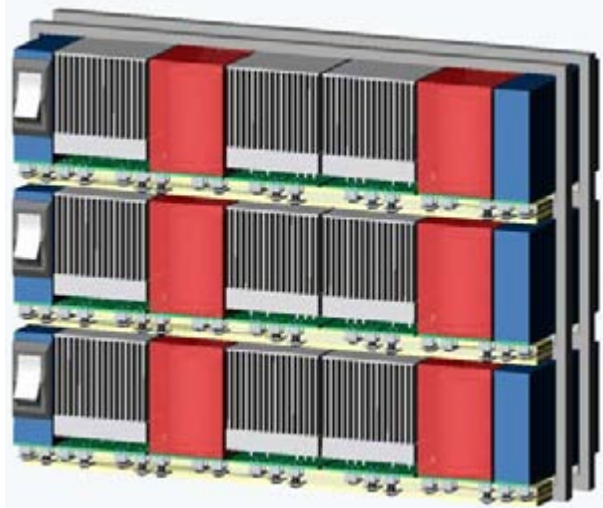
Bricks and Buses Converter



CEC, 24th Aug 2006

GV -14

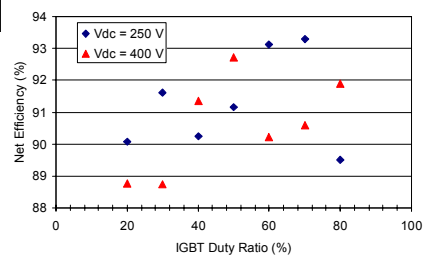
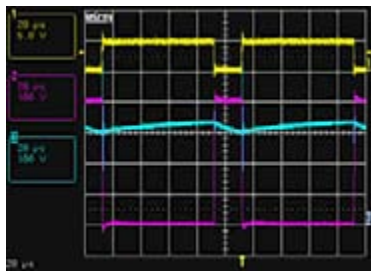
Bricks and Buses Converter



CEC, 24th Aug 2006

GV -15

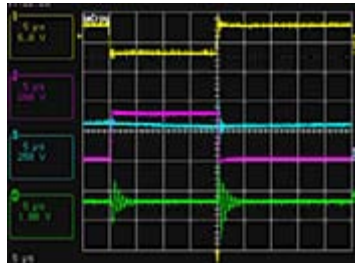
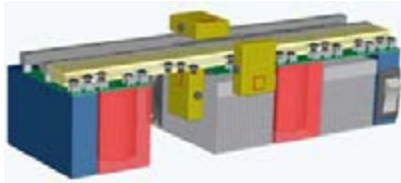
Test results



CEC, 24th Aug 2006

GV -16

Radiated Coupling



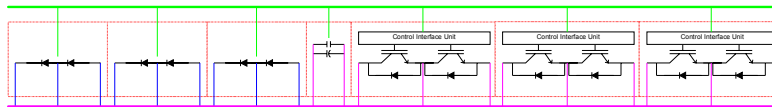
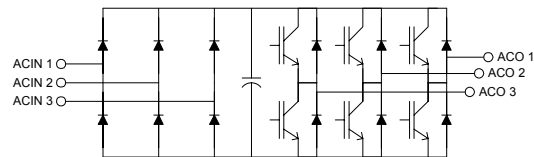
Location	V_{PK-PK} / Area (mV/cm ²)
A	0.413
B	0.263
C	0.620

Bricks & Buses

- Standardized dimensions – depth and height
- Incremental scaling of width
- Each brick thermally self managed
- Variable volume
- Proportional scaling of surface area
- Decoupled power bus and signal bus
- Contained interconnect EMI



3 phase ac-dc-ac converter



CEC, 24th Aug 2006

GV -19



Accomplishments to date

- \$70k demonstration seed through CERTS DG Integration (2001-2004)
- Demonstrated a concept prototype
- Adhoc design
- Comparable electrical performance
- Increased power density
- Modular packaging
- Improved manufacturability

CEC, 24th Aug 2006

GV -20



Challenges

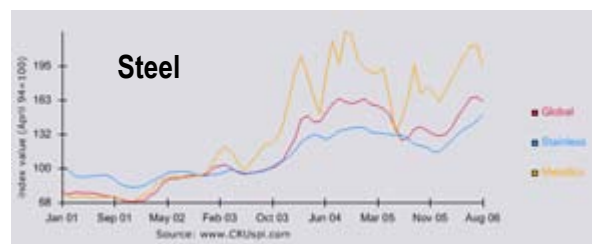
- Electronics – Silicon
- Capacitors – Film, Foil
- Magnetic elements – Copper, Iron
- Cooling – Heat-sink, Cold plates
- Auxiliary – Switchgear
- Interconnections – Printed circuits, busbars
- Design, manufacturing, applications

CEC, 24th Aug 2006

GV -21



Magnetics - trends

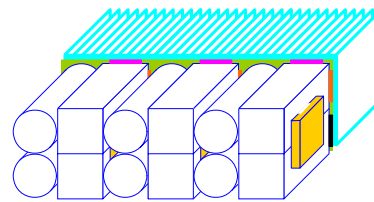
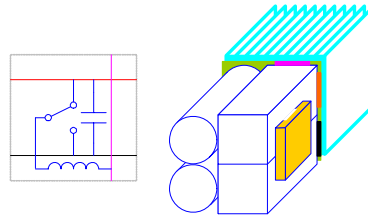
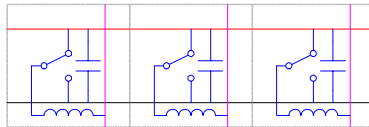


CEC, 24th Aug 2006

GV -22

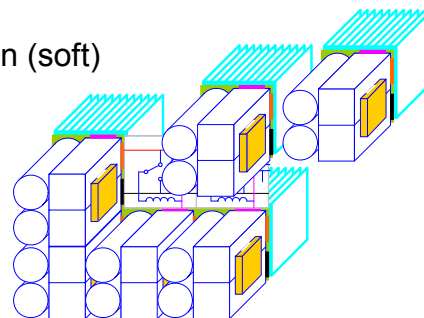
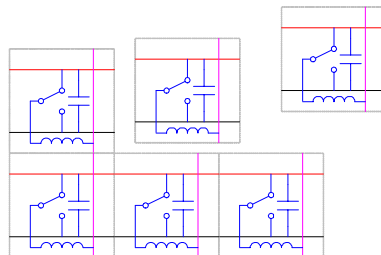
Beyond Si - Cellular design

- Cell definition
 - Switch
 - Throw capacitance
 - Pole magnetics
 - Thermal



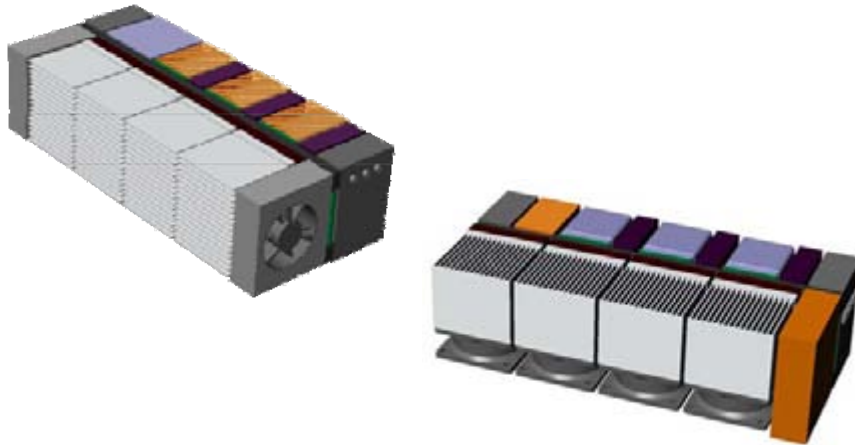
Step and repeat process

- Conforming and compatible layers
 - Thermal management
 - Switching electronics
 - Reactive elements
 - Control/communication (soft)





Air-cooled concept designs



CEC, 24th Aug 2006

GV -25



Liquid-cooled concept designs

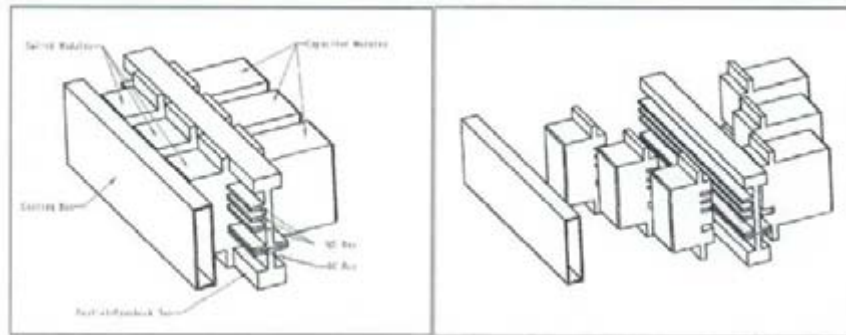


CEC, 24th Aug 2006

GV -26

Bus Centered Assembly

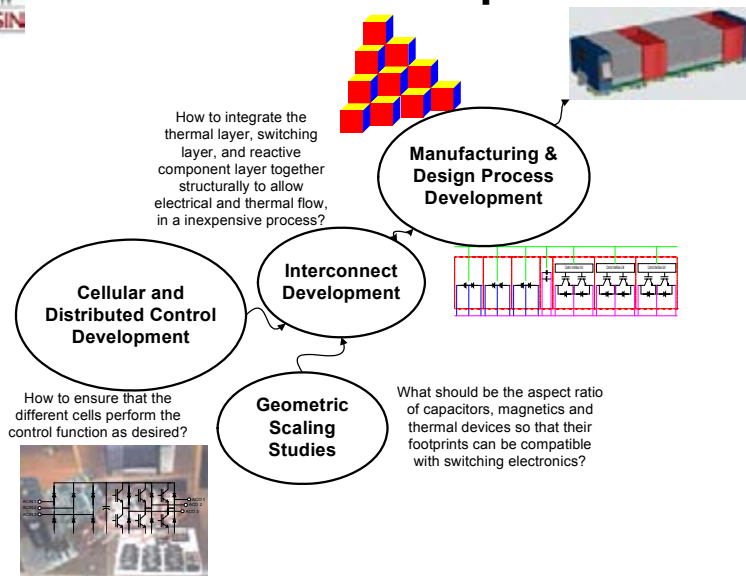
- Electrical and structural interconnection
- Similar to MCCB panel-boards



CEC, 24th Aug 2006

GV -27

Roadmap



CEC, 24th Aug 2006

GV -28

Advanced Topologies for DE Interface

Ned Mohan
University of Minnesota
Distributed Energy Workshop
Sacramento, CA
August 24, 2006

1

Workshop on Renewable Energy for Minnesota McNamara Alumni Center, University of Minnesota, Minneapolis Thursday October 12, 2006

Objectives:

- Discuss renewable energy prospects in Minnesota
- Bring renewable energy curriculum into K-12
- Describe the research being conducted in this field in the Department of Electrical and Computer Engineering (funded by XcelEnergy, National Science Foundation and ONR)

Who should Attend: Everyone concerned with energy, particularly the technical issues, and its impact on the environment and society.

Tentative Schedule:

- 7:30-8:00 **Registration, Coffee and Rolls**
- 8:00-8:30 **Welcome and Introduction**
- Welcoming Remarks: *Steven Crouch*, Dean – Institute of Technology, U of M
 - Workshop Objectives and Agenda: *Ned Mohan*, ElectE, U of M
 - Renewable Energy Development Fund: *Michelle Swanson*, XcelEnergy
- 8:30-10:00 **Renewable Energy Overview**
- A Power Grid for the Hydrogen Economy: *Thomas Overbye*, Professor, University of Illinois
 - Lessons From Norway: *Terje Gjengedal*, Vice President - STATKRAFT, NORWAY, in charge of renewable energy projects
 - What is Happening in Minnesota?: *Michael Bull*, Assistant Commissioner, Minnesota Department of Commerce (invited)
- 10:00-10:30 **Coffee Break**
- 10:30-11:30 **Wind Energy**
- Present Projects and Potential in Minnesota: *John Dunlop*, American Wind Energy Association
 - Transmission Planning in Minnesota – CapX 2020: *Gordon Pietsch*, Great River Energy
- 11:30-12:00 **Research in Renewable Energy at the ECE Dept, University of Minnesota**
- Results of Research funded by NSF, XcelEnergy and ONR: *Ned Mohan*, ElectE, U of M
- 12:00-1:00 **Lunch** (buffet lunch provided)
- 1:00-2:00 **Hydrogen and Fuel Cells: Making the Connection**
- Hydrogen From Wind: *Lanny Schmidt*, Regents Professor, ChemE, U of M
 - Research in Fuel Cells: *Brad Palmer*, Cummins Power Generation, Fridley, Minnesota
- 2:00-3:00 **Bringing Renewable Energy and Conservation Curriculum into K-12 Courses**
- Sustainable Architecture: Virajita Singh and John Carmody, U of M
 - Group Discussion led by: *Steven Pullar*, Woodbury Math and Science Academy, MN and *Michael Maas*, Eden Prairie High School, MN

Posters on Display: Research being conducted in this field in the Department of Electrical and Computer Engineering, funded by XcelEnergy, National Science Foundation and ONR.

2

Registration Fee: \$65
University of Minnesota Faculty: No Fee (Registration includes free Lunch, No parking)
Student Fee: \$65 (Registration includes free Bus Lunch, No parking)
 The registration fee of \$65 includes admission, materials, lunch, books and parking. Park at the University Avenue
 Bus Stop adjacent to the McNamara Alumni Center and bring your ticket to the registration desk for validation.
 Students and the University of Minnesota faculty may attend the workshop for free but must provide for their own
 parking. No refunds are available. You must register by mail. Be sure to use the enclosed registration form. If
 you are a University of Minnesota faculty member, please indicate so in the box for the Registration Fee.

Location
 The McNamara Alumni Center is located at 240 Oak Street SE in Minneapolis, Minnesota (on the Minneapolis
 campus of the University of Minnesota). For directions visit: www.mcnameralc.org. Commuters helping to
 be available at the Radisson University Hotel. Call 612.579.6000 for rates and to make a reservation.

Continuing Education Units (CEUs)
 Attendees will earn 7 hours of Continuing Education Units through the College of Continuing Education at the
 University of Minnesota.

Contact
 For registration questions, contact Kate Karseth, 612.624.1756, or kkarseth@mcnameralc.org
 For technical questions, contact Paul Mohan, 612.625.1762, or pmohan@mcnameralc.org

Web Site: www.mcnameralc.org/workshop
 Group Photo: Renewable Energy Workshop 2015 in McNamara Center (www.mcnameralc.org/workshop)



About The University of Minnesota - Minneapolis Campus
 Arguably the most vibrant and beautiful campus that spans both sides of the Mississippi as it begins its 2,100 mile
 journey towards the Gulf of Mexico, it is also the second largest with the Fall 2010 enrollment of 34,179 (only
 ASU's campus was larger with 34,787). How many universities can boast 147 registered student organizations?

It is almost within walking distance of the downtown, which is a major cultural center between Chicago and San
 Francisco, with hundreds of ethnic restaurants reflecting the cosmopolitan nature of this city. Minneapolis-St. Paul
 are well connected, with non-stop flights from most major cities in the United States.

The Twin Cities weather is never dull, i.e., it can be brutal in winter. But with an extensive network of underground
 tunnels (called the Capital Way) connecting most major buildings, including the Radisson Hotel, the weather here is
 the same pretty often.



Continuing Education Unit number 1-12
 Photo taken by www.mcnameralc.org, Feb. 19, 2015

3

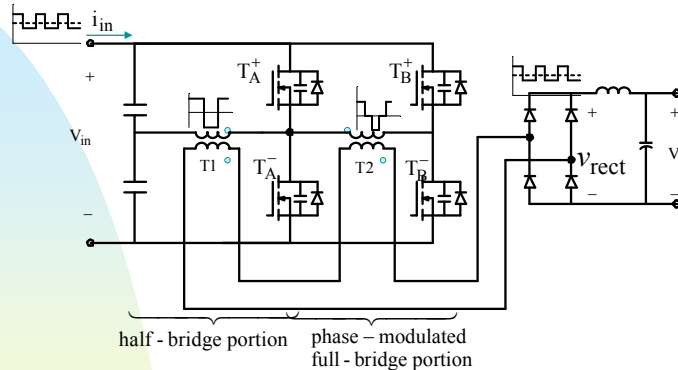
Sources of Distributed Energy

- Photovoltaic
- Fuel Cells
- Wind
- Micro-Turbines

4

An Ultra-Compact High-Efficiency DC-DC Soft-Switching Converter for Photovoltaic and Fuel Cells

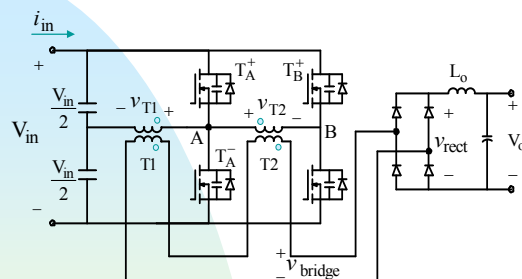
(US Patent:6,310,785 University of Minnesota)



- Combination of uncontrolled half-bridge and phase shifted full-bridge
- Uses 4 switches with combined VA ratings identical to PMC
- ✓ ZVS down to no load
- ✓ Reduced magnetics
- ✓ Smaller conduction loss compared to PMC
- ✓ Better dynamic response

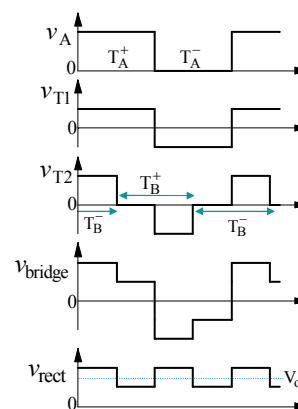
5

Operating principles



- all switches switch at 50% duty-ratio and constant switching frequency

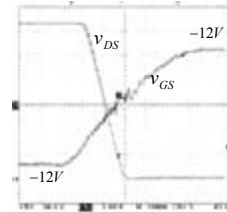
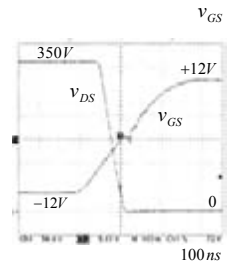
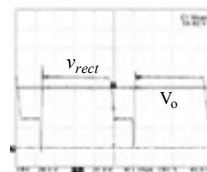
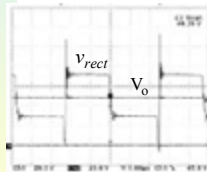
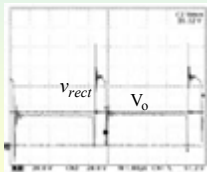
$$\frac{V_o}{V_{in}} = \frac{n_1}{2} + D n_2$$



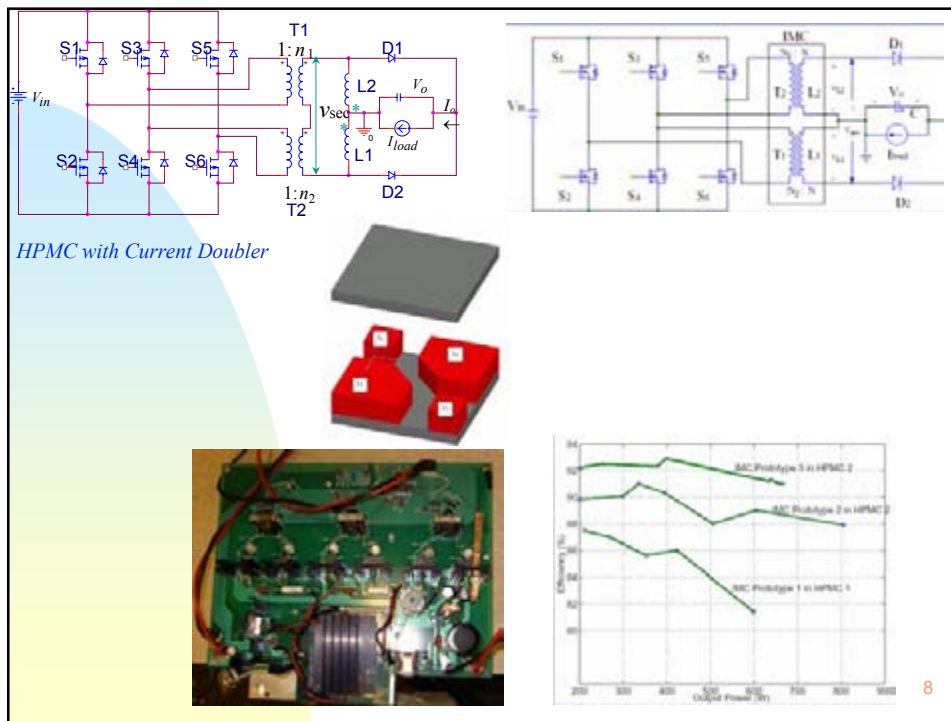
6

Experimental waveforms

$V_{in} : 350V - 400V$
 $V_o : 36V - 60V$
 $@ 20A$
 $f_{sw} : 100kHz$



7



A Multi-Port DC/DC Converter

Hariharan Krishnaswami, Ned Mohan, Department of Electrical & Computer Engineering, University of Minnesota

Objective:

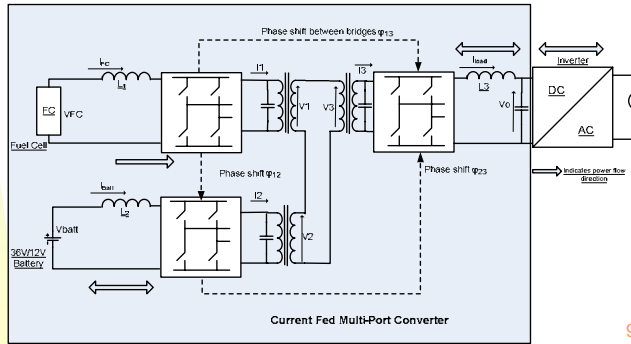
The goal of this project is to develop a compact & efficient dc/dc converter that can serve as an interface between 2 or more energy sources (e.g., Fuel cells, PV array, batteries) and the load. Such a converter is termed a multi-port converter with each port connected to a source or a load.

Characteristics of the multi-port converter:

1. A single converter interfacing with several energy sources leads to part count reduction.
2. Power flow can be controlled from different energy sources to load.
3. Each port of the converter is bidirectional in nature, for example, a battery needs a bidirectional port.
4. Applications are in hybrid vehicles, pluggable hybrids and residential homes/buildings.

Proposed converter topology

The block diagram shows two sources Fuel cell and battery interfacing with a motor drive inverter. The battery and inverter ports are bi-directional.



9

A Multi-Port DC/DC Converter

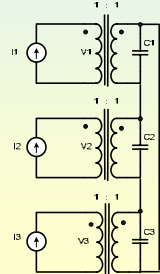
Hariharan Krishnaswami, Ned Mohan, Department of Electrical & Computer Engineering, University of Minnesota

Advantages of proposed converter topology:

1. The proposed converter circuit is the dual of the existing voltage fed multi-port converter
2. The source current ripple is reduced due to the inductor at the input.
3. High step-up of voltage possible due to the inverse topology.
4. Power flow control is by varying the phase shift between the full bridges as shown in the block diagram.
5. By appropriately selecting the turns ratio and matching the voltage levels of the sources and the load, Zero Current Switching (ZCS) can be achieved over a significant range of load and input voltage variations.

Principle of operation:

The equivalent circuit for analysis can be reduced to high frequency square wave current sources I_1, I_2 & I_3 derived from the input dc currents I_{FC} , I_{Batt} and I_{load} respectively. The capacitors are reflected to the secondary of the transformers. The resultant power flow equations between ports 1(Fuel cell), 2(Battery) and 3(Load) are given in eqn.1. The final load voltage expression after some algebra is also given in eqn. 2.



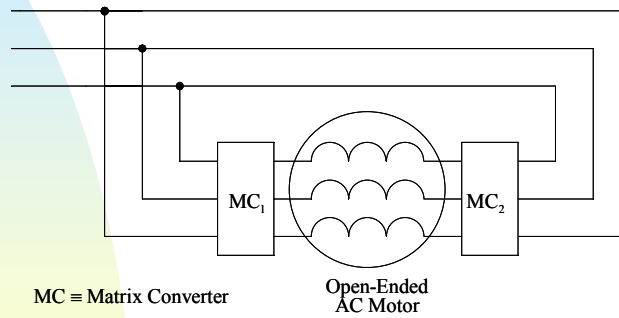
I_1, I_2, I_3 are high frequency injected wave current sources. C_2 lags I_1 by an angle ϕ_{12} . C_3 lags I_2 by an angle ϕ_{23} . C_1 lags I_3 by an angle ϕ_{13} .

$$\begin{aligned} C_1' &= \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) C_1 C_3 \\ C_2' &= \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) C_1 C_2 \\ C_3' &= \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) C_2 C_3 \end{aligned} \quad \begin{aligned} P_{13} &= \frac{I_{FC} I_O}{C_1'} \phi_{13} \left(1 - \frac{\phi_{13}}{T_s/2} \right) \\ P_{21} &= \frac{I_{Batt} I_{FC}}{C_2'} \phi_{21} \left(1 - \frac{\phi_{21}}{T_s/2} \right) \\ P_{32} &= \frac{I_{Batt} I_O}{C_3'} \phi_{32} \left(1 - \frac{\phi_{32}}{T_s/2} \right) \end{aligned} \rightarrow (1)$$

$$V_O = \frac{C_2'}{\phi_{12} \left(1 - \frac{\phi_{12}}{T_s/2} \right)} \left[\frac{V_{FC}}{C_3'} \phi_{23} \left(1 - \frac{\phi_{23}}{T_s/2} \right) - \frac{V_{Batt}}{C_1'} \phi_{13} \left(1 - \frac{\phi_{13}}{T_s/2} \right) \right] \rightarrow (2)$$

10

SiC-Based Matrix Converters for Open-Ended AC Drives for Wind Generators and Micro-Turbines



11

Advantages of SiC Devices

- Closer to an ideal switch
- Lower Losses; Higher Efficiency
- High Temperature; Compact Design

Press Release 2006

- 110 kVA SiC-based Inverter by Kansai Electric and CREE
- 50% less conversion losses compared to Si inverters



12

Power Electronic Systems

- Voltage-Link

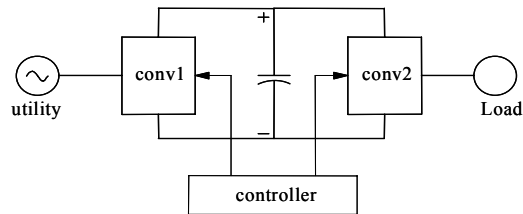


Figure 1-19 Load-side converter in a voltage-source structure.

- Current-Link

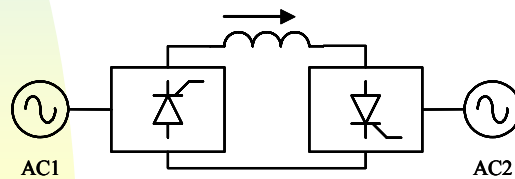


Figure 1-17 Current-link structure of power electronics interface.

13

- Voltage-Link

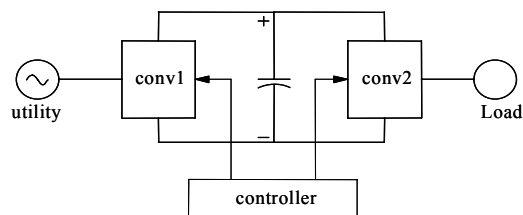


Figure 1-19 Load-side converter in a voltage-source structure.

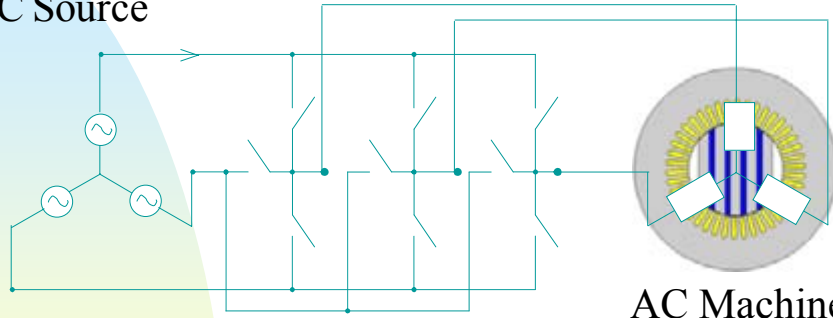
Problems with the Storage Capacitor:

1. Weight and cost
2. Reliability
3. Inrush Current at switch-on
4. Additional currents under input unbalance
5. Difficult to integrate motor and the inverter

14

Matrix Converters

AC Source



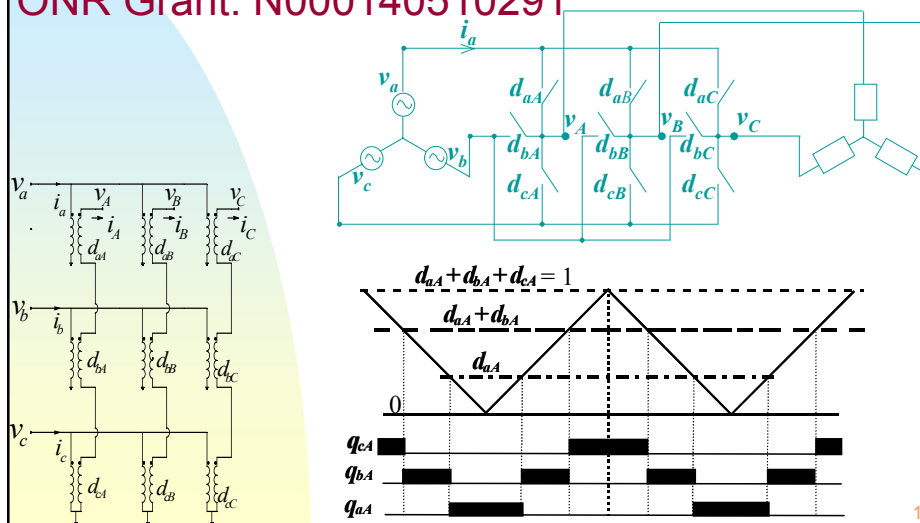
AC Machine

- Direct-Link (no energy storage)
- Ideal with SiC Devices

15

Highly Simplified Control of Matrix Converters

ONR Grant: N000140510291



16

Laboratory Demonstration

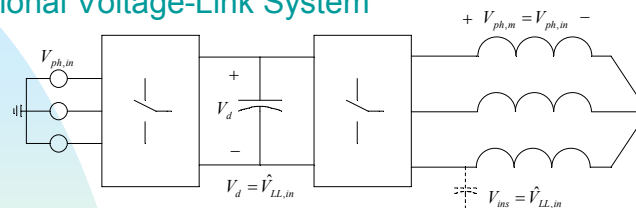


- Novel : Intellectual Property Disclosure
- Papers Attached
 - IEEE-PESC 2006 and IEEE-APEC 2006

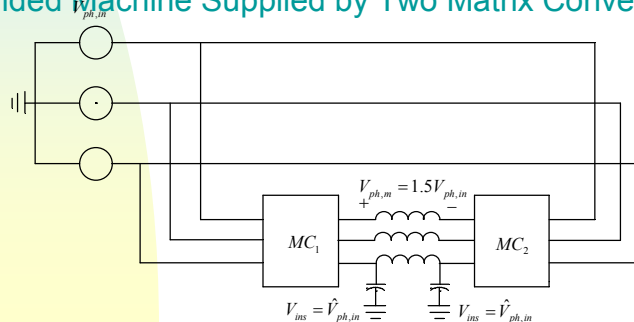
17

Nearly Doubling (1.876) the Drive Output

Conventional Voltage-Link System



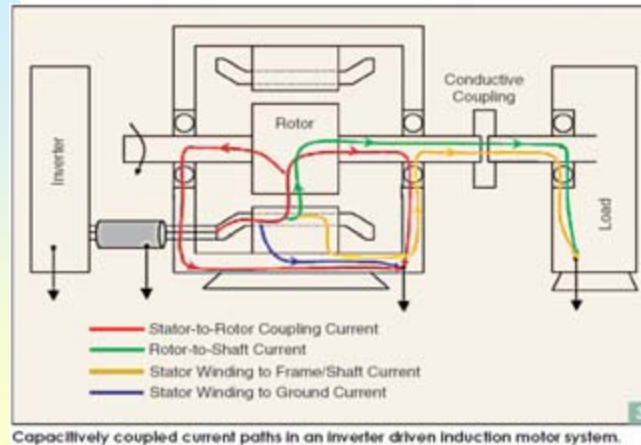
Open-Ended Machine Supplied by Two Matrix Converters



18

Switching of Common Mode Voltages Results in Bearing Currents

- SiC devices will make this more acute

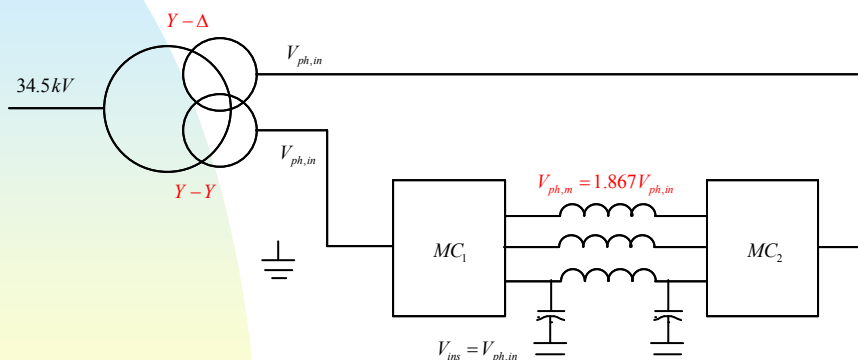


Source: Prof. Gopakumar, IISc

19

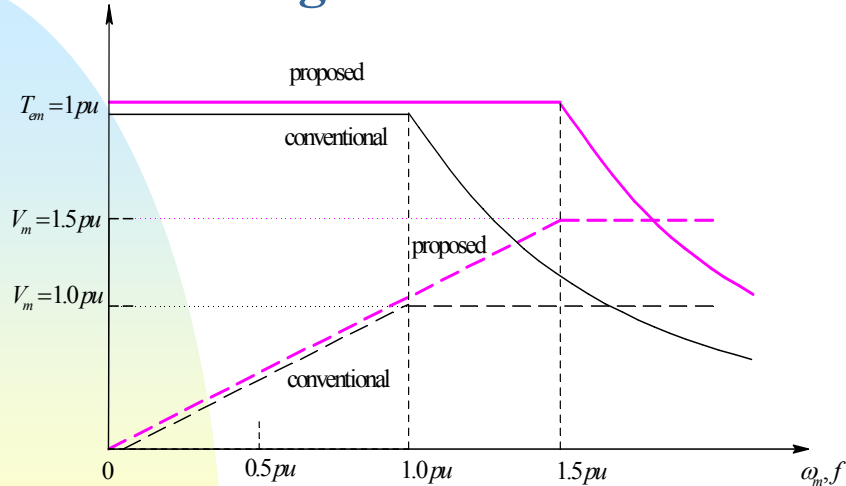
Isolated Inputs with 30 deg phase shift

- Power Capability increases to 186.7%
- Ideal for Wind Electric Systems as shown below



20

Capability Curves with Common Mode Voltages Eliminated*



* Extended to 1.867 pu if input voltages at two sides are isolated from each other and 30 deg phase shifted 21

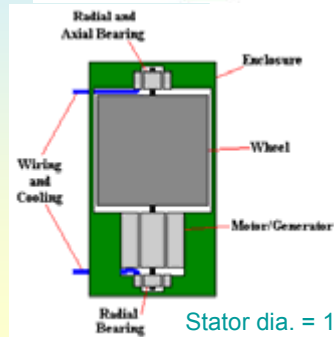
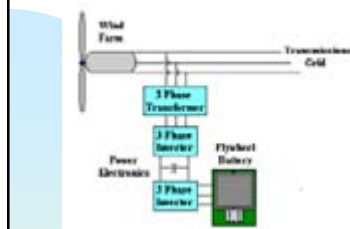
Simultaneous Benefits

1. Increases available voltage to 150%*
 - rated torque up to 150%* of the rated speed
 - 150%* power output capability
2. Bearing currents are eliminated
3. Slot insulation reduced by a factor 1.73
4. Comparable efficiency at the rated power?
5. Smaller current ripple?
6. Input power factor is controllable
7. Elimination of Energy Storage Capacitor
 - Bulky, inrush current, current under unbalance

* 186.7% if isolated inputs and 30 phase shifted

22

Flywheel Battery

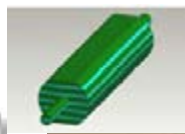
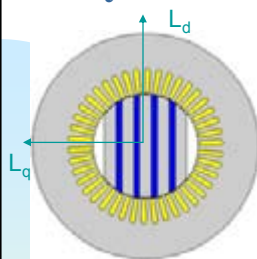


Stator dia. = 19 in
Length = 42 in

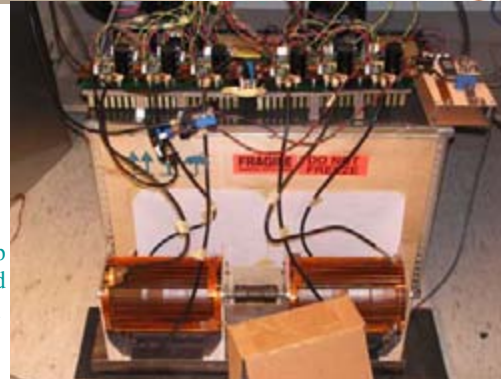
- Objectives of Flywheel Battery
 - ◆ Firm up wind resources on a short-term basis
 - ◆ Interface with alternative generation
 - ◆ Voltage support to the transmission grid
- Flywheel Battery Components
 - ◆ Wheel – made with lightweight composites
 - ◆ Enclosure – designed to maintain a low windage loss environment
 - ◆ Magnetic Bearings – used for low rotational loss
 - ◆ Motor/Generator – charges and discharges the battery
 - ◆ Power Electronics and Controls – Control the Motor/Generator and Magnetic Bearings
- Flywheel Battery Specifications
 - ◆ Power = 2 MW
 - ◆ Energy = 100 kWhrs
 - ◆ Speed range = 7,500 to 15,000 rpm
 - ◆ High in-out efficiency
 - ◆ Lowest cost possible

23

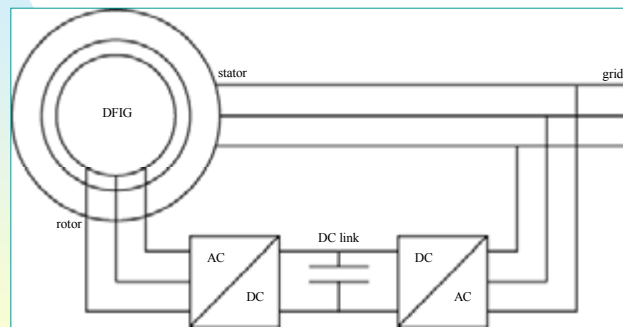
Synchronous Reluctance Motor/Generator



- Synchronous reluctance machine
 - ◆ Low cost and no loss at idle
 - ◆ Relatively low rotor loss
 - ◆ High rotor operating temperature of 250 °C (Most important)
- Large ratio of L_d to L_q inductance
- Axial Laminated small-scale rotor designed due to high L_d/L_q ratio
 - ◆ Machines tested in back to back setup
 - ◆ Machine able to operate at high speed
 - ◆ Due to thickness hot rolled steel used for magnetic layers

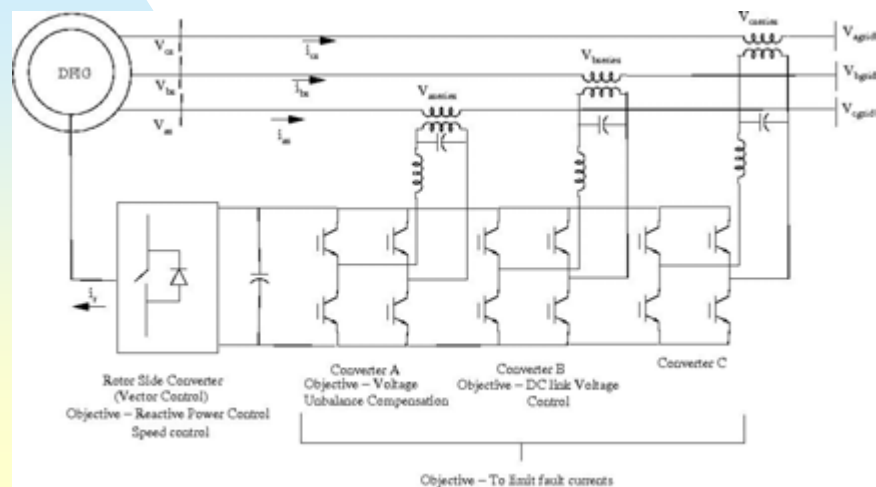


Control of a Doubly-Fed Induction Wind Generator Under Unbalanced Grid Voltage Conditions



25

Application of Series Compensation in Wind Power



26

Innovative Methods to Triple Efficiencies of FAN Motors



(a)



(b)

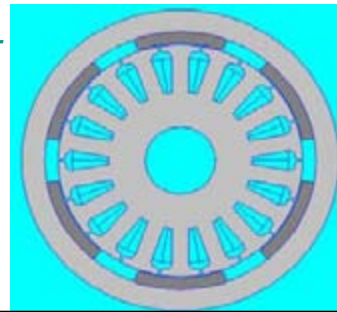
Present FAN motor

- Max Efficiency = 30%
- Starting Problem
- Poor Power Factor
- Pulsating Torque
- Low efficient speed regulator
- Efficiency goes further down at low speed

	Speed Setting	Input Power (W)	Efficiency
Fan 1	High	118.81	28%
	Mid	91.4	26%
	Low	67.69	14%
Fan 2	High	56.2	31%
	Mid	43.17	26%
	Low	35.82	21%
Fan 3	High	51.86	29%
	Mid	34.12	18%
	Low	25.97	11%

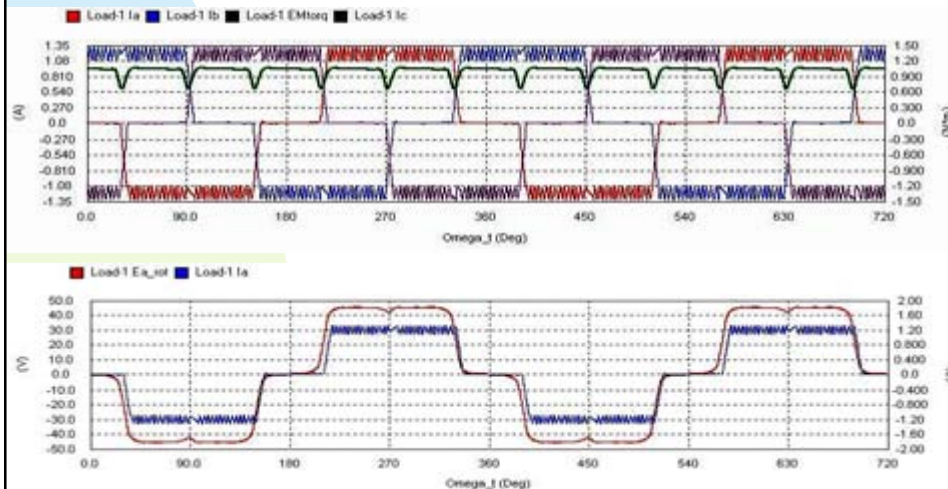
Proposed FAN motor

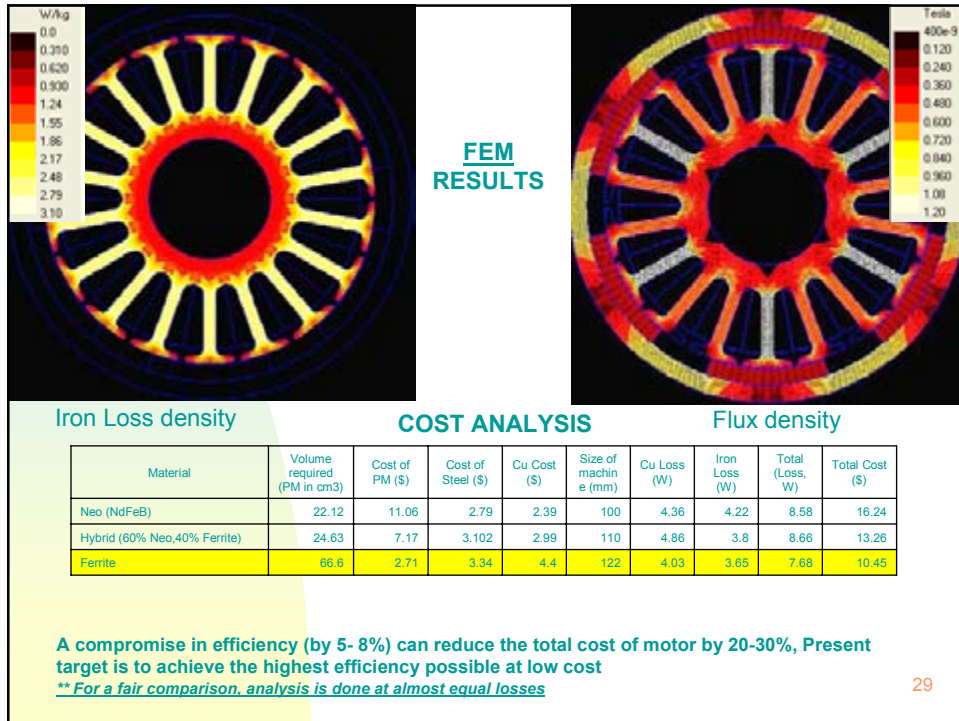
- High Efficiency (close to 90%)
- Power factor close to 0.9 (Design dependent)
- Can be wound with the available winding technology for AC machine
- Easy to manufacture, small size, ease in winding (Outer rotor)
- Low cost, readily available ferrite magnet as permanent magnet
- Low assembly cost and not a multi-step process



SIMULATION RESULT : Outer Rotor Configuration

Torq	RPM	Freq	P_in	P_out	P_loss	VA	P.F.	Effic	CktVs	PwmIndx	AF_ang
(N-M)	(Rpm)	(Hz)	(W)	(W)	(W)	(VA)	(PU)	(PU)	(V)	(PU)	(deg)
0.966	1000	50	108.7	101	7.68	123.2	0.88	0.93	165	1	0





Integrated Modules Simplify Systems Design

By: John Mookken
SEMIKRON USA

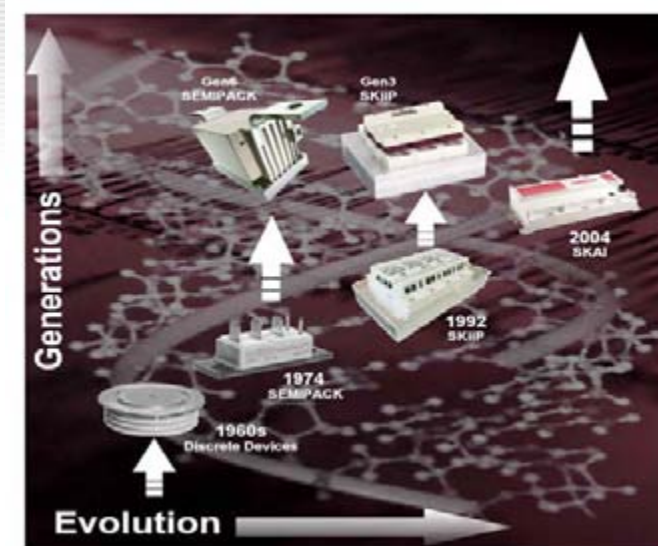
8/24/06

Advanced Power Electronics DE Workshop
Sacramento, CA

11/2/2006

1

Evolution of the Power Module



11/2/2006

2

Why Integrate?



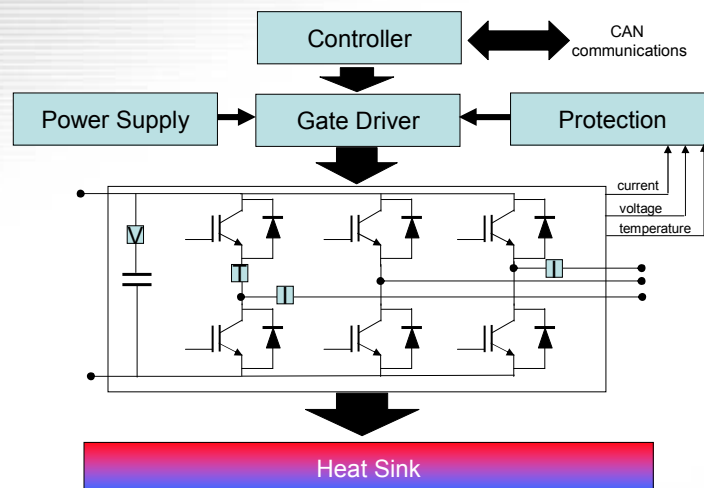
- ✦ Shorter time to market
- ✦ Easier system design & assembly
- ✦ Economical
- ✦ Reduced number of components
- ✦ Customized solution without the custom pricing
- ✦ Standard Interface
- ✦ Commonality or standard platform



11/2/2006

3

SKAI: Block diagram



11/2/2006

4

SEMIKUBE



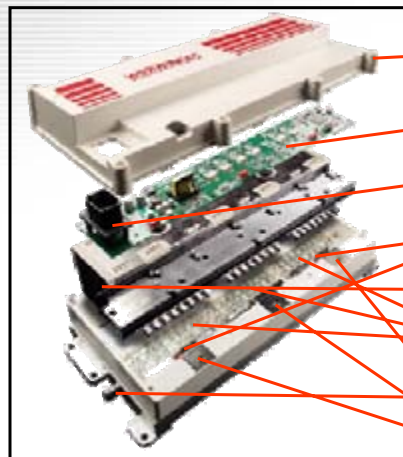
- « A 390A rectifier + inverter into a 400mm cube »^(*)
- Includes all sensing (current, voltage, temperature)

(*) actual max dimensions are 412 x 435 x 380

11/2/2006

5

SKAI: Components



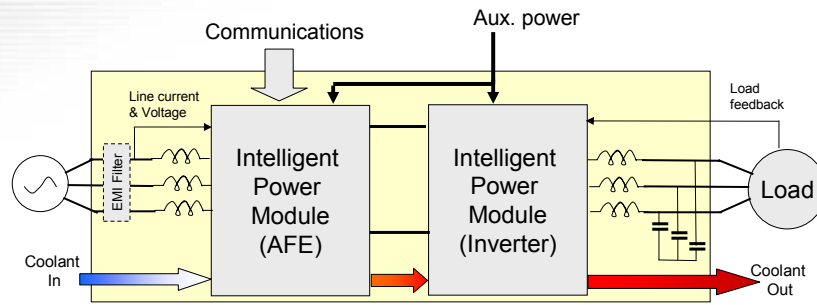
1200/600V IGBT SKAI module

- Cover
- Driver / Controller board
- Sealed 14 pin connector
- Current sensors
- DC Filter Capacitor
- DCB /w Si devices
- Heat sink
- Power terminals

11/2/2006

6

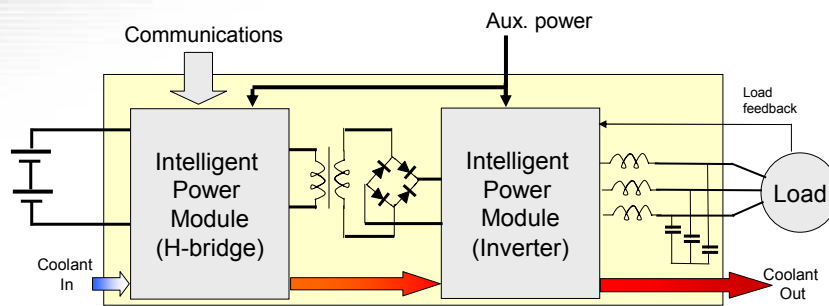
AFE / Inverter Example



11/2/2006

7

DC/DC Example



11/2/2006

8

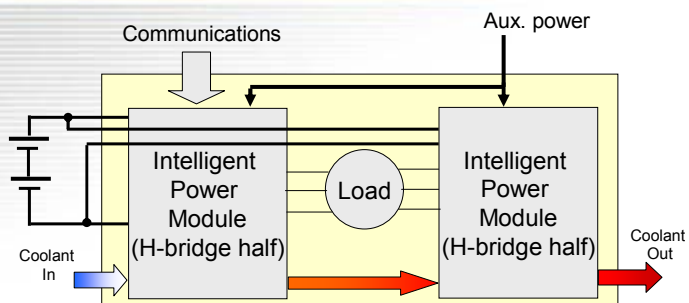
Example Systems



11/2/2006

9

H-Bridge Example



Dual modules assembled
on motor end bell / heat sink



11/2/2006

10

SKAI: Heatsink Options



Air



Liquid



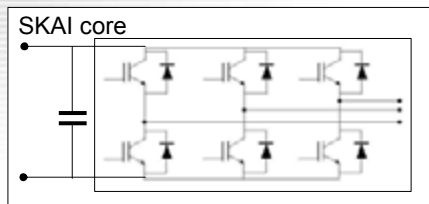
Metal Plate

Options available with
LV or HV SKAI modules
Modules can also be assembled
on custom heat sinks on request

11/2/2006

11

IPM: Solution



Application Specific
SKAI module

Choose Std. SKAI options

Heat sink
Driver/Controller
Current Sensors

Customer adds
Application software

11/2/2006

12

www.SEMIKRON.com



**Thank you
for your attention**

**Questions or
Comments ?**

John Mookken
John.mookken@semikron.com



11/2/2008

13



Distributed Energy

Advanced Power Electronic Interfaces

Ben Kroposki
National Renewable Energy Laboratory



Distributed Energy (DE) Applications



Advanced Turbines



Reciprocating Engines



Photovoltaics



Wind



Fuel Cells

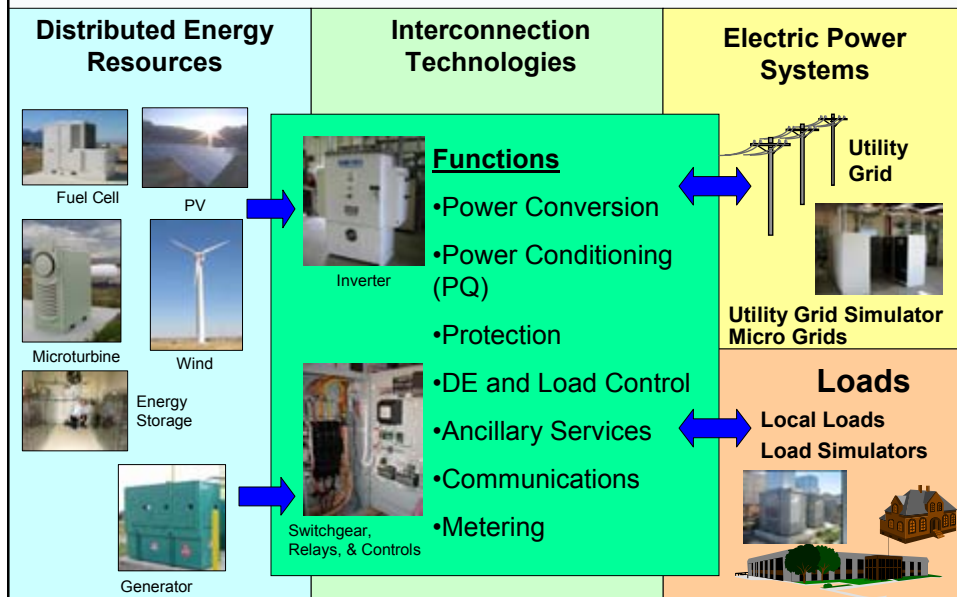


Microturbines

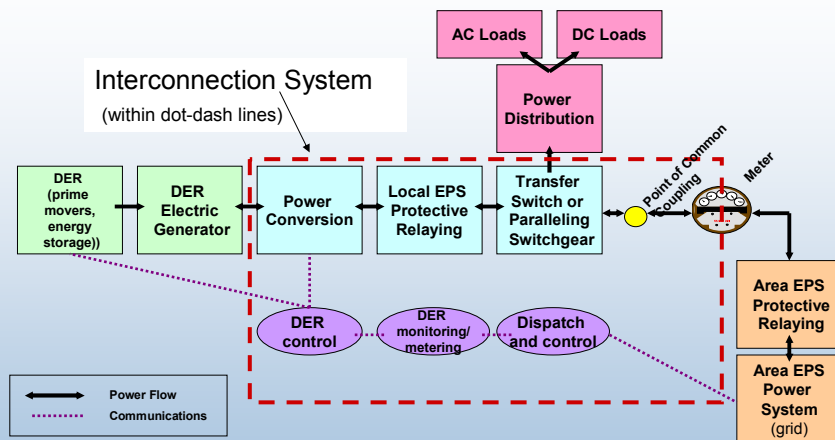
- Energy Management
- Electricity to Grid
- Baseload/CHP
- Peak/Demand Reduction
- Reliability/Backup Power
- Power Quality
- Grid Ancillary Services



DE Grid Interconnection

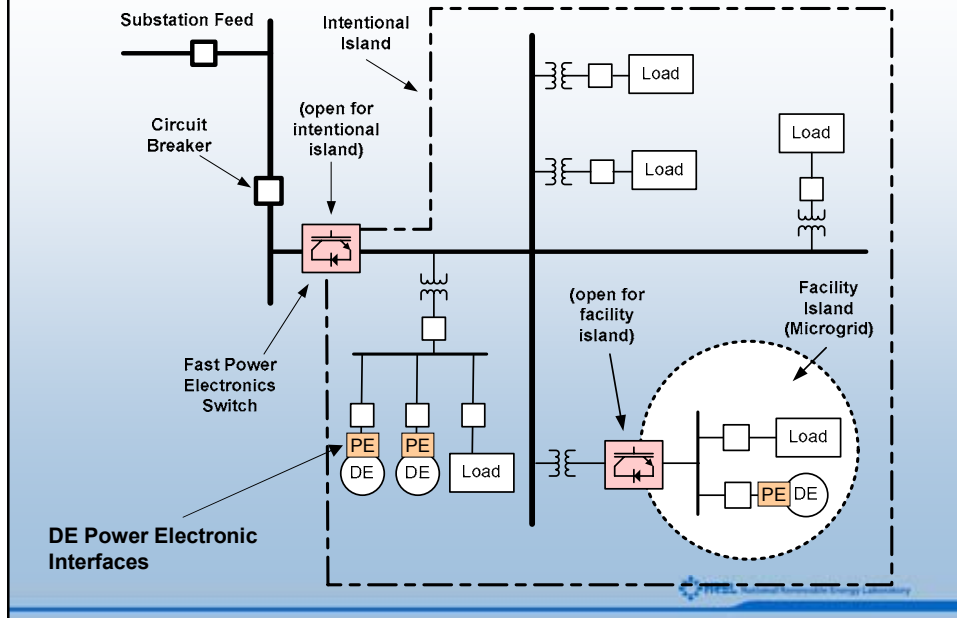


Interconnection System Functional Block Diagram



The interconnection system (within the dotted line) is designed to handle the power between and serve as the communication and control gateway among the DER, the Area EPS and the customer loads. Workshops with industry provided a forum for furthering this activity and several manufacturers are working on developing and validating standardized, advanced, universal interconnection technologies [NREL/SR-560-32459].

PE Applications with DE Systems

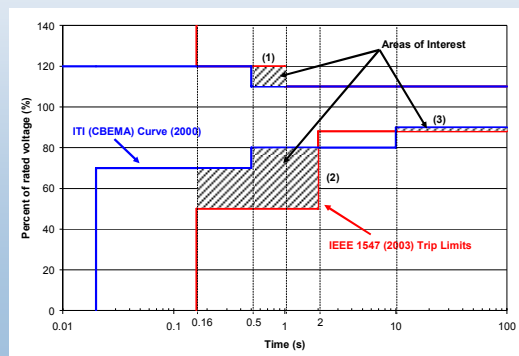


Benefits of Power Electronic Interfaces for DE

- Improved Operating Efficiencies
 - Variety of topologies for power electronic interfaces can improve conversion efficiencies
 - Allow for variable speed operation of internal combustion engine DG

Benefits of Power Electronic Interfaces for DE

- Power Quality
 - Harmonic Control
 - Power for Sensitive Loads

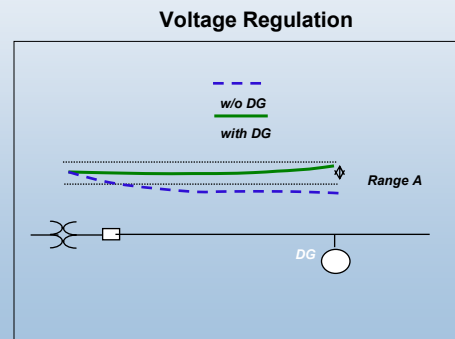
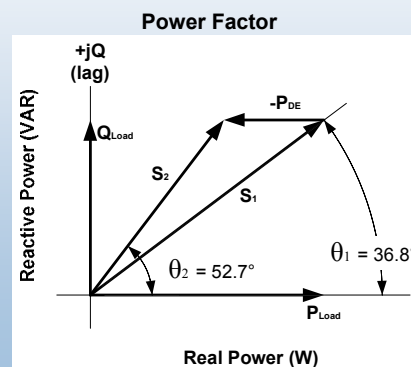


- **Sustained Interruptions** – DE can provide backup power if designed to do so. This may improve reliability if designed and operated properly.
- **Voltage Regulation** – DE can provide voltage regulation if allowed. This can also be a limiting factor as to penetration on a feeder.
- **Harmonics** – There are harmonic concerns with both rotating and inverter based DE.
- **Voltage Sag** – DE may be able to help keep voltage up, but only if allowed to do so.

NREL National Renewable Energy Laboratory

Benefits of Power Electronic Interfaces for DE

- VAR Support and Voltage Regulation



NREL National Renewable Energy Laboratory

Benefits of Power Electronic Interfaces for DE

- Reduced DE Fault Currents
 - Ability to recognize di/dt of fault currents and clamp or disconnect
 - This allows for use of DE on networked systems and easier integration with protection system
- Interoperability with a variety of other DE sources
- Standardization and Modularity
 - High volume manufacturing techniques

IEEE 1547 Series Standards

1547-2003 Standard for Interconnecting Distributed Resources with Electric Power Systems

1547.1-2005 Conformance Test Procedures for Equipment Interconnecting DR with EPS

Current Projects

P1547.2 Application Guide for IEEE 1547 Standard for Interconnecting DR with EPS

P1547.3 Guide for Monitoring, Information Exchange and Control of DR

P1547.4 Guide for Design, Operation, and Integration of DR Island Systems with EPS

P1547.5 Guidelines for Interconnection of Electric Power Sources Greater Than 10 MVA to the Power Transmission Grid

P1547.6 Recommended Practice for Interconnecting DR With EPS Distribution Secondary Networks

Future Projects

DG Specifications and Performance

Guide for Grid/DG Impacts Determination

Interconnection System Certification Guide

Power Electronic Interface Specifications for DR

Covers IEEE 1547 Section 4.3.2

Covers IEEE 1547 Section 4.1.4

IEEE 1547.1 Interconnection Tests have been incorporated into UL 1741 for product certification

DE Interconnection Equipment Certification Approach

IEEE 1547

Interconnection System Requirements

- Voltage Regulation
- Grounding
- Disconnects
- Monitoring
- Islanding

IEEE 1547.1

Interconnection System Testing

- O/U Voltage and Frequency
- Synchronization
- EMI
- Surge Withstand
- DC injection
- Harmonics
- Islanding
- Reconnection

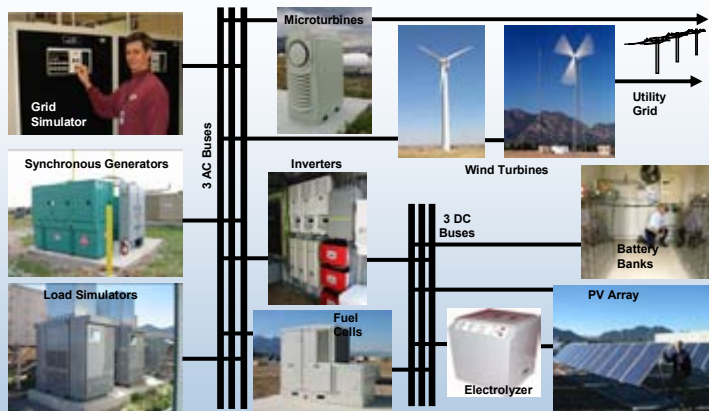
UL 1741

Interconnection Equipment

- Construction
- Protection against risks of injury to persons
- Rating, Marking
- Specific DR Tests for various technologies



NREL DER Test Facility



- Test Systems up to 200kW
- Natural Gas on site
- All DER Technologies
- Full IEEE 1547.1 testing





Modular and Scalable Power Converters in the UPS Industry

Ian Wallace
Eaton Corporation, Innovation Center

© 2006 Eaton Corporation. All rights reserved.

Content

- Eaton Overview
- Eaton Electric – UPS Business
- Today's Critical Power Systems
- UPS Market Drivers
- Modern UPS converter technology
 - Design for reliability
 - Scalability & Redundant Systems for high 9's reliability
 - Topology and control
- Modularity : Power Control
 - Two examples:
 - 9390 UPS power / control structure
 - Blade UPS modularity / power density.



2

© 2006 Eaton Corporation. All rights reserved.

Eaton Overview

Electrical



Fluid Power



Automotive



Truck



- A global diversified industrial manufacturer
 - 2005 sales: \$11.1 billion
- A leader in:
 - **Electrical power quality and control**
 - Fluid power systems
 - Automotive engine air management
 - Intelligent drivetrain and safety systems for trucks & heavy vehicles



3

© 2006 Eaton Corporation. All rights reserved.

What Markets Does Eaton Serve?



**Industrial Facilities
& Utilities**



Residential

Telecom / Data Centers



Commercial/Institutional Facility



4

© 2006 Eaton Corporation. All rights reserved.

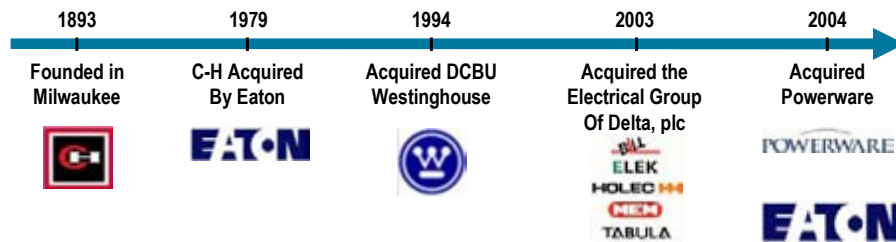
Eaton Business Segment – Electrical

\$3.7 billion sales in 2005.

14,000 employees, 57 factories in 19 countries

→ electrical control, power distribution, UPS, industrial automation products & services, ...

- [Power Quality Systems](#)
- [Power Component & Systems](#)
- [Electrical Components / Industrial Control](#)



5

© 2006 Eaton Corporation. All rights reserved.

Eaton Electrical – Power Quality Systems

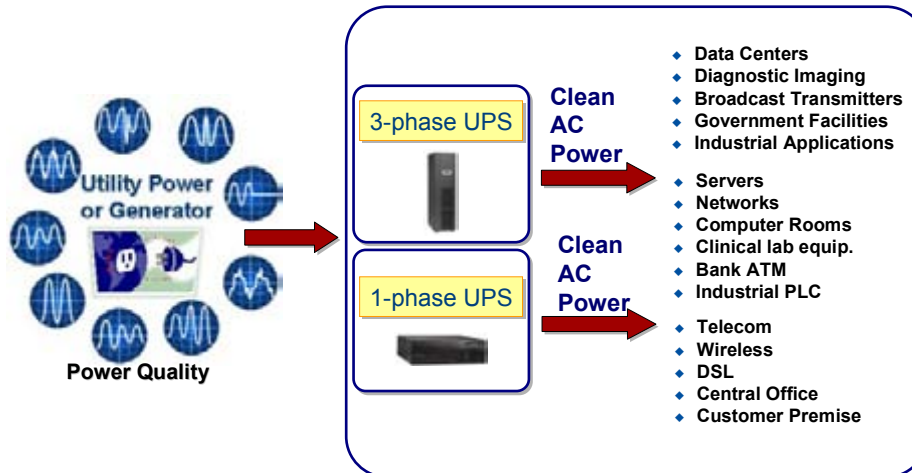
- Mission Critical UPS systems for highest power reliability (emergency back-up)
- Single phase & three phase UPS Modular, transformerless up to 160 kVA
- Industrial & Rack-mount UPS
- Sag Ride-through Power Conditioner
- Active and Passive Harmonic Filters
- Static Transfer Switches
- Advanced Battery Management
- Integration & Global Service Support



6

© 2006 Eaton Corporation. All rights reserved.

UPS Systems – Key to 24/7 Daily Life



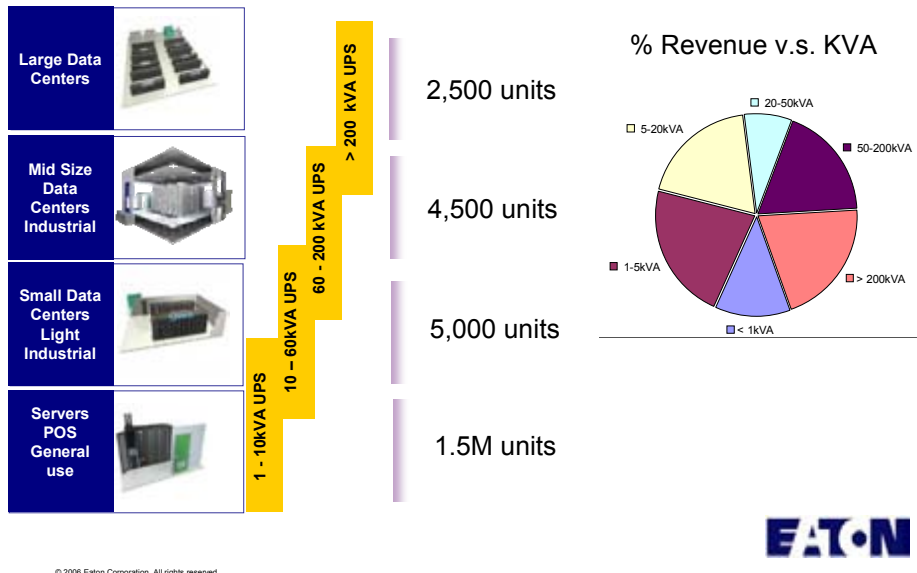
EAT•N

Eaton UPS Market Position

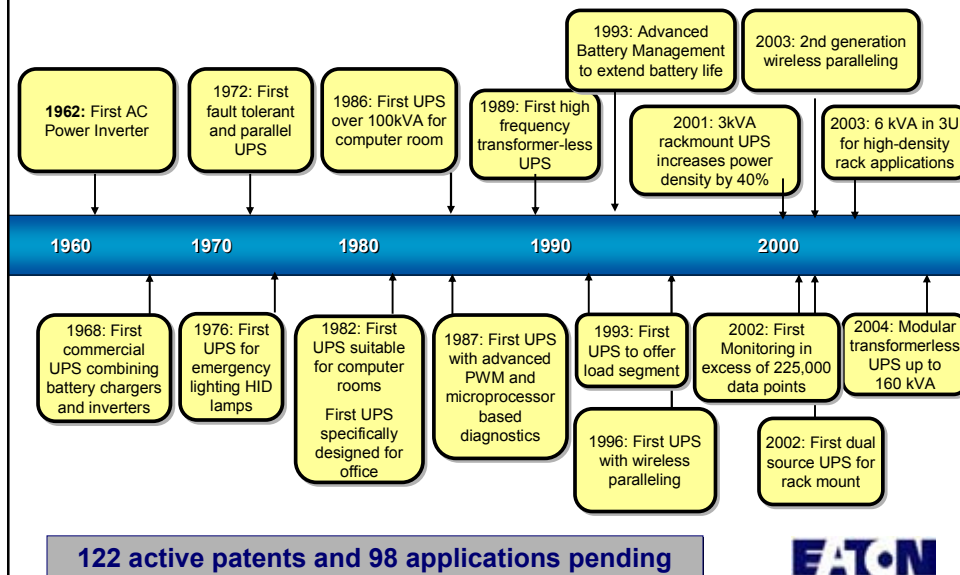
- Eaton is an industry leader and globally recognized provider of innovative, effective power quality solutions, delivered under the Powerware brand
 - Power protection revenue ~ \$900M
 - #1 in worldwide UPS sales above 5 kVA
 - #2 in worldwide UPS sales at and under 5 kVA
 - Total volume: >1.5 million units / year
 - 3-Phase volume: ~ 7,000 3-phase units / year
 - Large installed base of more than 45,000 3-phase UPSs worldwide

EAT•N

Eaton UPS Market Position



Eaton UPS Technology Leadership

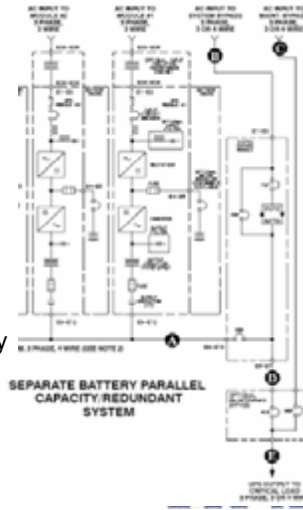


Today's Critical Power Systems

- Main elements of Critical Power systems

Measured by 9's of availability

- Multi-source / storage systems
 - Utility (single / multiple feeds)
 - DC Batteries
 - AC Generator
 - DC Flywheels & ultra capacitors
- UPS – one element in high 9's system
 - System design for redundancy
 - UPS paralleling for redundancy and capacity
 - Static UPS bypass
 - Manual / Maintenance bypass



11

© 2006 Eaton Corporation. All rights reserved.

Today's UPS Market Drivers

- Power quality under utility disturbances
- Flexible architectures for high 9's reliability
 - Parallel redundancy
 - Expandable for capacity
- High system reliability, MTBF
 - No single point failure

Interruption Costs	
Business / Industry	Cost
Paper Industry	\$10,000 – \$30,000 / event
Textile Industry	\$10,000 – \$40,000 / event
Data Processing	\$10,000 – \$40,000 / event
Plastics Industry	\$10,000 – \$50,000 / event
Semiconductor Industry	\$10,000 – \$50,000 / event
Automotive Manufacturing	\$15,000 / event
Air Traffic Control	\$15,000 / minute
Office Building	\$22,000 per 1200 kVA of critical load
Broadcast Facility	\$100,000 / 30 minutes

Source: EPRI - Power Quality Applications Guide for Architects and Engineers

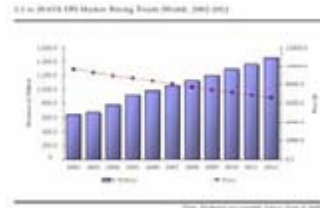
EATON

12

© 2006 Eaton Corporation. All rights reserved.

Today's UPS Market Drivers

- Low installation cost
- Low operating cost - high efficiency
- High power quality utility interface
- High power density
- Serviceability – MTTR
- Multi - power source compatibility
- Global sourcing and manufacturing
- Monitoring, diagnostics & prognostics
- Maintenance services



- Revenue → ~10% growth / yr
- Price → ~ 4% \$ reduction / yr



13

© 2006 Eaton Corporation. All rights reserved.

Today's UPS Technology

- Market drivers are addressed by:
 - Design for reliability
 - Scalable multi-unit operation for high 9's architectures
 - Elimination of single point failures
 - Fault identification and selective trip
 - Power module topology and design
 - Converter modulation and control techniques
 - Modular power and control modules
 - Build a scalable product line via modularity



14

© 2006 Eaton Corporation. All rights reserved.

Converter Design for Reliability

- HALT: Highly Acceleration Life Test
 - Thermal cycling, rapid thermal transitions, load cycling ...
 - Identify weakest link via product destruction
- HASS: Highly Accelerated Stress Screen
 - Ongoing production screening.
 - Verify production units continue meet reliability objectives
- MTBF targets
 - UPS Converter > 60,000 hrs
 - Parallel redundant systems > 300,000hrs



EAT•N

15

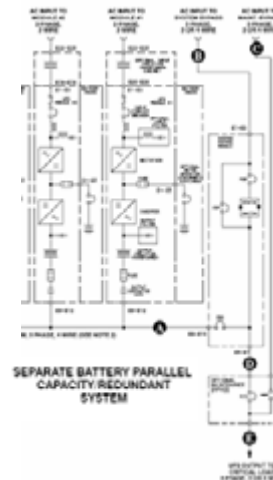
System Level Modularity and Scalability

System Level Drivers:

- Key to achieving high 9's of reliability
 - parallel for redundancy
- Parallel for capacity - load expansion

Enablers

- Eliminate single point failure
 - power & controls
- Communication less paralleling
Hot Sync™ Technology
- Fault location detection



EAT•N

16

Power Availability for Mission Critical Apps

The power grid typically provides 3 - 9's, or 99.9% reliability. This equates to almost 9 hours of downtime per year. 'High 9's' are generally considered to mean 6 - 9's and above.

<u>9's</u>		<u>Downtime per Year</u>
3	99.9%	8 hr, 45 min, 36 sec
4	99.99%	52 min, 33.6 sec
5	99.999%	5 min, 15.36 sec
6	99.9999%	31.5 sec
7	99.99999%	3.15 sec



EAT•N

17

© 2006 Eaton Corporation. All rights reserved.

Increasing Availability of Power

Parallel redundant systems offer substantially increased availability

- Can provide "high 9's" availability
 - The best opportunity to increase availability at the source
- There are two fundamental technical issues to solve for parallel redundant power systems
 - Control and stability of two or more AC power sources being paralleled
 - Elimination of all potential system-level single-point-of-failure
- The resulting performance is depending on design implementation of:
 - Load sharing
 - Fault isolation

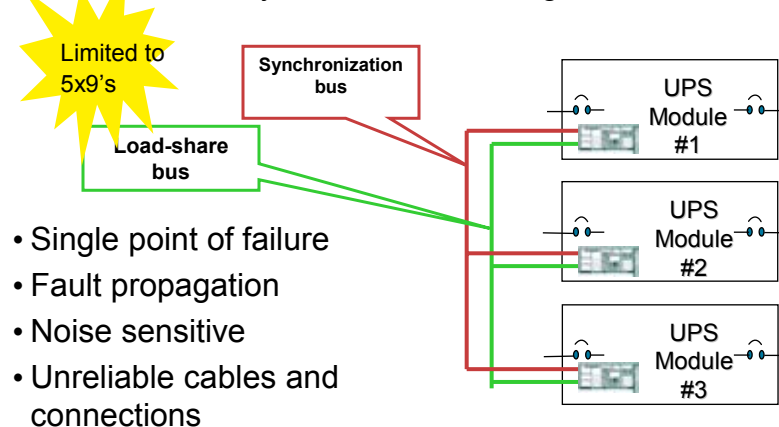
EAT•N

18

© 2006 Eaton Corporation. All rights reserved.

Legacy Systems

Load share and synchronization wiring between modules

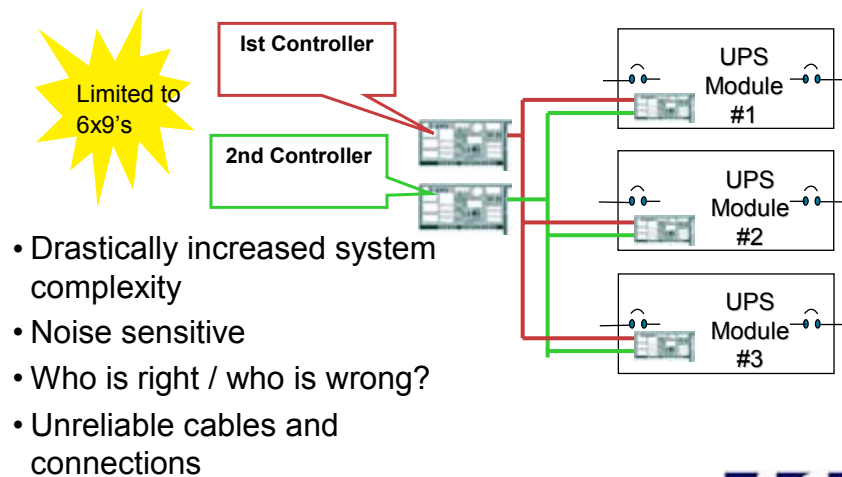


EAT•N

19

Legacy Systems

Master / redundant controllers



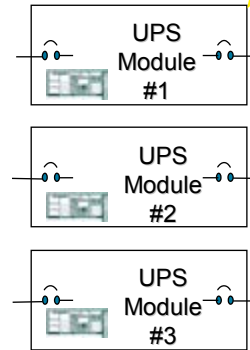
EAT•N

20

Powerware Hot Sync™

“Wireless” paralleling of AC sources

- Reduced system complexity
- No single point of failure
- Modules are identical
- Modules act as peers
- No Primary / Secondary relationship
- No “Main Intelligence Module” required



Can provide
7x9's

EAT•N

21

© 2006 Eaton Corporation. All rights reserved.

Powerware Hot Sync™

Hot Sync™ provides automatic load sharing and selective tripping in a parallel system.

- No control wiring required between modules for current sharing or selective tripping
- Designed to share load with any power source, including the utility
- Provides flexibility and scalability
- The UPS can be decentralized into the server equipment and still operate in parallel with additional server racks
- Ideal for distributed power system applications

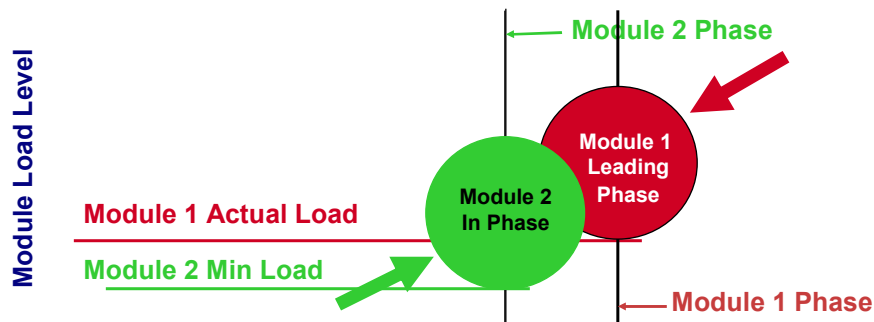
EAT•N

22

© 2006 Eaton Corporation. All rights reserved.

Hot Sync™ Load Share Pictorial

Parallel load share control algorithm constantly drives the module to carry the least amount of load. This will drive Module 1 back in Phase with Module 2.



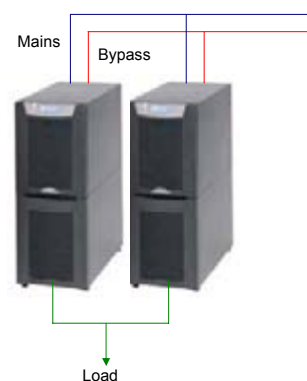
- Eaton developed technology – US patents #5,745,356 & 5,745,355



23

Hot Sync™ Benefits

- Can provide up to 7x9's availability of power
- Ultimate scalability with no additional controls
- Modules in Parallel:
 - are absolute peers
 - have absolute autonomy
 - use 100% intrinsic components
- Seamless transition from capacity to redundancy
- Increased serviceability



Direct extension to autonomous operation of grid interface
Scalable DG converters

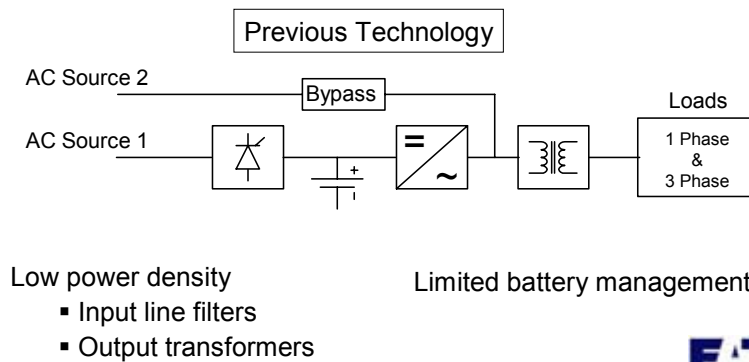


24

© 2006 Eaton Corporation. All rights reserved.

Input Power Quality and Efficiency

- Online UPS: maximum protection from utility disturbances
- Source 3-wire and 4-wire loads.
- Maintain efficiency > 95%
- Manage battery lifetime



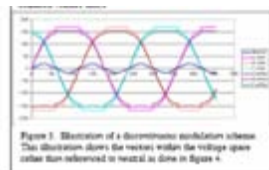
EAT•N

25

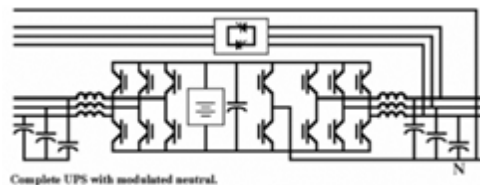
© 2006 Eaton Corporation. All rights reserved.

Input Power Quality & Efficiency

- Active front end IGBT Converters (10-200kVA) improve:
 - Power quality, grid and generator interface
- Transformerless Double-Conversion UPS Topology
 - Elimination of distribution transformers (4 wire source / loads)
 - Novel modulation scheme for 4 leg inverters
 - Maximized DC bus utilization to maintain efficiency
 - Ultra small filter size: optimization of magnetic component & switching frequency



Increased power density



26

© 2006 Eaton Corporation. All rights reserved.

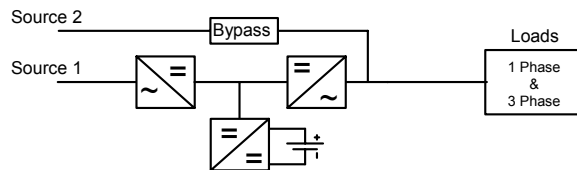
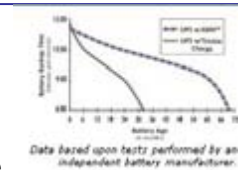
Battery Management

• Battery Systems

▪ Advanced Battery Management:

- 3 stage charging technique - doubles battery life & optimizes battery recharge time.
- Prognostics / Diagnostics- provides up to 60-day advanced notification of the end of useful battery life.

• ProActive Service – max uptime via 24x7 corrective maintenance, remote monitoring



EAT•N

27

© 2006 Eaton Corporation. All rights reserved.

Modular Product Approaches

• Motivation

- Build a product line to cover wide power range
- Maintain low cost and high reliability
- Enable N+1 redundancy: high MTBF
- Serviceability - Maintain low MTTR

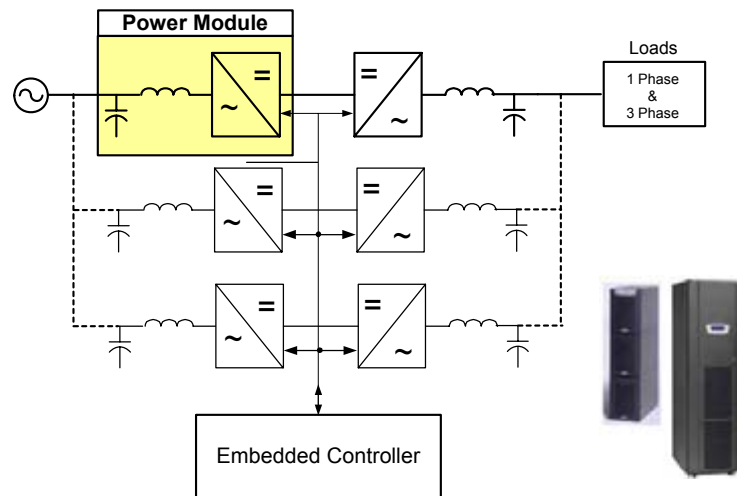
• Where is the appropriate division and extent of modularity ?

EAT•N

28

© 2006 Eaton Corporation. All rights reserved.

Modular Power Block Approach



29

© 2006 Eaton Corporation. All rights reserved.

Rack Mount Modular UPS

• BladeUPS:

- 12-60 kW modular, rack-based N+1 power protection



• Features:

- Very compact design, high power density (6U)..
- Highest power density on the market
- No single points of failure in system
- Mounts in any industry standard rack
- Each module is autonomous - establishes peer-to-peer relationship when paralleled.
- Hot Sync reliability, redundancy, and scalability
 - Scalable from 12kW to 60kW
- High Efficiency up to 97%
- Features hot-swappable battery modules and electronics
- Advanced Battery Management (ABM)



30

© 2006 Eaton Corporation. All rights reserved.

EATON

Thank You



Presentation for:

California Energy Commission

REVOLUTIONIZING THE WAY THE WORLD USES ELECTRICITY™



Presenter



Perry Schugart

Director, Power Converter Products
12 years, Power Semiconductors
9 years, Power Electronic Systems
Bachelor of Science, Physics

pschugart@amsuper.com

Phone: +1.262.901.6036

Fax: +1.262.901.0104

Distributed Energy Applications Leverage High Volume, Modular Power Converters

***Advanced Power Electronic Interfaces
for DE Workshop***

Sacramento, CA

August 24, 2006

Modular & Configurable High Power Converters

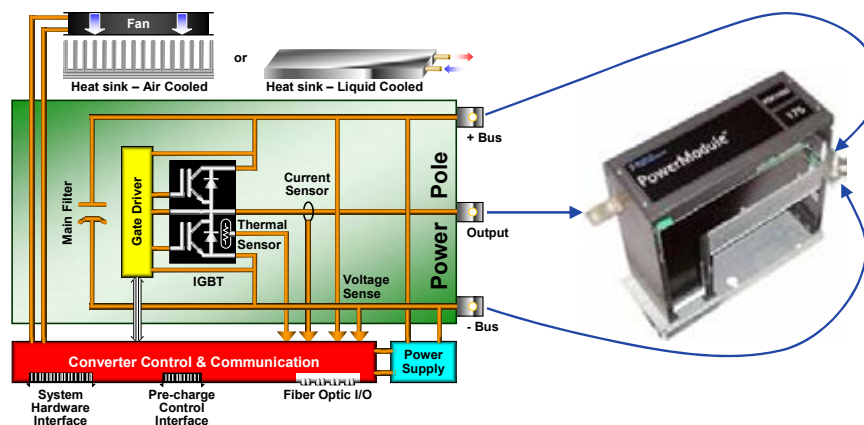


- Programmable Electronic Building Blocks (PEBB)
- Configurable for different power conversion needs
- High volume, modular architecture
- Rapid product development

3

American Superconductor

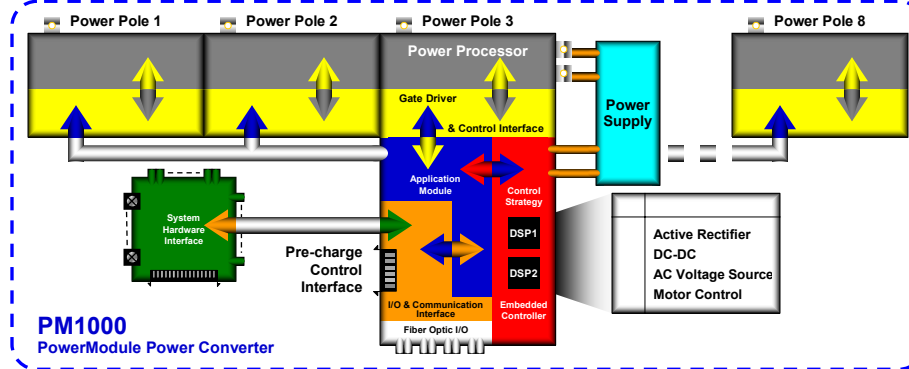
Integrated Modularity with Power Pole Architecture



4

American Superconductor

PM1000 – Configurable Power Converter

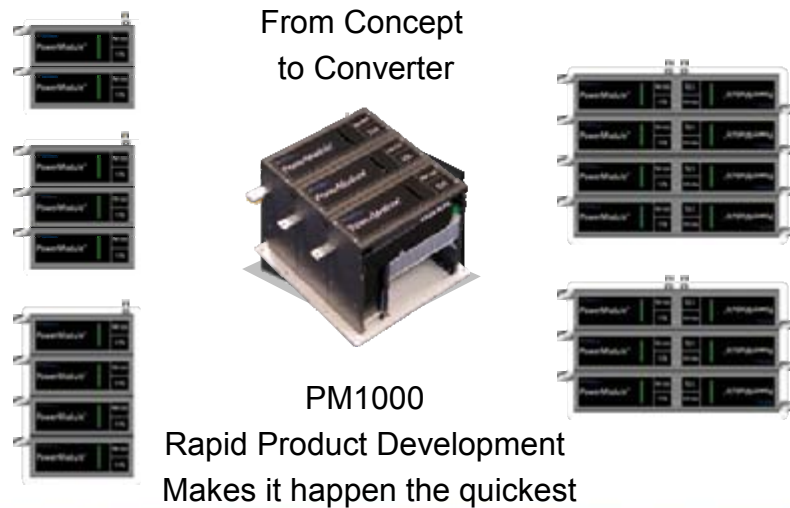


- Analog and digital I/O
- Dual digital signal processors
- Fiber optic communications
 - CAN, asynchronous serial
- Gate drivers
- Auxiliary power supply
- Cooling
 - Liquid & air

5

American Superconductor

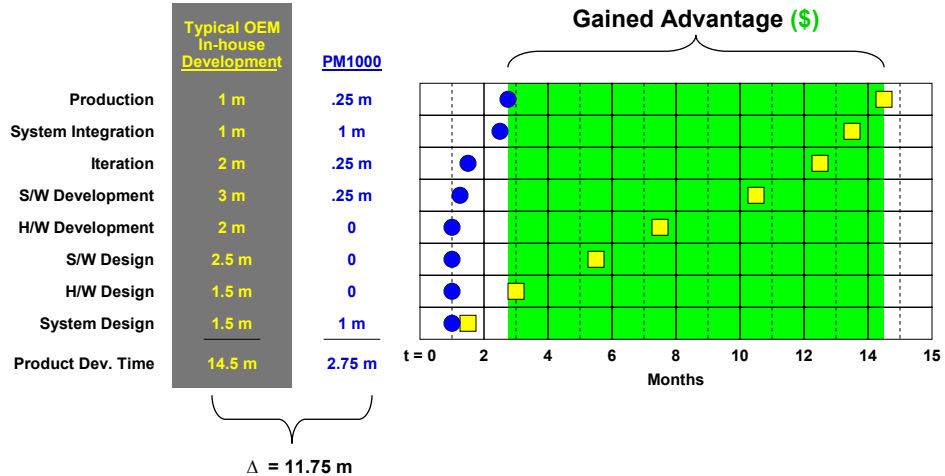
Rapid Product Development



6

American Superconductor

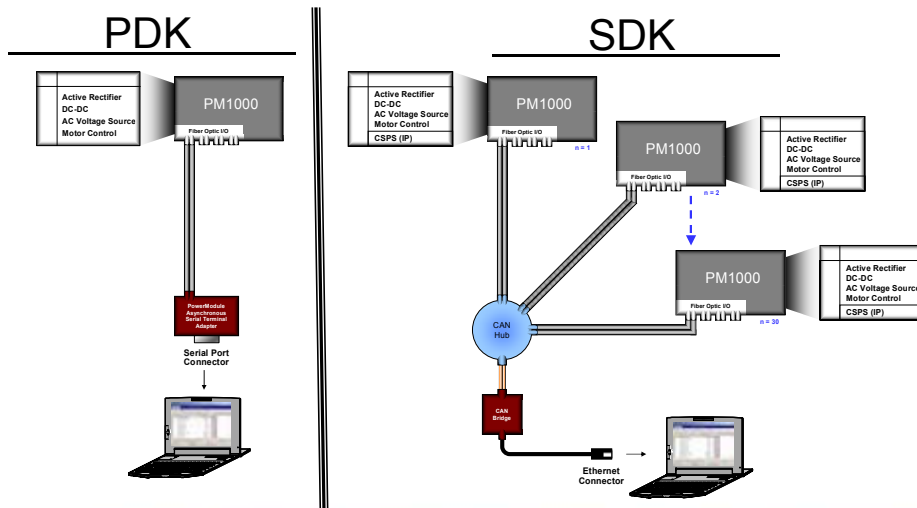
PM1000 Rapid Product Development Benefits



7

American Superconductor

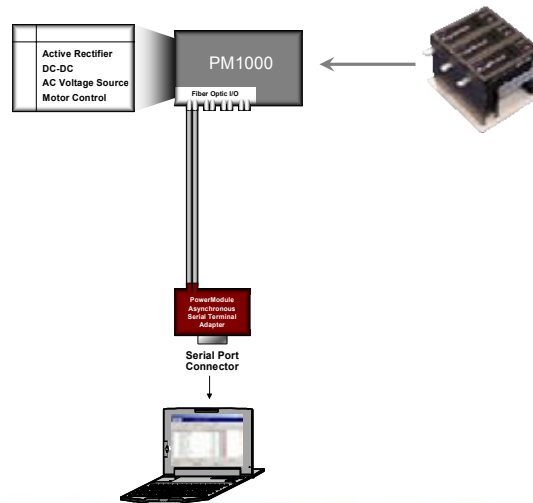
Simplify Power Electronic System Development



8

American Superconductor

PM1000 Product Developer Kit – PDK



9

American
Superconductor

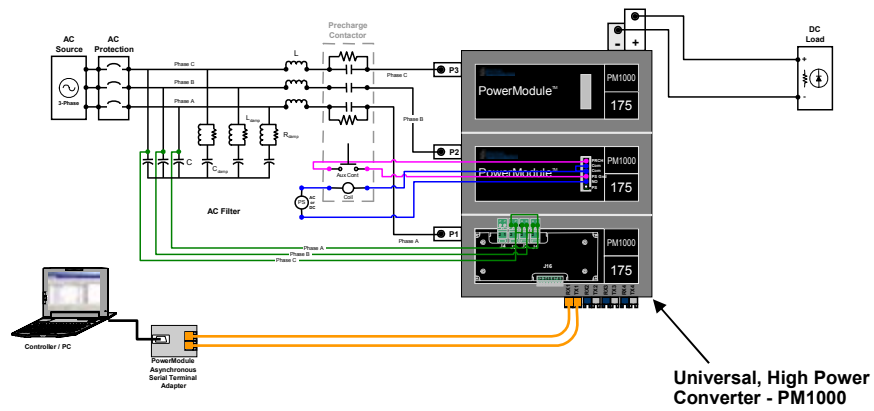
PM1000 PDK



10

American
Superconductor

PM1000 PDK – Active Rectifier

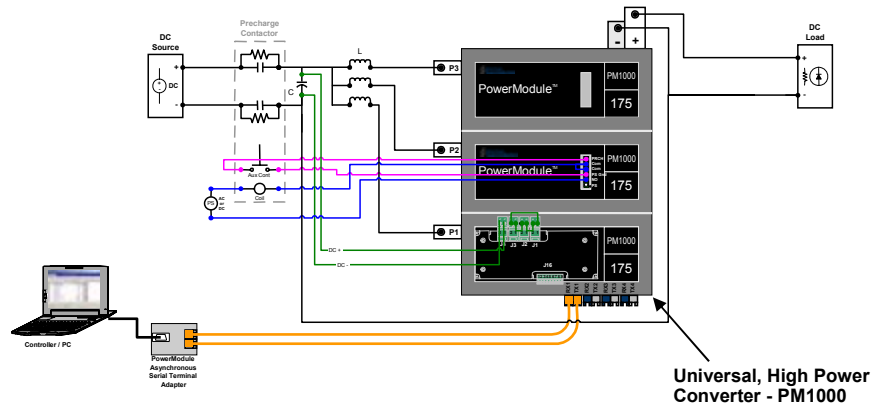


Universal, High Power Converter - PM1000

11

American Superconductor

PM1000 PDK – DC/DC Boost

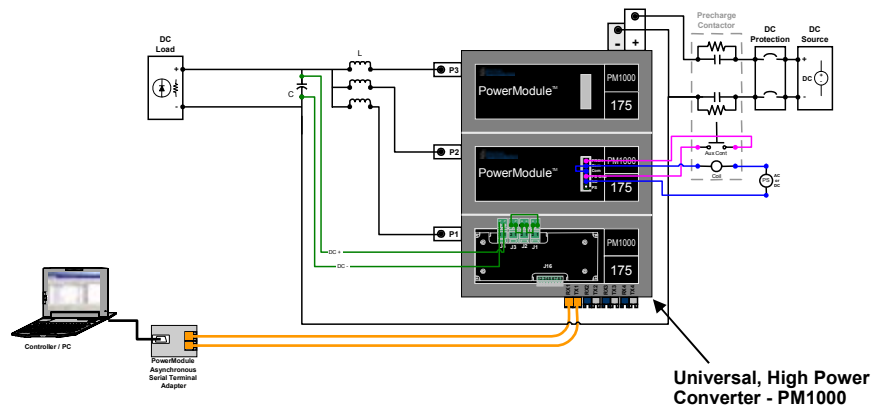


Universal, High Power Converter - PM1000

12

American Superconductor

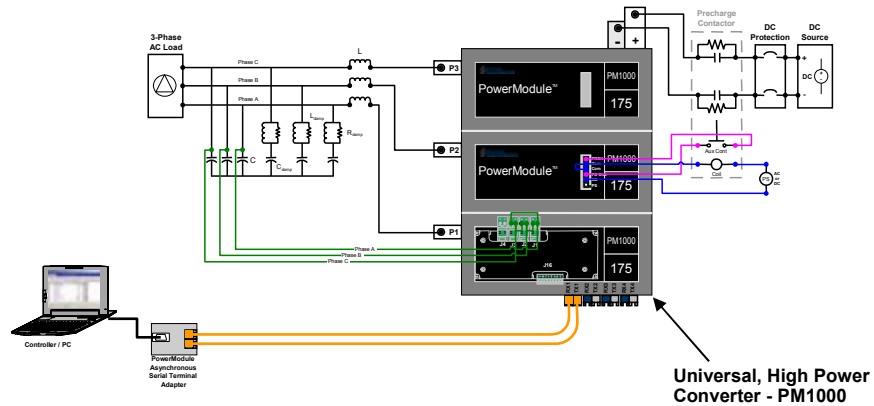
PM1000 PDK – DC/DC Buck



13

American
Superconductor

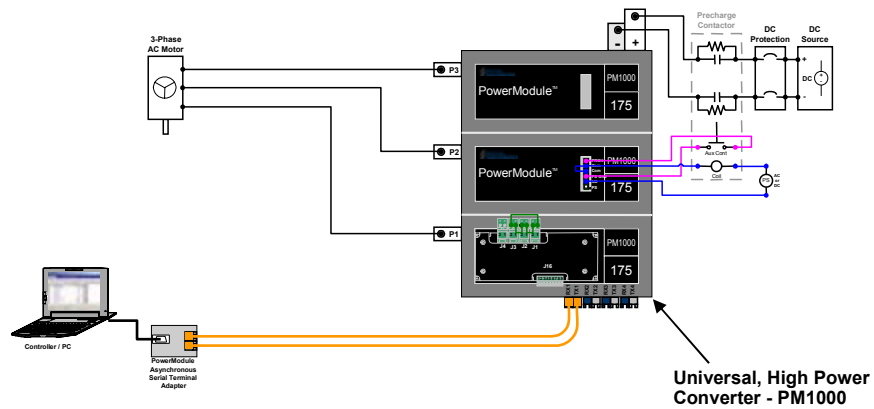
PM1000 PDK – AC Voltage Source



14

American
Superconductor

PM1000 PDK – Motor Control

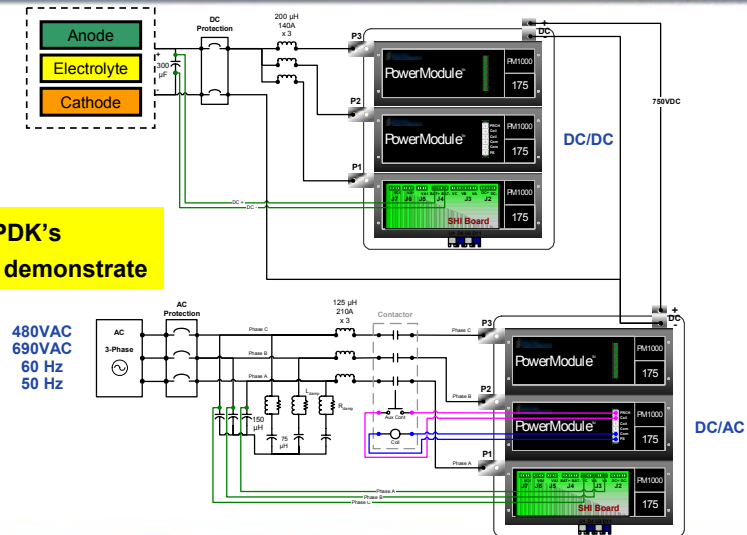


15

American Superconductor

PM1000 PDK Success Story – Stationary Fuel Cell

2 PM1000 PDK's
<1 week to demonstrate



16

American Superconductor

PM1000 PDK Success Story – Fuel Cell Bus



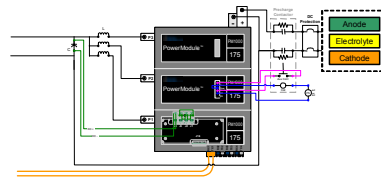
3 PM1000 PDK's
DC/DC boost converters



17

American
Superconductor

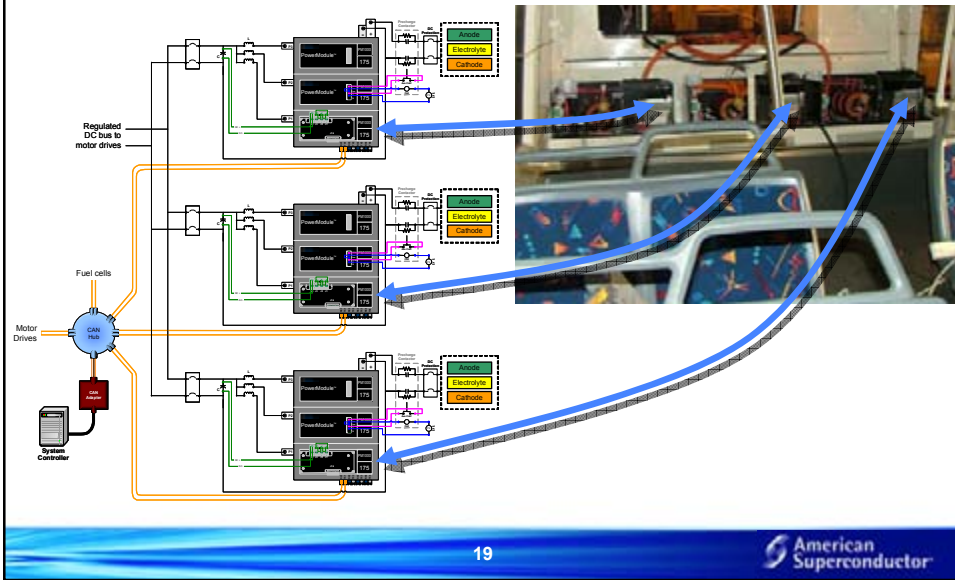
PM1000 PDK Success Story – Fuel Cell Bus



18

American
Superconductor

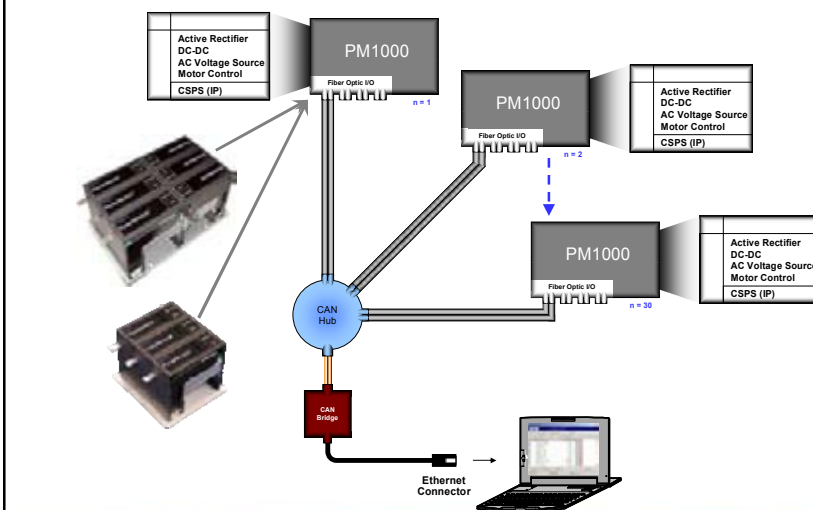
PM1000 PDK Success Story – Fuel Cell Bus



19

American Superconductor

PM1000 System Developer Kit – SDK

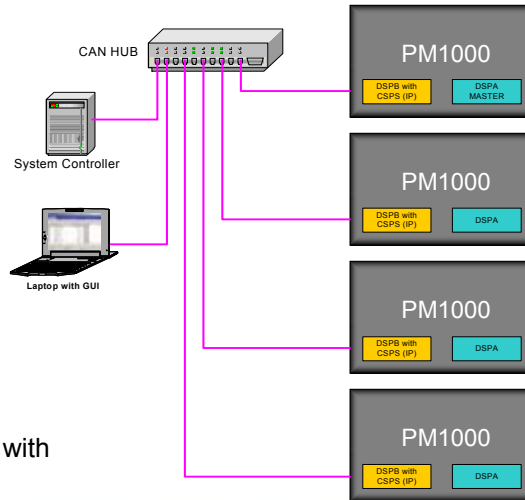


20

American Superconductor

PM1000 SDK – Custom SW & User Programmability

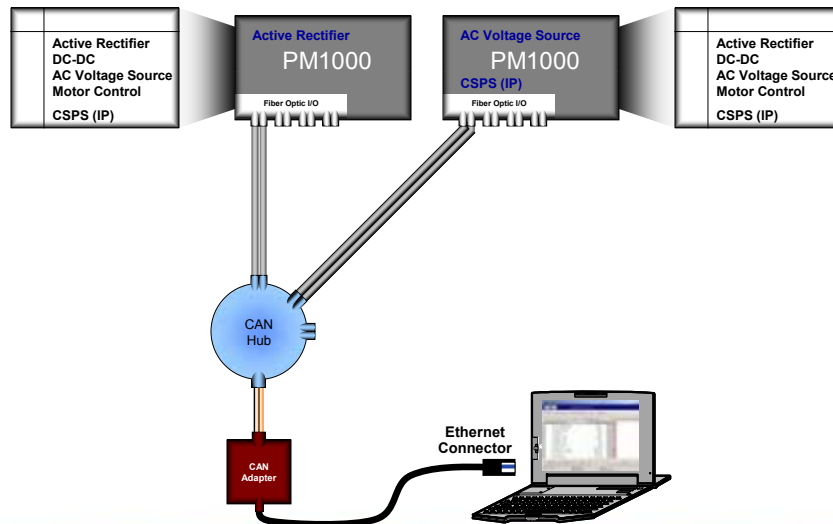
- Series and/or parallel PM1000s
- Master DSPA
- DSPB with Customer Specific Proprietary Software (CSPS)
- Laptop with GUI
 - Configure PM1000s
 - Monitor
 - Download software
- System level controller with customer software



21

American Superconductor

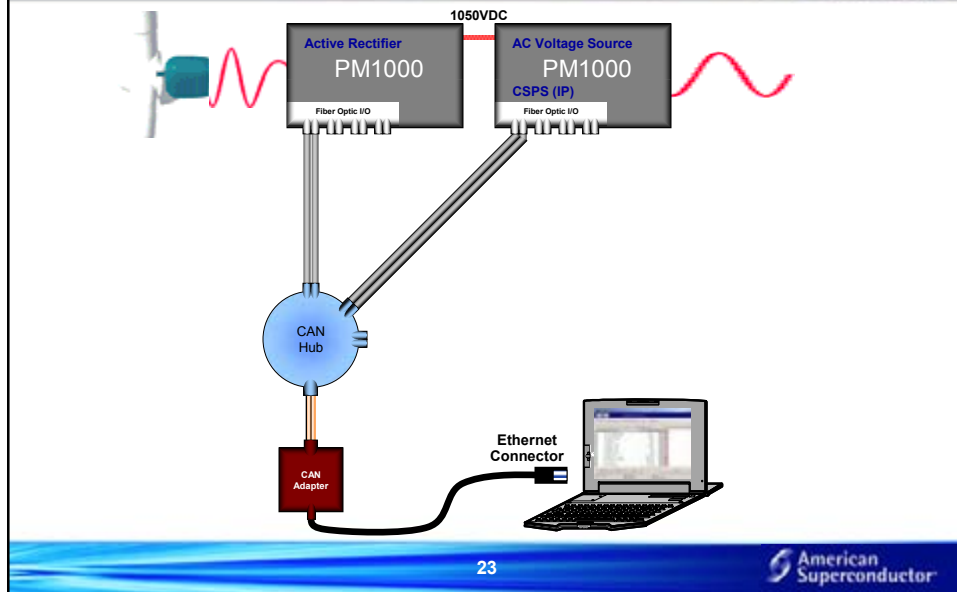
PM1000 SDK – Wind Turbine Application



22

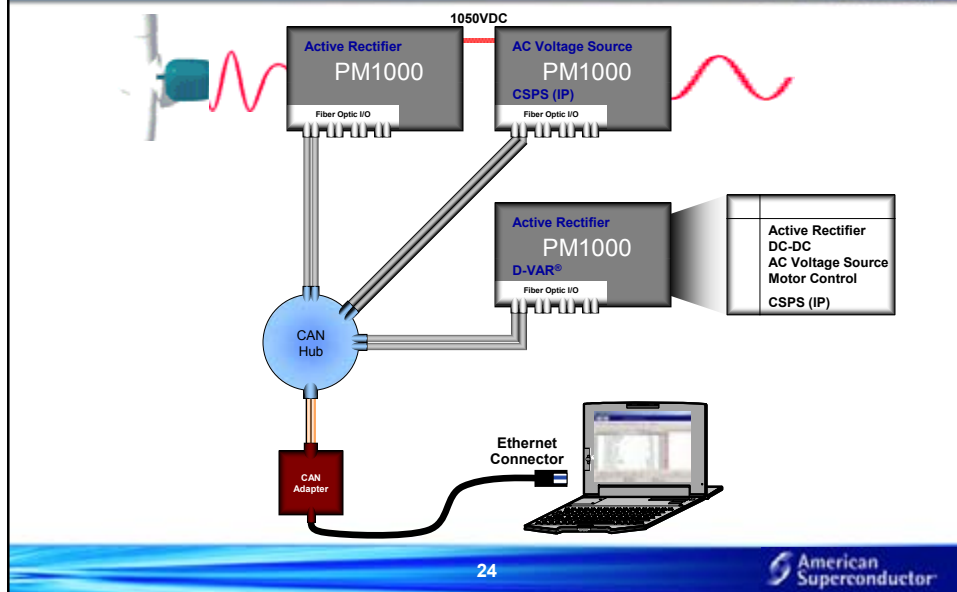
American Superconductor

PM1000 SDK – Wind Turbine Application



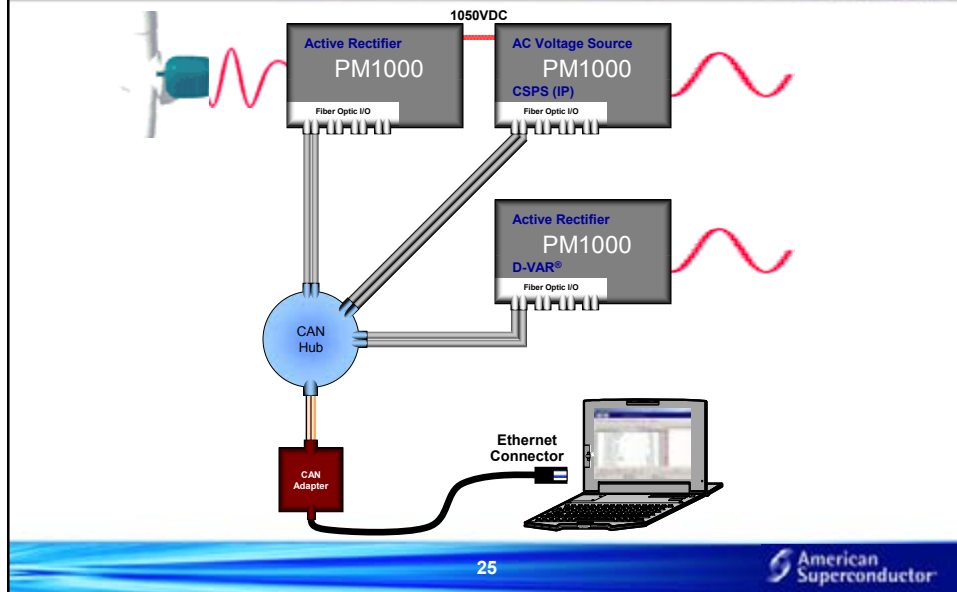
23

PM1000 SDK – Wind Turbine Application

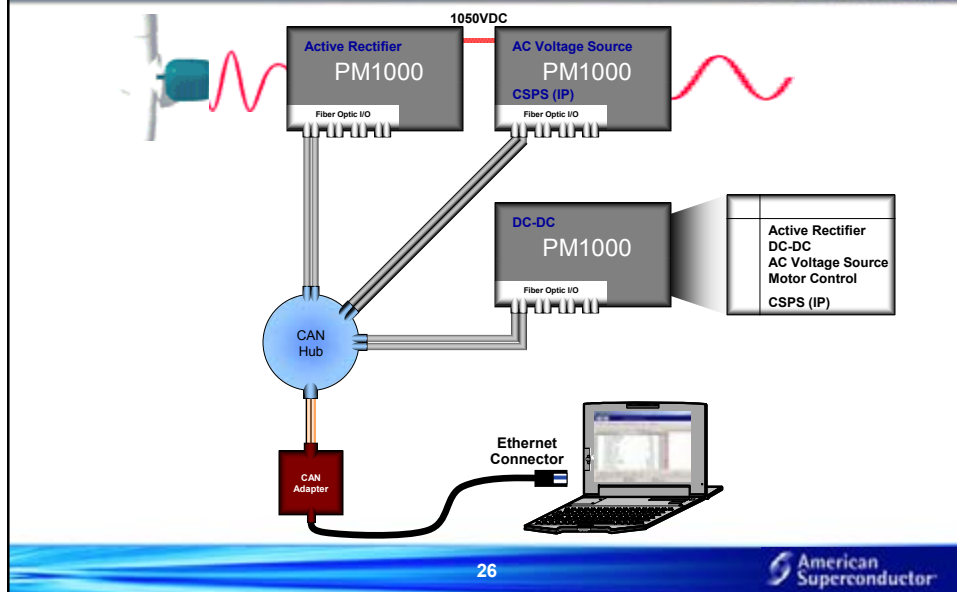


24

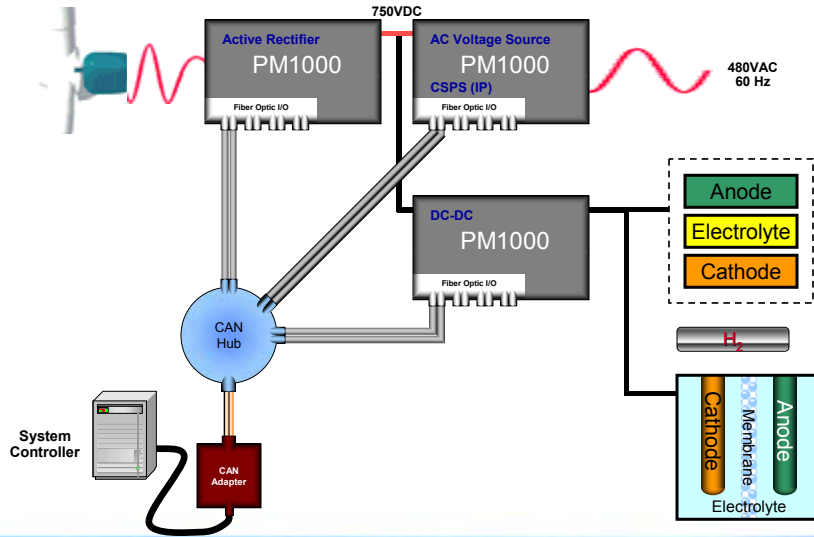
PM1000 SDK – Wind Turbine Application



PM1000 Wind Turbine & Fuel Cell Application



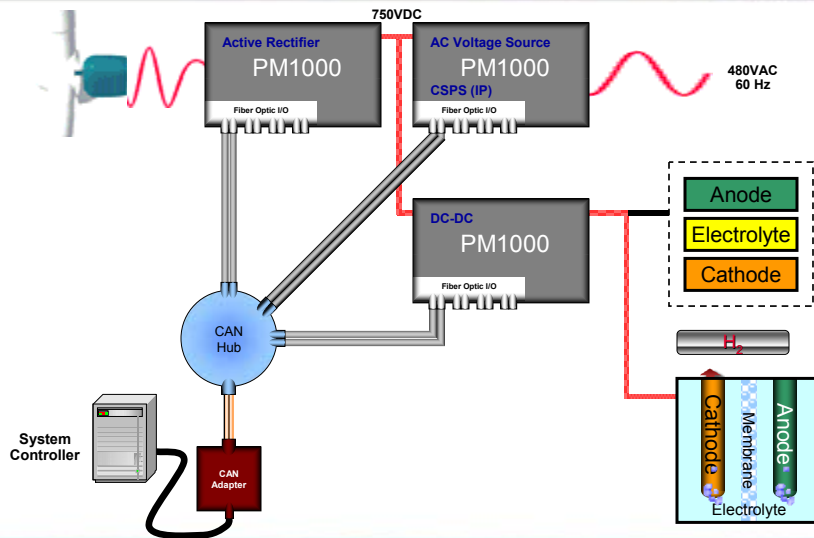
PM1000 SDK – Fuel Cell UPS Application



27

American
Superconductor

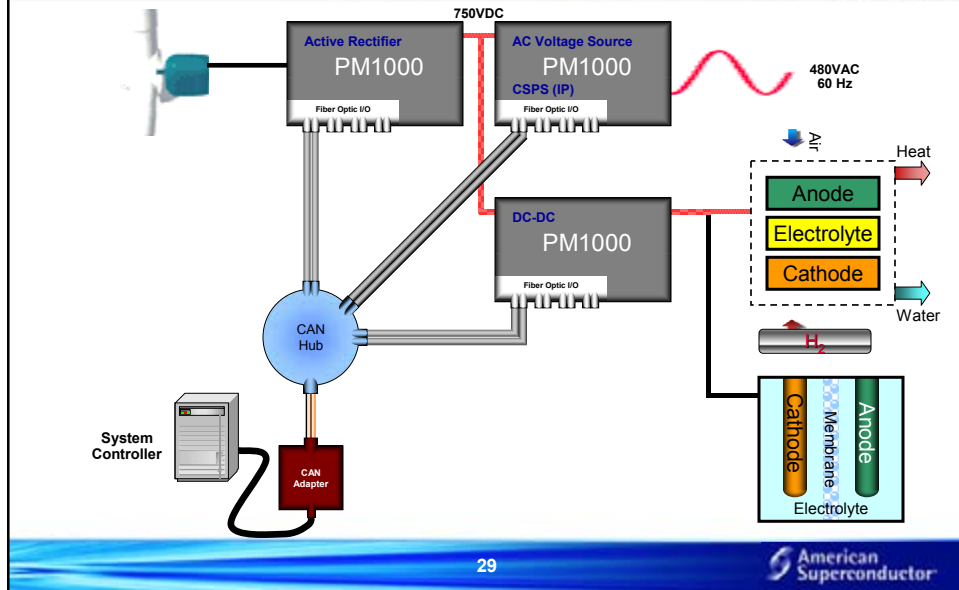
PM1000 SDK – Fuel Cell UPS Application



28

American
Superconductor

PM1000 SDK – Fuel Cell UPS Application



PM1000 2MW Generator Set Application



PM1000 Distributed Generation Applications

Wind Turbine

PM1000 provides power flow control of the wind turbine's output.



Generator Set

2MW gen-set using a high speed alternator and PM1000 for UK Ministry of Defense naval applications.



Fuel Cell

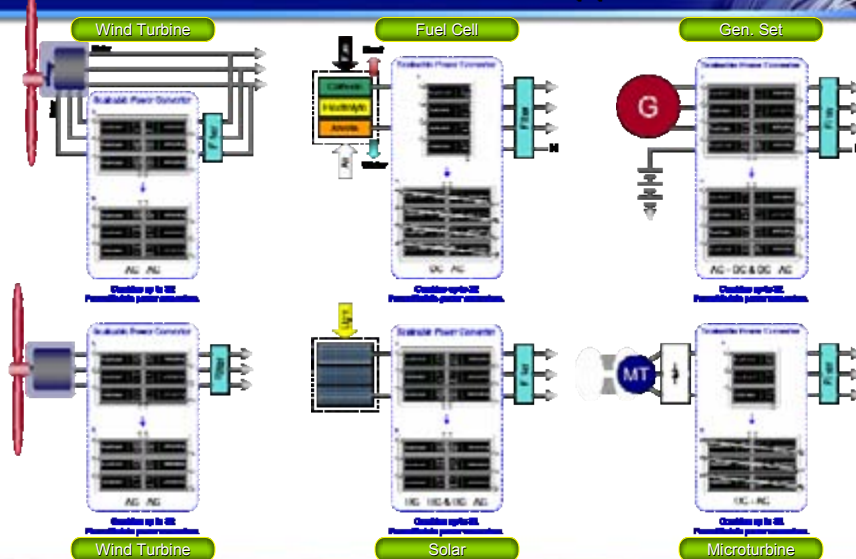
PM1000 used to provide a regulated output voltage from the fuel cell.



31

American Superconductor

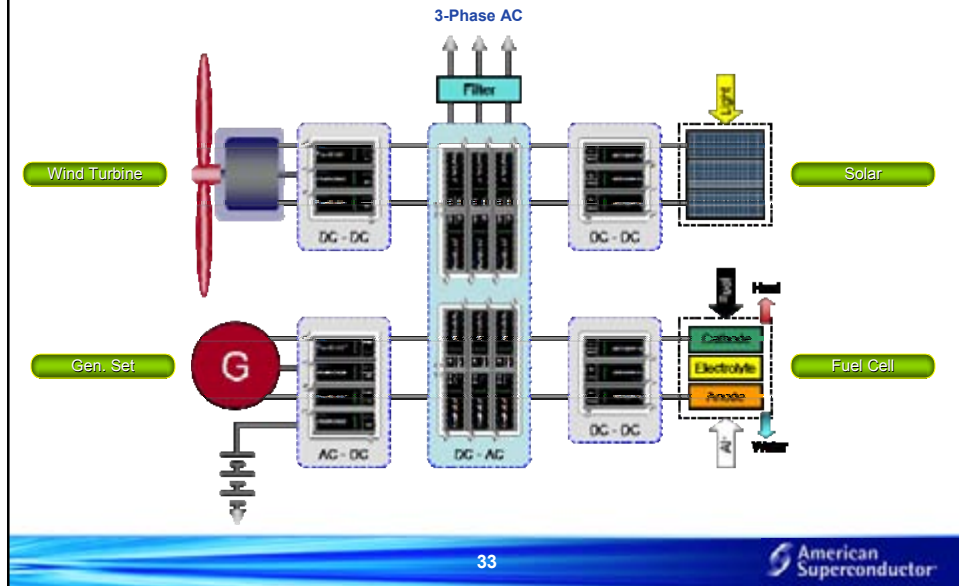
PM1000 Distributed Generation Applications



32

American Superconductor

PM1000 Distributed Generation Applications



PM2000



Modular Inverters for Distributed Generation

Matthew Zolot

UQM Technologies

*Presented at the Advanced Power Electronics
Interfaces for DE Workshop*

August 24th, 2006

Outline

- **UQM Specialization**
- **Functional Specifications**
- **Design for Modularity**
- **System Integration Issues**

Company Overview



UQM Technologies is a technological leader in the development and manufacture of very high performance, power dense and energy efficient:

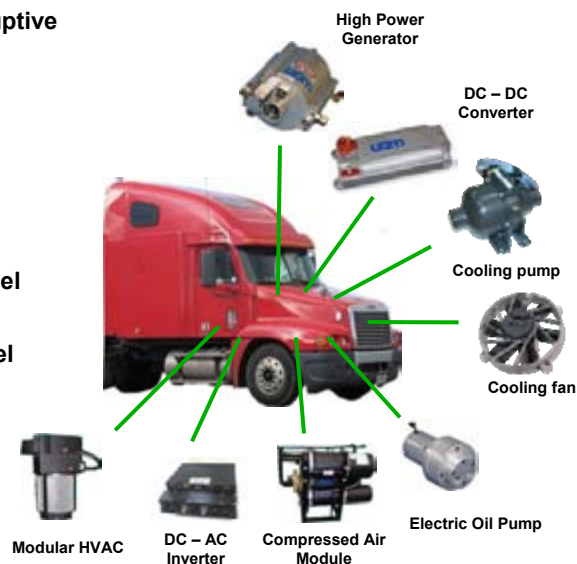
- ▶ electric motors
- ▶ generators
- ▶ power electronic controllers

for vehicle electrification.

Electrification of Engine-Driven Auxiliaries



- Easily adapted, non-disruptive
- Improved controllability
- Improved reliability
- More easily serviced
- Flexible architecture
- Available export power
- Key strategy to meet diesel emission mandates
- 7-15% improvement in fuel economy



UQM Core Competencies



- UQM products have technology advantages over conventional systems
 - **Power density**
 - smaller and lighter weight
 - **Efficiency**
 - consume less energy
 - **Performance**
 - eliminate gearing
 - adaptive software control
 - **Rugged**
 - automotive & military grade packaging



Motor Controller Example



UQM's experience with small, lightweight vehicle electronics helped us win this SBIR award

CD40-400L Controller

- DC to AC 3-phase motor / generator controller (4 quadrant)
- 140 kW maximum input (350 VDC, 400 ADC)
- 380 x 365 x 120 mm dimensions
- 16 kg weight
- Liquid (water/glycol) cooled

Outline



- UQM Specialization
- **Functional Specifications**
- Design for Modularity
- System Integration Issues

Bringing Unique Perspective to DG

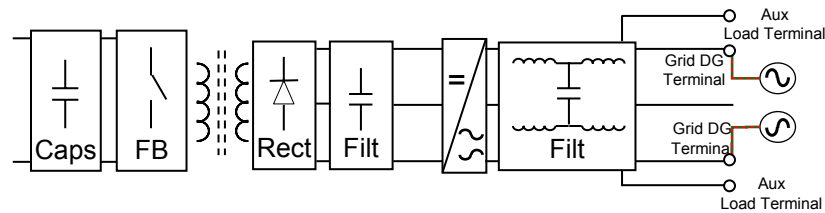


- Plug-in varieties of Hybrid Electric Vehicles are getting a lot of attention these days.
- Automotive requirements for DG products will differ from stand-alone implementations.
 - High voltage
 - High density
 - Light weight
 - High efficiency
 - Rugged packaging &
 - Low Cost (key to automotive)

UQM DG Inverter Specifications:

- V_{in} : 150 – 360 V
- P_{out} : 250 – 5000W (3 - 1.7kW modules)
- Efficiency: >90%
- Galvanic Isolation
- Grid & Stand-alone operation, 50/60 Hz
- Standards: UL 1741, IEEE 1547, IEEE 519

Overall Layout



Automated Control Code Generation

Mathworks Autocoding with DSP platforms

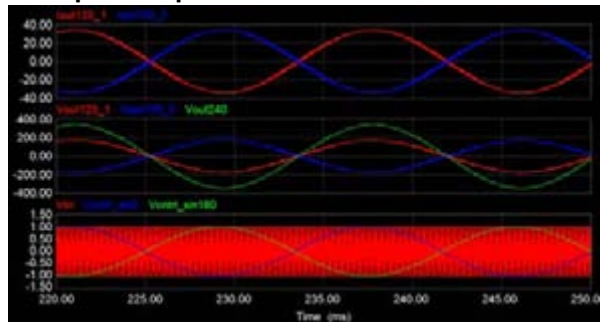
- Existing and customized MATLAB blocks are used selectively to quickly develop new systems
- Popular Mathworks platform leveraged for system simulation
- Embedded safety features
- OEM configurable parameters
- Successfully used within several development programs

True Sine Wave AC Generation



Texas Instruments DSP platforms

- Enables the use of advanced signal processing
- PWM based True Sine wave generation
- Software configurable for split-phase, in-phase, & 3-phase operation



Outline



- UQM Specialization
- Functional Specifications
- Design for Modularity
- System Integration Issues

Modular Inverter – Design Trade-offs

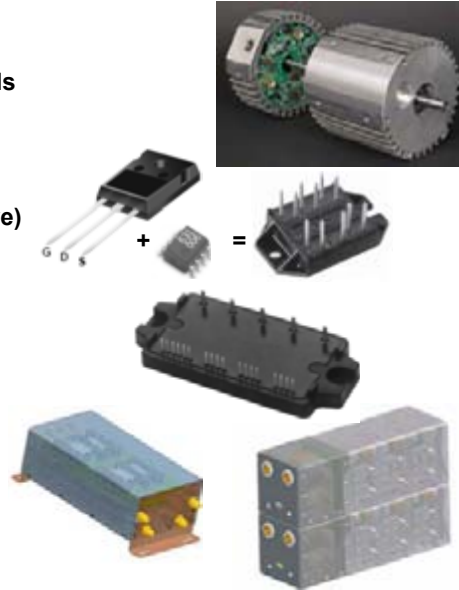


➤ Higher component integration levels vs. discrete components on FR4

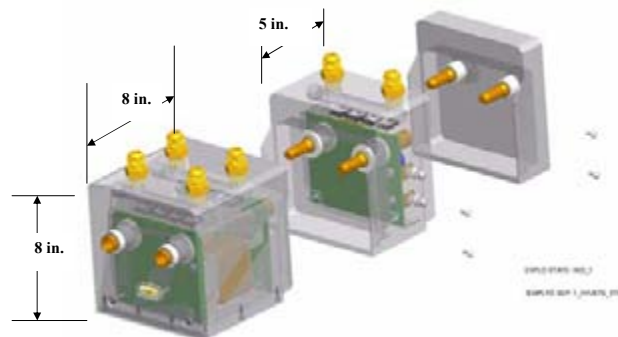
- Highly dependant on operating specifications (P, I, V)
- Cost (top priority for Automotive)
- Packaging density
- Performance (High frequency, inductance, trace lengths, etc.)

➤ Level of Modularity {PEBB}

- Component Level
- Board Level
- Package Level



Modular Inverter – Initial Design (Base Package)



DC-DC module 8x8x8"

Inverter modules 8x8x5" respectively

➤ High frequency, Isolated DC-DC front end: 5kW

- Capable of stand-alone operation

➤ Modular Inverter (up to 3 modules, each 1.7kW)

➤ Liquid Cooled (automotive variety)

Modular Inverter – Interconnection Potential



1.67 kW Inverter



5 kW Inverter



10 kW Inverter



➤ Sub-Block Modularity

- 1.7 kW, 3.4 kW, or 5 kW at 120/240 VAC 60 Hz single phase, or 5 kW 3-phase

➤ Block Modularity

- 5 kW, 10 kW, etc... operation

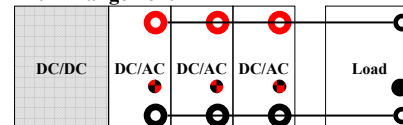
Functional Modularity



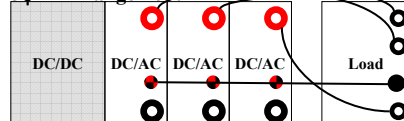
120 Split Phase Arrangement



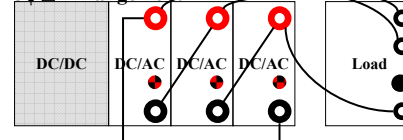
240 Arrangement



3 ϕ Y Arrangement



3 ϕ Δ Arrangement



Terminals	
	120 $\angle$ 0 $^\circ$ Hot OR 240 Hot
	120 $\angle$ 0 $^\circ$ & 120 $\angle$ 180 $^\circ$ Neutral
	120 $\angle$ 180 $^\circ$ Hot OR 240 Neutral

Outline



- UQM Specialization
- Functional Specifications
- Design for Modularity
- **System Integration Issues**

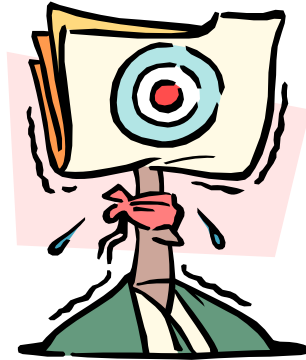
Challenges to Going Modular



- **Goal: prevent redesign/modifications for every unique implementation**
 - Enable higher volumes and reduced costs

Challenges:

- **Evaluate mechanical connections for all types of terminal requirements (Input & Output)**
- **Communication: between modules & packages**
- **Anti-Islanding: Identification and prevention**
- **New market: will the egg grow into a Chicken?**





MAGNETEK  **UNCOMMON POWER**

Power Electronics Conversion for Distributed Energy Applications

By: Dr. Alex Levrin
EVP & CTO, Magnetek Inc
CEC & NREL

www.alternative-energies.com



Overview:

- **Technology**
- **Applications and Products**
 - Wind
 - PV
 - Variable Speed
 - Energy Storage
 - Fuel cells
- **Future Trends**



Magnetek Inc - Fast Facts



Headquarters: Los Angeles, CA (USA)

Listed on NYSE, ticker MAG

Sales >\$250M

1,500+ Associates worldwide

7 plants in Europe, North America, Asia

Core Technology: Power Electronics Conversion

Embedded products and Systems



Distributed Energy Technologies

- **Wind**

- Large farms compete with central generation
- Residential applications <10kW

- **Photovoltaic**

- Growing Commercial and residential applications.
- Lower cost materials and manufacturing processes for PV panels key to increased market penetration

- **Energy Storage**

- Full range of batteries, flywheels and ultra-capacitors evolving for managing transients, compressed air, SMES

- **Fuel Cells**

- Automotive applications key to small-scale FC economics
- Limited success in commercial and telecom

- **Variable Speed Generation**

- **Microturbines**

- Lower cost, higher reliability critical for market expansion



MAGNETEK
UNCOMMON POWER

Power Electronic Conversion - Requirements

- Grid Connection
 - Anti Islanding, kVAR control, Unbalance/Nonlinear Loads
 - Low and medium voltages
 - Power Quality and Harmonic Distortion (IEEE 519)
 - IEEE 1547 Standard for Interconnecting Distributed Resources with EPS.
 - DC current injection (w/o transformer)
- Higher Efficiencies
 - Power Conversion
 - Energy Harvesting
- Mechanical Packaging
 - Parallelable, scalable designs
 - Indoor and outdoor applications
 - Thermal management : air and liquid cooling
 - Compact designs, higher power densities
- Improved Reliability
- Cost competitiveness
- Communication and Remote Monitoring
 - Power Line and/or RF Communication
 - SCADA and GIS interfaces



MAGNETEK
UNCOMMON POWER

Power Electronic Inverters Technology

- **Converters/Inverters Topology:**
 - Voltage source for stand alone. Current Source for grid connected operation
 - Sinusoidal PWM, multi(three) level or space vector modulation.
 - Low or high frequency galvanic isolation
 - Non-controlled and active rectifiers. Buck /Boost Converters.
 - Unidirectional and bidirectional architectures/operations.
 - System integration configurations: cascade inverters, cascade rectifiers, cascade total conversion systems
- **Control Circuits and Algorithms (digital):**
 - Voltage, Current and Frequency Control
 - Power Flow Control
 - Real and Reactive Power Sharing
 - Protection Circuits
- **Local and Remote Communication Protocols**
(supervision, controls, and monitoring)

MAGNETEK
UNCOMMON POWER

Strategy: To lead the market of power electronic interfaces for alternative energy systems.

- High reliability and efficiency power converters
- Primary energy source control
- Grid interface know-how (grid tied, stand alone, hybrid)
- High power density and compact size
- System level control
- Modular design for multiple sources (PV, wind, FC).
- Scalable design. common building blocks & platforms

Photovoltaic Systems

Wind Generators

Fuel Cell Systems

Microturbines and Variable Speed Distributed Generation

MAGNETEK
UNCOMMON POWER

Wind Power Conversion

COMPLETE POWER INTERFACE FOR SMALL POWER WIND SYSTEMS

- Up to 10kW
- Most compact design available on the market
- Stand Alone and Grid-tied operating modes
- Optional Photovoltaic and Genset inputs
- Split phase inverter for worldwide 110V/60Hz or 220V/50Hz operation
- Aurora PV platform with minor change.
- Parallelable.
- Advanced communication

POWER CONVERTER FOR LARGE POWER WIND SYSTEMS

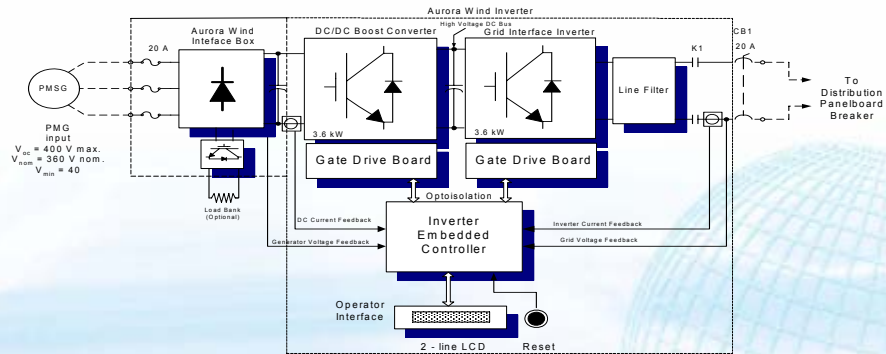
- Up to 3.0 MW
- DSP based digital control
- Parallel multiple 625 kW inverters



MAGNETEK
UNCOMMON POWER

Small Power Wind Inverter Topology

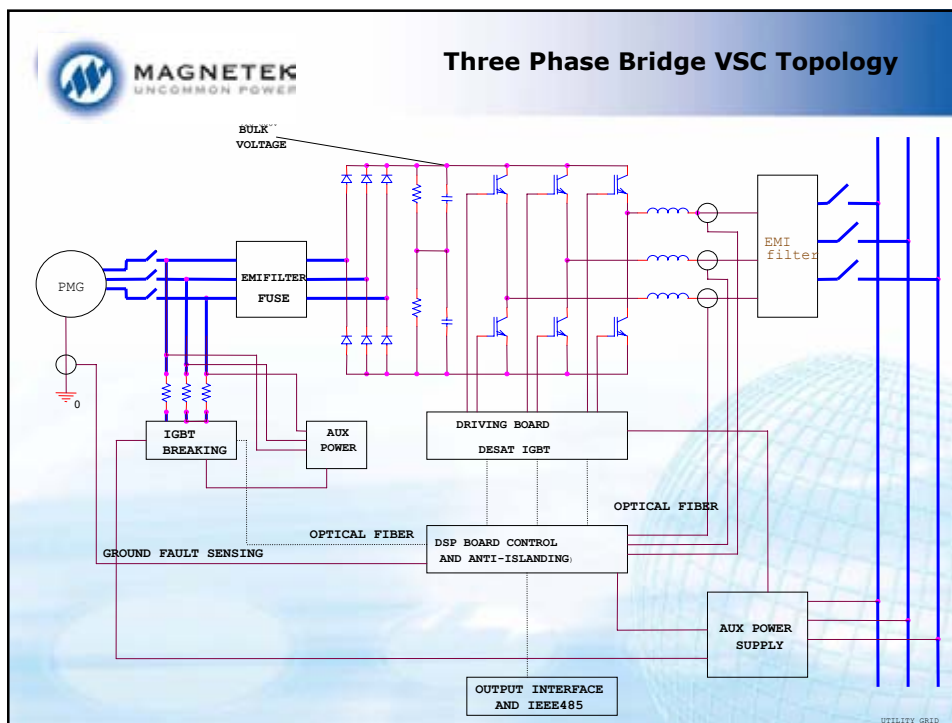
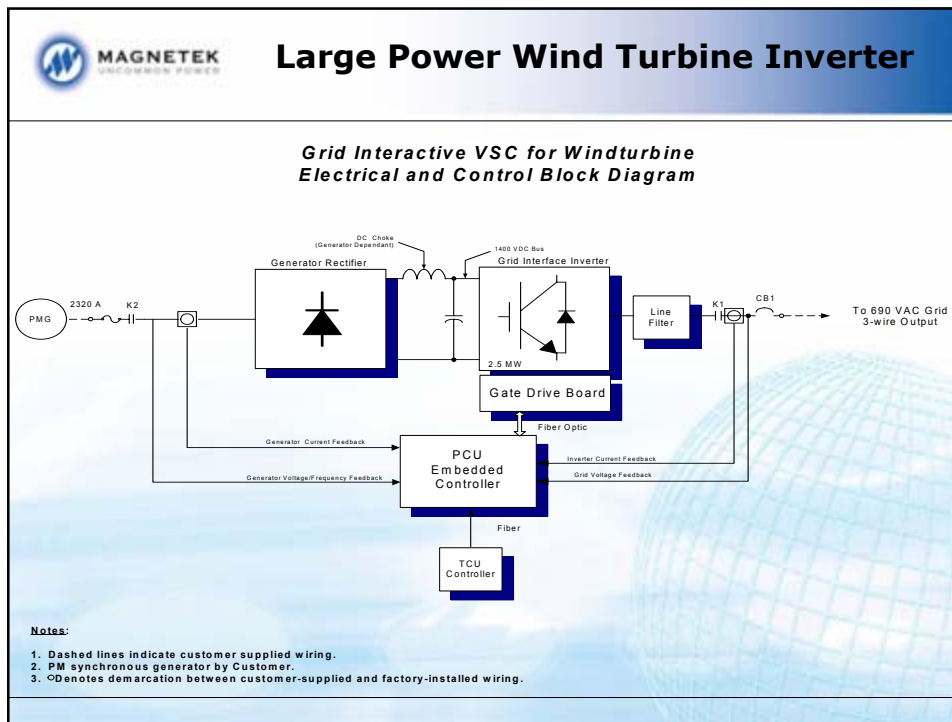
Grid Interactive Inverter System for Small Wind Turbine Electrical and Control Block Diagram

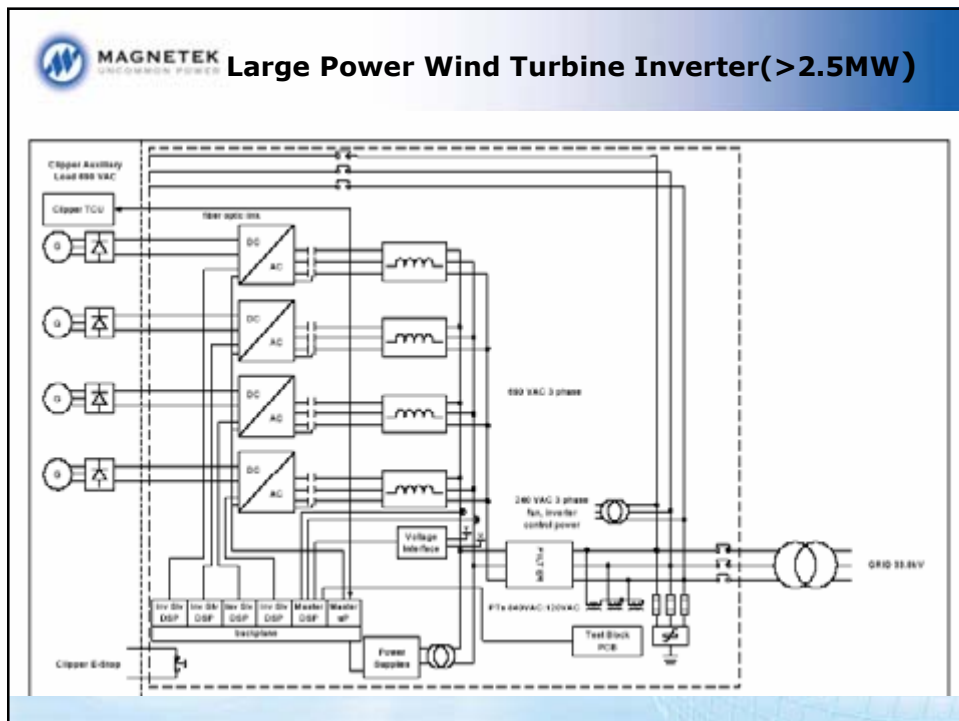
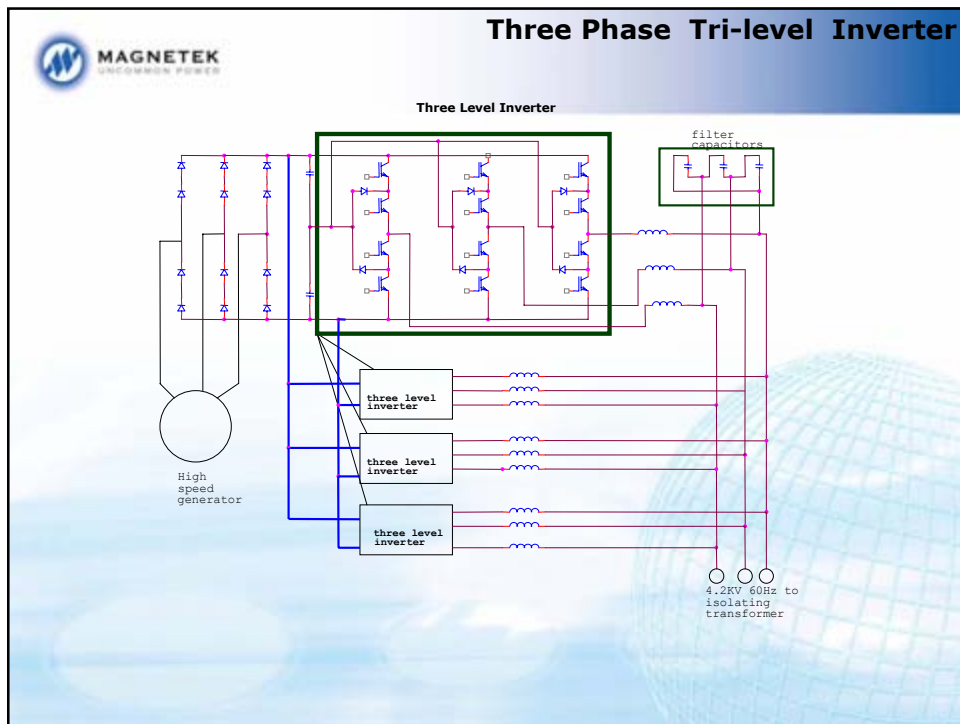


MAGNETEK
UNCOMMON POWER

Large Power Wind Turbine Inverter

- **Typical Characteristics:**
 - Output Voltages: Low to medium
 - Grid Connection: UL1741 or Stand Alone
 - Indoor and outdoor designs. Air and water cooled designs.
- **Topology:**
 - Full bridge rectifier
 - Voltage fed three phase inverter with adjusted current
 - Three Level Inverter or Space Vector Modulation
 - Bi-directional conversion for doubly fed generators.
- **Features:**
 - High efficiency (>97%)
 - Low THD meets IEEE 519
 - Modular and scalable designs
 - Enhanced voltage regulation
 - Compact design
 - Advanced communication
 - Closed loop controls with the turbine







Advantages of Large Wind PMG Turbine- Up to 5.0 MW

Variable Speed Converter (VSC) Value Proposition

Advantages of Full Scale Conversion with PMG (Permanent Magnet Generator):

Increase efficiency of 7 1/2% over wound rotor technology for variable speed:

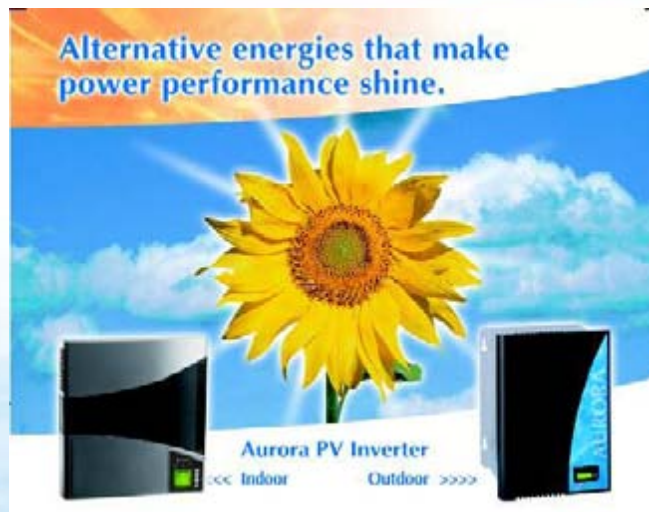
- PMG Generator 3% more efficient than the Wound rotor induction generator
- PMG is 1/3 the size and cost
- Gear box 1/2 the size and cost, while 2% more efficient
- Converter is 2 1/2 % more efficient and 1.5 x cost
- Wound rotor systems in the 2 MW range are \$.047 kWh vs. \$.032 kWh with Full conversion utilizing PMG
- Avoids infringements of current IP
- No brushes as with wound rotor generators for higher reliability



Photovoltaic Power Conversion

AURORA PHOTOVOLTAIC INVERTERS

- Up to 6000W
- Top level performance
- Indoor and Outdoor models
- Advanced remote communications





MAGNETEK
UNCOMMON POWER

Residential Photovoltaic Inverters

- **Topology:**

- Single or multi-string conversion
- Typical Architectures:
 - Boost converters with DC link and PWM full bridge inverter with or without low frequency transformer isolation (grounded PV panels)
 - Single inversion stage with low frequency transformer for galvanic isolation and voltage adjustment.

- **Typical Performance:**

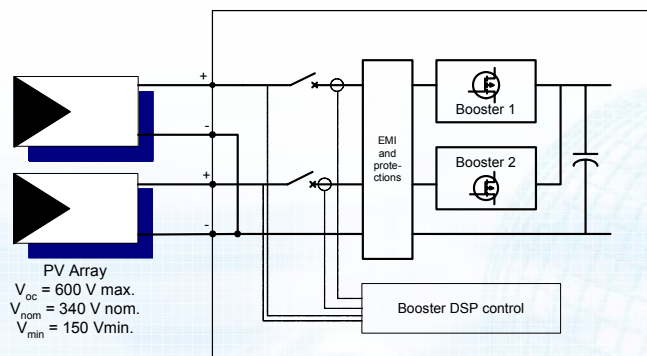
- Power Ratings: 500W to 8000W
- Wide open circuit voltage range from 90VDC to 600VDC
- High efficiency: Exceeding 96%
- Cost competitive, high power density design
- Harmonics: meets IEEE 519 spec
- Grid connected operation: Meets UL 1741 and VDE requirements.
- High overload capabilities, operates at high temperatures, and anti-islanding protection
- Packaging: Indoor meets Nema2(IP21) and outdoor meets Nema4(IP65)
- Advanced local and remote communications and continuous data logger

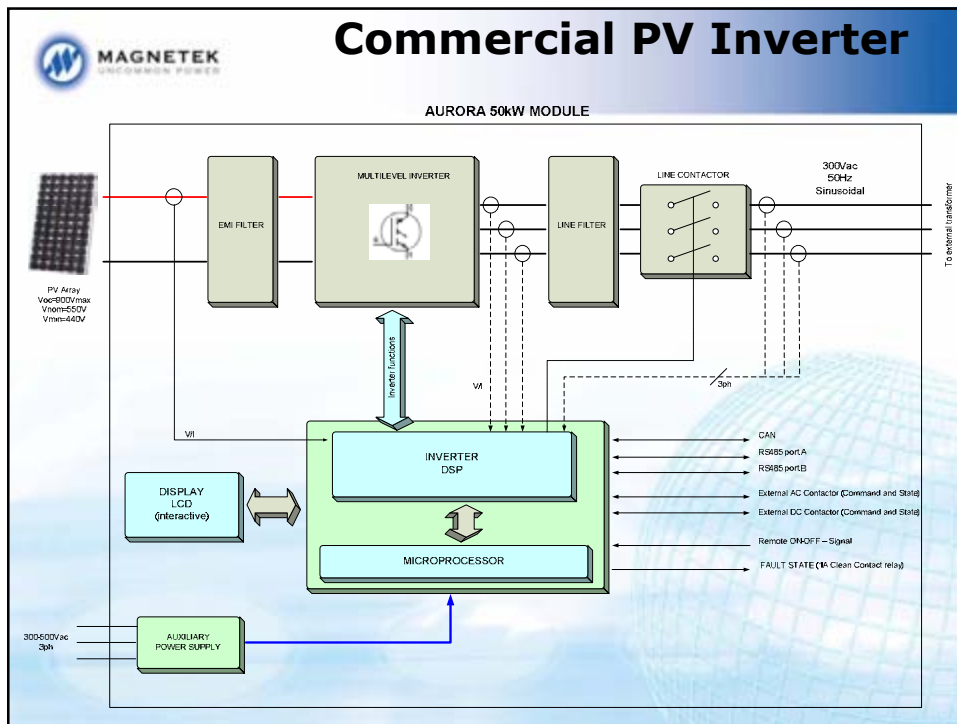


MAGNETEK
UNCOMMON POWER

Optimal Performance

Aurora higher power models are Multistring inverters with two independent and fast Maximum Power Point Tracking (MPPT) inputs



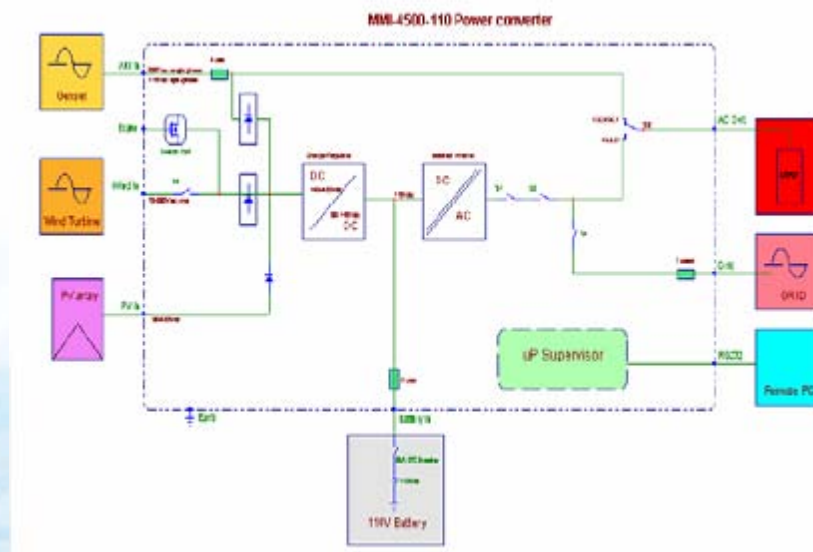


MAGNETEK
UNCOMMON POWER

Commercial Photovoltaic Inverters

- **Topology:**
 - Full Bridge with PWM or multilevel controls and topologies.
 - Parallel-able with advanced master/slave assignment algorithm
- **Typical Performance:**
 - Power Ratings: 30kW to 250kW. 50kW modules
 - Wide open circuit voltage range from 300VDC to 600VDC or 400VDC to 900VDC
 - High efficiency: Exceeding 97%
 - Advanced MPPT algorithm to harvest higher energy
 - Cost competitive, high power density design
 - Harmonics: meets IEEE 519 spec. Low DC current components.
 - Grid connected operation: Meets UL 1741 and VDE requirements.
 - High overload capabilities, operates at high temperatures, and anti-islanding protection
 - Packaging: Indoor meets Nema2(IP21) and outdoor meets Nema4(IP65)
 - Advanced local and remote communications and continuous data logger
 - Output transformer section (low frequency, low and medium voltages)

- **Typical Characteristics:**
 - Multi mode operation: Grid Connected, Stand-alone, UPS
 - Universal Inverter: Single phase 230VAC, 110VAC, 50Hz and 60Hz
 - Multi Source: Wind, PV (max 420VDC), Gen-sets (115VAC split phase 230VAC, 10%), batteries (48V/110A or 110V/50A).
- **Topology:**
 - Two stage conversion: DC/DC converter and single phase full bridge inverter.
- **Typical Performance:**
 - Power Ratings: 2500W to 6000W
 - High efficiency: Exceeding 90% from renewable source and 92% from Battery.
 - Cost competitive compact design
 - Harmonics: meets IEEE 519 spec
 - Grid connected operation: Meets UL 1741 requirements
 - Advanced local and remote communications





MAGNETEK
UNCOMMON POWER

Microturbine - Compact Power Generator



- 50kW and 100kW
- Easily Transportable (light and small)
- High Reliability
- High Power Quality
- Reduced emissions
- Cogeneration
- Versatile



MAGNETEK
UNCOMMON POWER

Fuel Cell Inverters



COMPLETE POWER INTERFACE FOR FUEL CELL SYSTEMS – RESIDENTIAL AND AUTOMOTIVE APPLICATIONS

- PCS – 2000W to 7400W
- Stand Alone and Grid-tied operation
- Auxiliary output for start-up phase of fuel cell stack
- Split phase inverter for worldwide 110V/60Hz or 220V/50Hz operation



COMPLETE POWER INTERFACE FOR FUEL CELL SYSTEMS – INDUSTRIAL APPLICATIONS

- PCS-3: 300 kW
- Grid tied and stand alone operating modes
- MULS (Multiple unit load sharing) up to six units
- Seamless transition with optional static switch



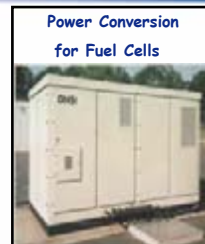
Fuel Cell Inverter Technology

- **Typical Characteristics:**
 - Convert DC output voltage from fuel cell module to three phase AC voltage.
 - Supports different fuel cell source technologies: Phosphoric Acid, Proton Exchange Membrane, Molten Carbonate, and Solid Oxide.
- **Topology:**
 - Two stage conversion. Three phase inverter PWM inverter.
 - Space vector modulation or sinusoidal PWM
- **Features:**
 - Indoor or outdoor designs.
 - Water cooled or air cooled
 - Efficiency over 93%
 - Harmonics: meets IEEE 519
 - Parallelable, scalable designs
 - Connection: stand-alone or grid connected UL 1741
 - Remote monitoring and control



Large Scale Fuel Cell Inverters > 200kW

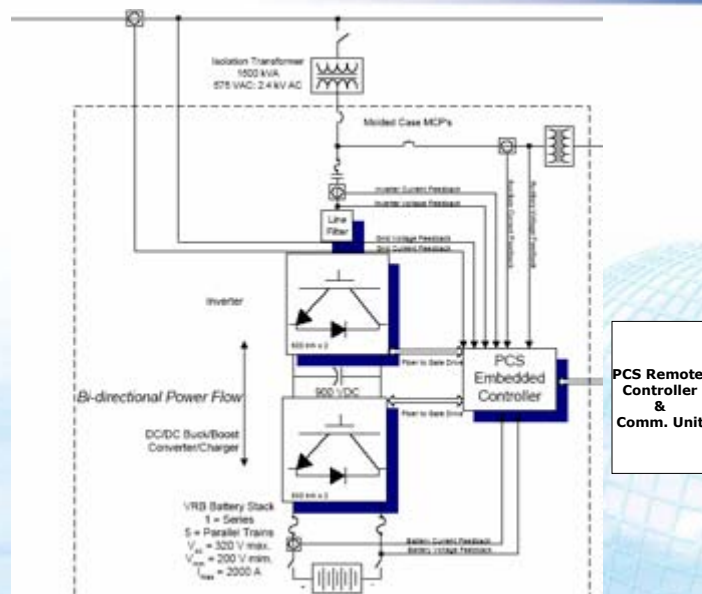
- UTC Fuel Cells: 200 kW, (160)
- Installed base exceeds 32 MW
- Other customers: 300kW modules



Energy Storage Converters

- **Applications:**
 - Load Leveling
 - Power Quality and Energy Management
 - Integration with renewable energy sources for enhanced efficiency and higher capacity
- **Sources:**
 - Batteries: Lead Acid, Sodium Sulphur-NAS, Nickel Cadmium(Ni-Cd), Nickel Metal Hydride(Ni-MH), Vanadium Redox (VRB), Lithium Ion(Li-Ion)
 - Flywheels, Compressed air storage
 - Superconductive Energy Storage
- **Typical Topology:**
 - Bi-directional Two stage conversion: Back/Boost DC Converters and PWM Inverters with transformer isolation.
- **Performance Features and Controls:**
 - Power range: 200kW to 10MW
 - Charging/discharging control algorithms to extend battery life
 - High efficiency
 - Low harmonic distortion

Energy Storage Converters

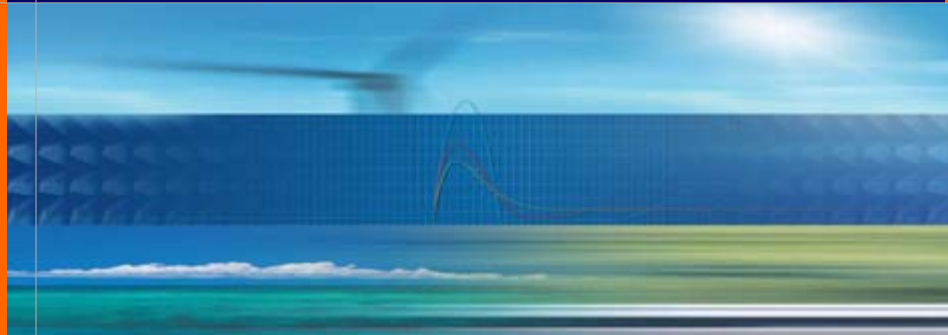




MAGNETEK
UNCOMMON POWER

Future Trends (>3years)

- **Inverter Technology:**
 - New Topologies (tri-level inverters) and improved control algorithms.
 - Higher voltage and current rating of IGBTs, and SiC components.
 - Improved thermal management devices (heat-sinks,
 - Improved driver and sensing circuits(fiber optical)
 - Improved capacitors and magnetic devices
 - Will drive:
 - Higher conversion efficiency, higher power density, higher reliability
 - Higher voltage (Medium), higher power, lower cost
- **Expansion of Modular designs:**
 - Flexibility of installation and application
 - Scalability
 - Multiple sources of energy, similar platforms (Topologies)
- **Improved Communication:**
 - Enhanced maintenance and service
- **Hybrid Systems:**
 - Combination of PV and Wind with advanced energy storage devices for better power quality and back-up power applications



Xantrex Power Electronics for Renewable Energy System Applications

Ray Hudson

Vice President Advanced Technology
ray.hudson@xantrex.com

Outline

- Xantrex Overview
- Renewable Energy Power Electronic Converter Products
 - Residential Solar – Grid Tied
 - Residential Solar – Off-Grid/Backup
 - Industrial/Commercial Solar – Grid Tied
 - Wind
 - Others
- Future Direction

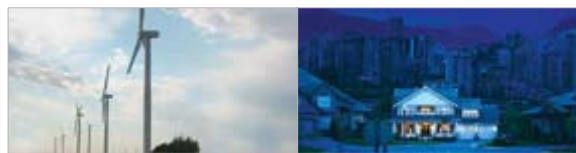
Xantrex Overview

Offices	Livermore, CA, San Luis Obispo, CA, Burnaby BC, Arlington WA, Elkhart IN, Barcelona Spain, Reading England, Beijing China
Manufacturing	Livermore CA, Burnaby BC, Arlington WA, Dominican Republic, China (4 Outsourced Locations)
Employees	500
Revenue	US\$143 Million in 2005
Patents	79 patents with 97 more in progress
Ownership	Public, Traded on Toronto Stock Exchange (XTX)
Established	1983

3

ADVANCED POWER ELECTRONICS Target Markets

Renewable Power



Portable & Mobile Power



Programmable Power



4

Mobile Power

xantrex

Mobile Power – Product Portfolio



Recreational Vehicles



RS2000/MS2000
Inverter/Chargers



Prosine
Inverters & Inverter/Chargers



Freedom Marine 458
Inverter/Chargers



TrueCharge
Chargers



Xantrex Battery
Chargers



Commercial Vehicles



Railmount
Inverter/Charger



Fleetpower
Inverter/Chargers



Prosine
Inverters & Inverter/Chargers



Portable Power



XPower
Powerpack 150



XPower
Powerpack 400



XPower Powerpack 300



Micro Inverters



XPower Plus Inverters



XPower Chargers



XPower Jumpchargers

5

Programmable Power

xantrex

Programmable Power – Product Portfolio



Design & Development



XFR 1.2 – 2.8kW
Full Rack Programmable
DC Power Supply



XDC 6-12kW
Digitally Controlled Programmable
DC Power Supply



Value Line (XDL, XPF, XPL, XPH)
Digitally Controlled Programmable
DC Power Supply



Manufacturing Test



XFR 1.2 – 2.8kW
Full Rack Programmable DC
Power Supply



XHR
Half Rack Programmable
DC Power Supply



XPD
Quarter rack Programmable
DC Power Supply



Precision Equipment



XDC 6 – 12kW
Digitally Controlled Programmable
DC Power Supply



XMP
Multiple Output Programmable
DC Power Supply



XT
Quarter rack Programmable
DC Power Supply

6

Renewable Power Examples



Solar



SW Plus
Off-Grid Inverter/Charger



PV Series
10 kW to 225 kW
NA 3 Phase
Commercial Grid Tie



GT Series
Residential
Grid-tie Inverter



GT100E
Int'l 3 Phase
Commercial Grid Tie



GT500E
Int'l 3 Phase Commercial Grid Tie



Wind



1.5 MW Converter
Industrial Wind



10 kW Grid Tech Inverter
Small Scale Wind



Backup



SW Power panel
Off-Grid Backup Power
Inverter/Charger



SW Plus
Off-Grid Backup Power
Inverter/Charger



DR
Inverter/Charger

Power Electronics for Solar Applications

- Convert DC from PV Array to AC
- Grid Connected Inverters
 - Only source power to utility grid
- Off Grid/Backup Inverters
 - Include storage for operation when grid not available
- Charge Controllers for battery interfacing
- Often included in "Balance of System"
- Is a very key system component
 - User interface
 - Implements safety features
 - "Heart and Brain" of the system
 - Sometimes viewed as system weak link

Solar Portfolio



Battery Based Inverters



DR Series



SW Plus Series



SW Series



Single Phase Grid Tie



GT Series
Residential
Grid-tie Inverter
2.5 to 3.8 kW



3-Phase Grid Tie



PV Series
10 kW to 225 kW
NA 3 Phase
Commercial Grid Tie

9

GT3 Series Residential Grid Tied Inverter Features

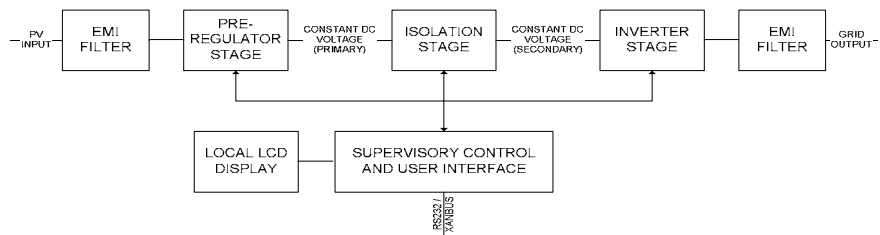
- True 2.5kW, 3kW, 3.6kW power rating
- High efficiency (CEC 94.5%)
- Wide PV DC MPPT range
- Faster and less expensive to install
 - Light weight and compact
 - Integrated DC/AC disconnect
 - Wiring box
 - Split chassis design (easy to service)
- Communications:
 - LCD display
 - Communication ports and software
- Attractive industrial design
- Passive cooling
- Demonstrated reliability



10

GT 3 Design Topology

- High frequency design
 - Reduces copper losses
 - Smaller, lighter magnetic components = compact/low weight
- Uses new, state-of-art power devices
 - Takes advantage of newer/more advanced semiconductors



11

SW Series

- Off Grid / Primary Power
- Backup Power
- Sell PV power back to utility / provide backup power
- Battery charger standard
- Sine wave output power
- Low frequency design topology
- 2.5, 4.0 & 5.5 kW 120 VAC 60 Hz
- 3.0 & 4.5 kW 230 VAC 50 Hz
- Most features of any inverter in the world – complex, but many variable programming options
- Over 30,000 sold worldwide



12

DR Series

- Off Grid / Primary Power
- Backup Power
- Battery charger standard
- Modified sine wave output power
- Low frequency design topology
- 1.5, 2.4, 3.6kW 120 VAC 60 Hz
- 1.5, 2.4 230 VAC 50 Hz
- 12 & 24 Volt
- High Surge Capacity
- Simple to install and use



13

C Series Charge Controllers

- Interface between DC and battery for charging
- 12, 35, 40, or 60 amps
- Solid state, electronically controlled, pulse width modulated (PWM) controllers
- Stand-alone lighting system controller (C12)
- Charge and diversion controllers (C35, C40, and C60)
- Optional temperature compensation
- Adjustable charge control set points
- Rugged & reliable



14

PV Series Product Overview

- Three-phase grid connect PV inverter for commercial, industrial and utility scale applications
- Three product platforms comprising 10 distinct models
- Single Stage DC to AC Inversion



- Single, “central” inverter minimizes installation and maintenance costs in large commercial applications

15

Real-World Installations

PV150 (34) 5.1MW - Tucson Electric Power
99.92% Inverter Availability in 2005



16

Key Requirements

		Xantrex
High efficiency	• Maximizes rebates and minimizes PV	✓
Sealed design	• No external contaminants, no filters to clean, higher reliability	✓
Communication capabilities	• Flexible options including free GUI to maximize uptime	✓
Low part count	• Better reliability and maintainability	✓
Low weight	• Easier to transport and install	✓
AC Disconnect on transformer output and soft start circuit	• Reduce tare loss and transformer inrush	✓
Wide MPPT Voltage Range	• Covers all temperature conditions and module types	✓
Negative & Positive Ground Arrays	• Allows use with positive ground modules	✓
FCC Part B compliant	• Less potential interference with communication, radio, and consumer electronics	✓
Meets all applicable codes including UL1741 and IEEE 1547	• Inverters can be installed in any jurisdiction	✓

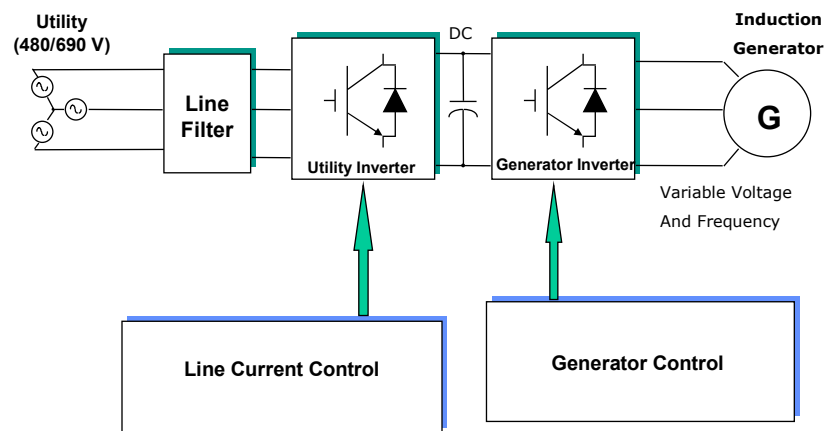
17

Power Electronics for Wind Applications

- Convert variable frequency and Voltage AC from generator to grid compatible AC
- Commercial scale – MW
 - Typically installed in North America in large “windplants” – similarities to central generation
 - Ride-Through – FERC requirements
 - Communications – utility SCADA
- Small Wind <30KW
 - Residential
 - Systems sometimes incorporate storage for off-grid or backup applications

18

Xantrex Converter Technology For Induction Generator



19

Xantrex Wind Converter Products

**410kW Windturbine
and Converter
33 Meter Blade
Diameter**



20

Xantrex Wind Converter Products

**750kW Windturbine
and Converter
50 Meter Blade
Diameter**



21

Xantrex Wind Converter Products

**1.5MW Windturbines
and Converter
70 Meter Blade
Diameter**



22

Xantrex Wind Converter Products

**2.5MW Windturbine
and Converter
93 Meter Blade
Diameter**



23

Power Electronics for Other DER Applications

- Xantrex has Experience with Power Electronics for other Distributed Energy Resource Applications
 - Fuel Cells
 - Microturbines
 - Advanced Energy Storage
 - Flow Batteries
 - Superconducting Magnetic Energy Storage
 - Fly Wheels
 - Large Hybrid Systems
- Relatively small volumes
- Xantrex approach is to leverage from wind and solar

24

Xantrex R&D

- Internal development activities
 - Wind is OEM product designed for each turbine
 - Advanced solar products
 - Other DER applications based on practical business case
- Sandia High Reliability Inverter Program
 - Residential Solar inverter incorporating storage
- NREL PV Manufacturing R&D Program
 - 500kW Solar Grid Interactive product
- We support DOE Systems Driven Approach and Solar America Initiative goals
- Goal of reducing cost of energy (\$/kWhr) is key!

25

Future DER Power Electronics Direction

- Optimal SYSTEM design
- Including "Balance of Systems" components
- Higher Performance Systems
 - Higher Reliability
 - Higher Efficiency
 - Longer Life
 - Lower Levelized Cost of Energy (LCOE)
 - Easier Installation
- CEC leading in setting high expectations for system performance requirements

26

Future Direction

- Support for Higher Penetration Levels
- Wind must meet FERC interconnect standards
- Wind – Ride Through and Grid Support (VARS)
- Solar UL 1741 and IEEE 1547
- Solar – Anti-Islanding and Unity Power Factor
- Likely to come together
- Other DG sources will follow – eventually
- Possibility to move to “Feed-In Tariff” incentive model in US more broadly
 - Maximize Energy Delivered (kWHrs)
 - Incentive to optimize all system elements

27

Thank You!

28



Power Electronics for DER & Renewable Applications

Northern Power Systems
CEC DE Workshop
August 24, 2006



Northern Power Systems

- Subsidiary of Distributed Energy Systems (DESC)
- High reliability power systems, products, and services
- 225 employees
- HQ and manufacturing facilities in Vermont
- Regional domestic and international offices for sales and service



Northern Power Business Segments

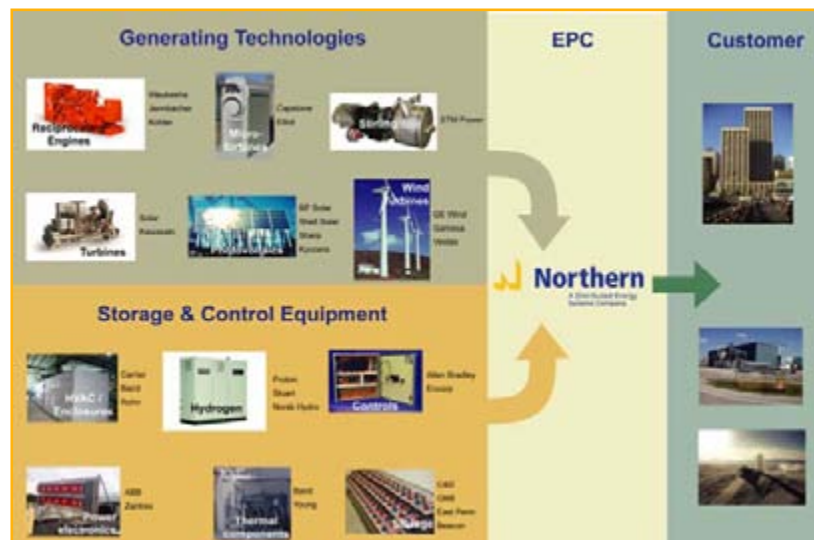
- Distributed Generation
 - Commercial
 - Industrial
- Remote power systems
 - Oil & Gas
 - Industrial infrastructure
 - Village Power
- Renewable power systems
 - Wind
 - PV
 - Biofuels



3

© 2006

Northern EPC Approach



4

© 2006

Power Electronics for DER Applications

Drivers for increased PE use

- New DER technologies require PE interface
 - DC, variable speed, non 50/60Hz generation and storage devices
- Use of advanced PE enables additional features and value across applications
 - Standardized interface for simpler interconnect approval
 - Advanced power system architectures
 - Utility distribution system support
 - Increased DER ancillary support capabilities
 - Increased DER penetration levels on distribution system



5

© 2006

Northern's Power Electronics Focus

- Flexible power converter platform for multiple markets
 - MW Wind
 - DER generation and storage assets
 - Utility support
- Control capabilities to enable advanced architectures
 - PowerRouter® control system
- Family of products to support advanced power systems
 - Fast DER switch for critical load support and microgrid applications
 - Site and fleet level energy management systems



6

© 2006

FlexPhase™ Power Converter Platform

Developed for wind and DER markets

- Modular converter system for 500kW to multi-MW applications
- Liquid and air cooled versions
- 480Vac, 690Vac versions
- Rack-in power modules
- Configurable power modules
 - DC-AC, AC-DC, DC-DC,
 - uni- or bi-directional power



7

© 2006

FlexPhase™ Power Module Features



- Bi-directional DC-AC or DC to DC power conversion
- Small footprint & high power density: 2.2 kVA/kg (1,956 kVA/m³) liquid cooled
- Flexible universal control architecture
- Include filtering and magnetics
- EMI controlled at module level
- Internal sensing with built in calibration
- Install and extract like draw-out circuit breakers
- Low mean time to repair



8

© 2006

FlexPhase™ Converter Platform Applications



9

© 2006

FlexPhase™ Platform Features & Benefits

- Modularity
 - Configurable for multiple applications and power ranges
 - Exchangeable modules for easy service and support
 - Low Mean Time To Repair
- High performance
 - Full grid support capabilities
 - Ride-through, VAR support, harmonic correction
 - Very low harmonics (<1%THD capability)
 - Reduced stress, longer life for generator and motor windings
 - PowerRouter® control system enables microgrid operation
 - Peer to peer aggregation of DER generation and storage assets
 - No high speed communication required
 - Modeless transition between grid & isolated operation
- Cost
 - FlexPhase design allows reduction in power switch costs
 - Modular design well suited for reduced manufacturing cost
- Size
 - High power density for reduced footprint



10

© 2006

Northern Current DER Applications

Trend to use PE with conventional DER assets

- Standardized grid interface across applications
- Elimination of fault current contribution
 - Simplifies interconnect approval
 - Allows interconnection to constrained systems
- Adds variable speed capability
- Enables advanced power system architectures
 - PowerRouter® controls
 - Microgrid and critical load support applications
 - PowerDistributor™ system
 - Interconnect DER asset(s) to multiple service entrances



11

© 2006

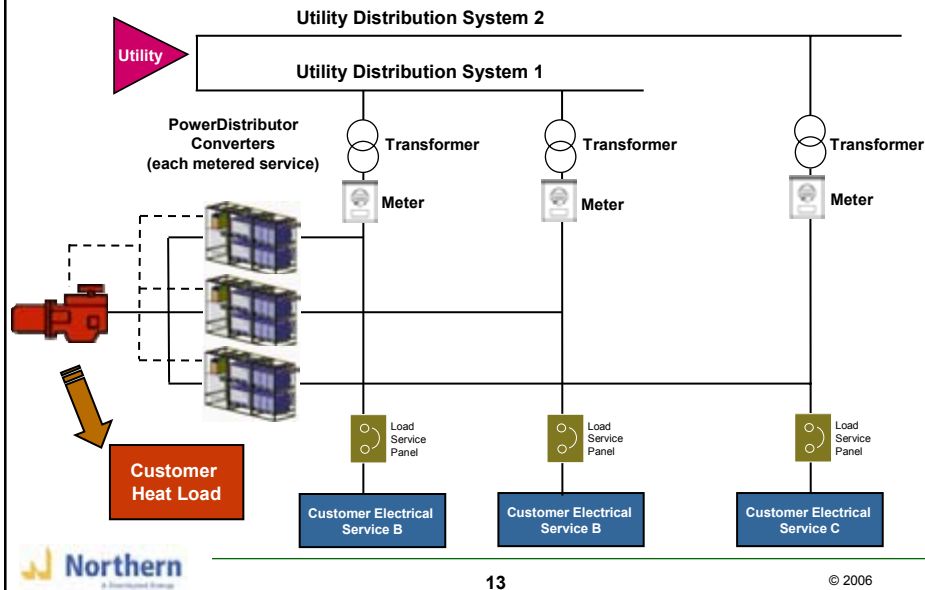
MicroGrid Power Network Test System



12

© 2006

PowerDistributor™ DER System

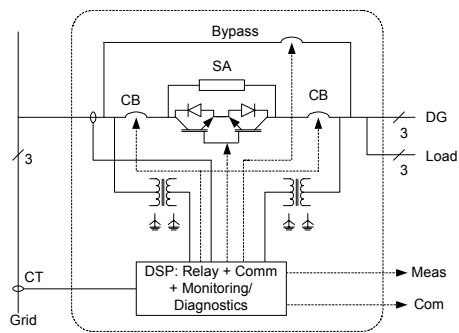


13

© 2006

DER Utility Interface Switch

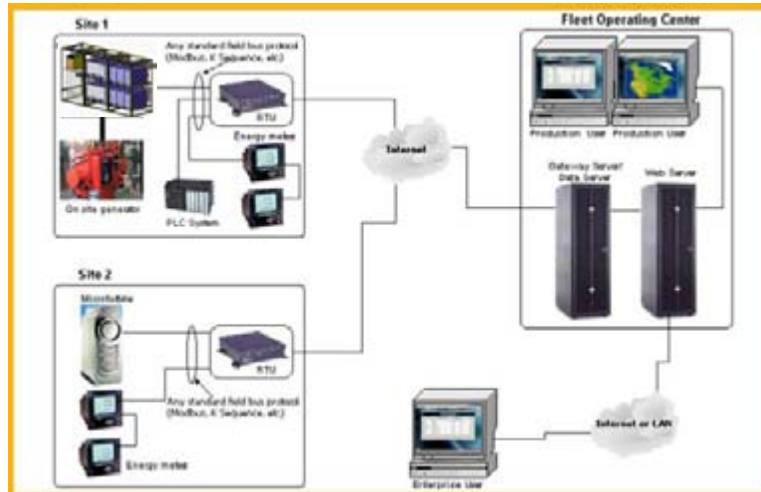
- Flexible, universal interface for connecting single or multiple DER systems
- Controls for CB, SCR, or IGBT switching modules
- Enables
 - Critical load support
 - Intentional islanding
 - Enhanced power quality
 - Anti-islanding protection



14

© 2006

SmartView® DER Management System



15

© 2006

For more information, contact:
Jonathan Lynch
(802) 583-7224
jlynch@northernpower.com

Northern Power Systems
 182 Mad River Park
 Waitsfield, Vermont 05673 USA
www.northernpower.com



16

© 2006

SMA America Advanced Power Electronics Interfaces Workshop



August 24, 2006



Who We Are And What We Do

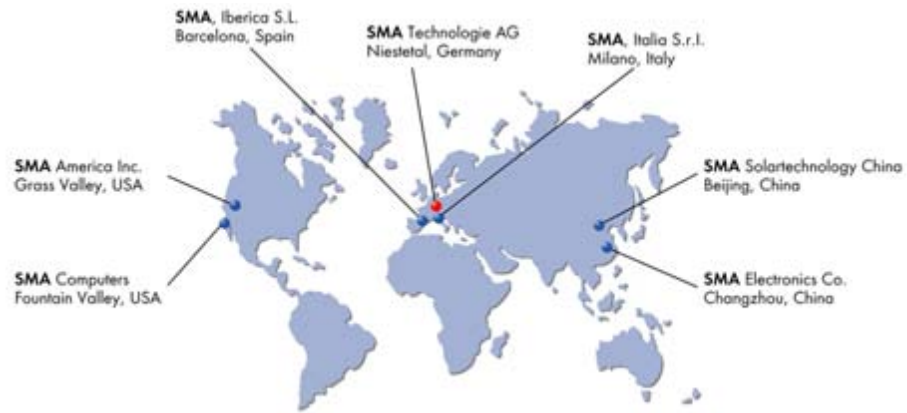


- Founded in 1981
- Headquartered in Niestetal, Germany
- Approx. 1,200 employees worldwide, more than 15 % are engineers
- Technology leader and trend-setter
- Privately held Ag corporation



2

Where We Are



- Office recently opened in Korea



3

Product areas



	SOLAR TECHNOLOGY System technology for photovoltaics
	COMMUNICATION & CONTROL Industrial computer technology for control and communication
	RAILWAY TECHNOLOGY Power supply systems for local and long-distance traffic
	INNOVATIVE ENERGY SYSTEMS Solutions for decentralized power supply



4

Synergies of key competence areas



5

US Inverter Products and Applications



■ Residential PV, Small Wind, Hydro

- SB1800U, SB2500U
- SB700U, SB1100U
- SB3300U, SB3800U, SB6000U



■ Commercial PV

- SC125U



■ Back-up Power and Off-grid

- SI4248U (partially funded by PIER)

■ AeroSmart Wind Turbine

- Further expansion of product family by 2007



6

Trendsetting Communication Services



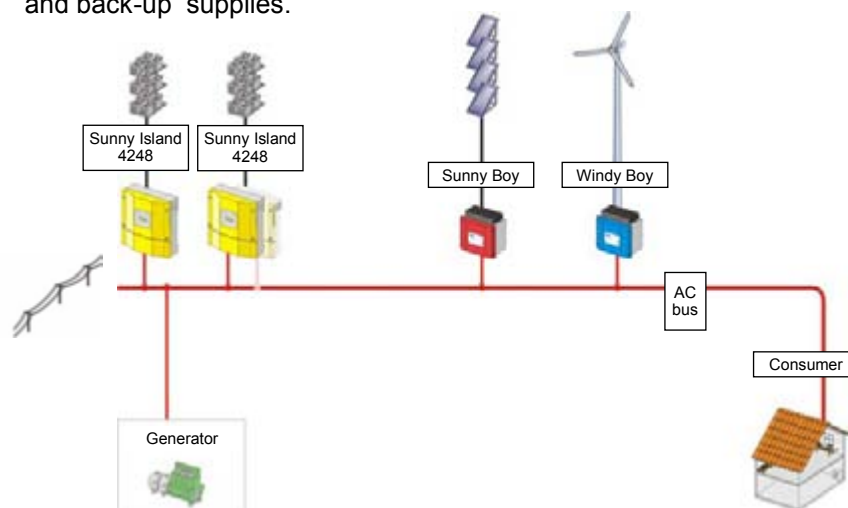
- Communication products
 - Web Box
 - Communication hub and system data logger
 - Sunny Portal
 - Free internet system performance server
- Services
 - Automated notification of performance and system alarms.
 - Automated performance analysis and notification



The Future of Distributed Energy



AC coupling: The best solution for flexibility and efficiency of off-grid and back-up supplies.



Design Improvements



- Opti-Cool forced-air cooling
- IGBT skip-packs
- Integrated aluminium enclosure and heat-sink
- Ethernet communication
- Load-break rated DC fused disconnect
- HALT/HASS testing

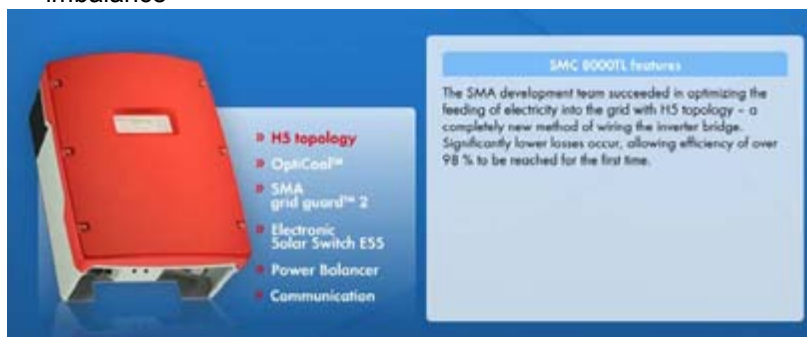


9

New Inverter Family Introduction



- Over 98% peak efficiency inverter topology
- Advanced communication and control features
- System performance analysis
- Intelligent off-grid & back-up power integration
- Intelligent three-phase integration to prevent generation imbalance



10

Recent History in the PV Market



- PV module prices increase 30% in 2 years.
- Inverter competition is high due to PV module shortages.
- IEEE-1547.1 has doubled regulatory certification costs (apr. \$100,000 per inverter).
- One time CEC rebate system rewards on name-plate ratings rather than system performance.
- CEC rebate continues to decline (\$2.60 per Watt).
- Copper, steel, specialty metals increased 40% in the last year.

- SB1 passed, rebate may return to \$2.80 per Watt.
- CEC Pilot Performance-Based Incentive Program is a step in the right direction.



11

Recent History at SMA



- SMA has reduced inverter prices by 20% over 2 years.
- Our aim is 5% per price reduction per year.
- Reliability and functionality has dramatically improved with new products.
- Advanced communication products positioned to:
 - Energy reporting for performance based incentives.
 - REC recording and trading



12

Moving Forward



- Shift to performance based incentives
 - Define equipment and metering requirements.
- Acceptance of transformerless inverter technologies by AHJ's
 - Immediate adoption of the NEC-2008 Article 690 upon publication.
- Ease regulatory requirements
 - UL has become a barrier to flexibility, responsiveness and innovation.
- Streamline accounting/reporting requirements for PIER funding to attract established companies.



13



Kent Sheldon
Sales Support Manager

SMA-America, Inc.
12438-C Loma Rica Drive
Grass Valley, CA 95945
530.273.4895 ext 107
www.sma-america.com



14

Appendix E. Additional Resources

Power Electronics Activities at ISET

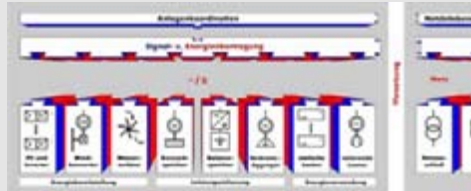
**Power Electronics for Grid Interfacing
Power Quality
Microgrids
Stand-alone Systems**

Dr.-Ing. A. Engler



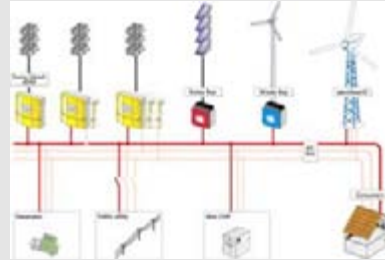
This presentation gives an overview about ISET's power electronics activities with regard to DER and grid integration

Modular Systems Technology



Concept, proof of concept
1993 - 1998

Components, control
1998 - 2001
Source: SMA Technologie AG



Interconnection, communication,
protection, EMS, 2001 - 2005

APEI-Workshop, August 2006, Dr. Ing. A. Engler



„Modularity“ has been a major topic at ISET for about 15 years!

E. g. within the frame of three national projects a modular concept has been developed. A whole DER-component family has been developed and transferred to commercial products (SMA). The next step have been the integration and interconnection issues.

Development of PV- and Battery Inverters



Hardware of PV-Inverter

Hardware of Battery-Inverter

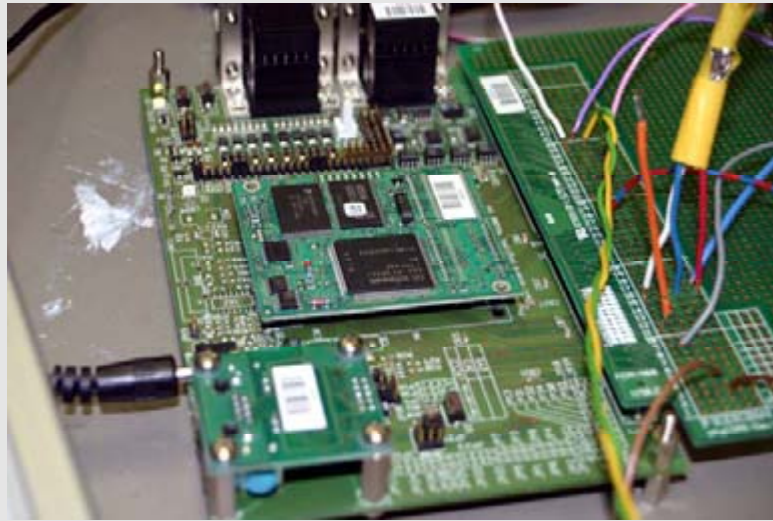


APEI-Workshop, August 2006, Dr. Ing. A. Engler



Development of commercial inverters in the kW-range for major PV-companies as SMA, KACO, etc.

Code Generation for Embedded Controllers



APEI-Workshop, August 2006, Dr. Ing. A. Engler

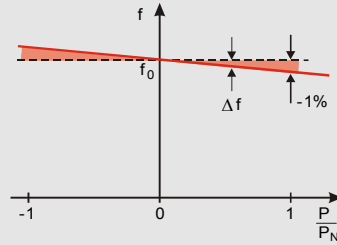


Embedded code generation by means of modern development tools enabling partially graphical implementation.

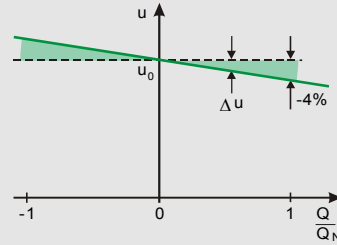
selfsync®: Droop control for inverters (patented in Europe and US)

5

Inverters are controlled by droops:



Frequency droop



Voltage droop

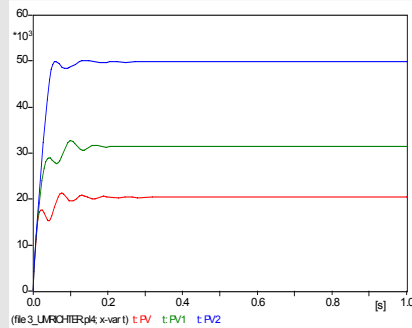
The special implementation of droops with the **selfsync®** algorithm enables synchronisation and load sharing of inverters without communication!

APEI-Workshop, August 2006, Dr. Ing. A. Engler

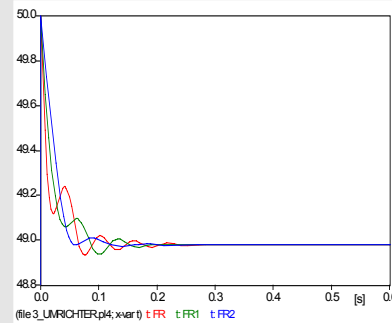


Development of efficient control algorithms especially for stand-alone systems and Microgrids.

Load sharing and frequency change (selfsync®)



Loadsharing: contribution depends on set-point of the idle frequencies



Frequency could be restored by a secondary control

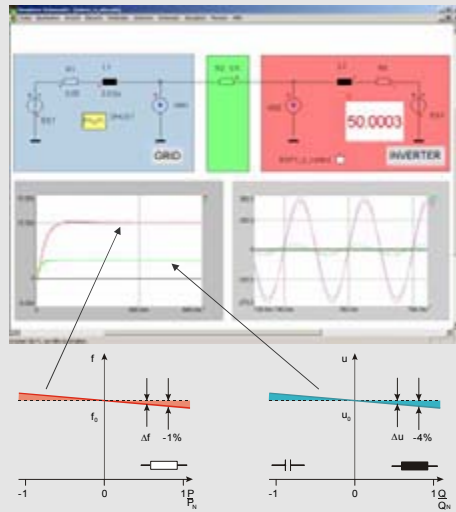
APEI-Workshop, August 2006, Dr. Ing. A. Engler



Selfsync® enables load sharing between inverters better than 1 %!

„Indirect operation“ of droops in case of resistive coupling (LV-case)

7



- Applied droop concept is based on inductive coupled voltage sources.
- In a LV-grid components are coupled resistively, thus voltage determines the active power distribution
- There are two effects of droops
 - **direct** (inductive coupling)
 - **indirect** (resistive coupling)
- The „indirect“ effect requires droops, which have the same sign for the frequency as well as the voltage droop and therefore the stable operation point is „in phase“.

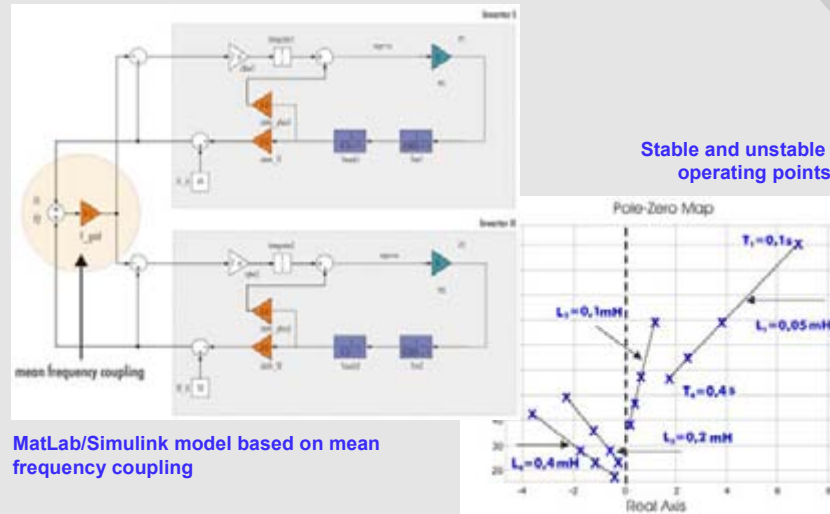
APEI-Workshop, August 2006, Dr. Ing. A. Engler



Selfsync® is applicable in LV-, MV and HV-Grids!

Stability assessment of multi-inverter systems (selfsync®)

8



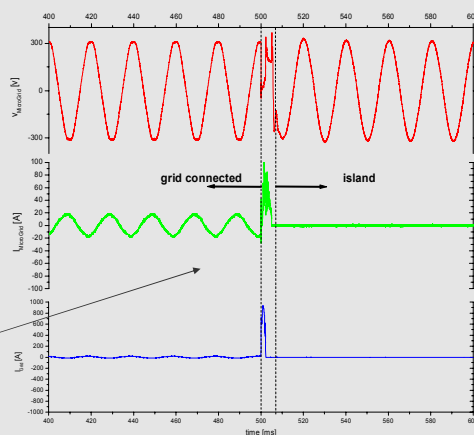
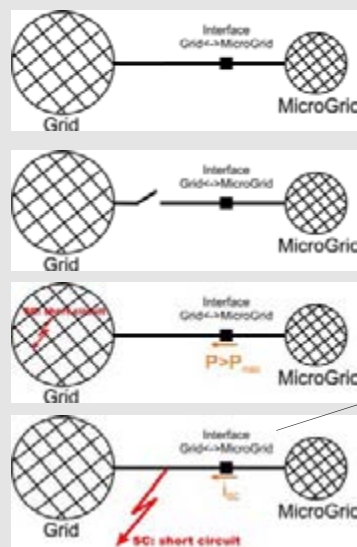
MatLab/Simulink model based on mean
frequency coupling

APEI-Workshop, August 2006, Dr. Ing. A. Engler



Inverters co-ordinated with selfsync® are scalable: One can operate as many inverters in parallel as necessary. They can be of different size (practically a ratio of 1 : 100 shouldn't be exceeded). By special means even dynamical loadsharing can be ensured.

Electronic switch: possible faults (selfsync®)

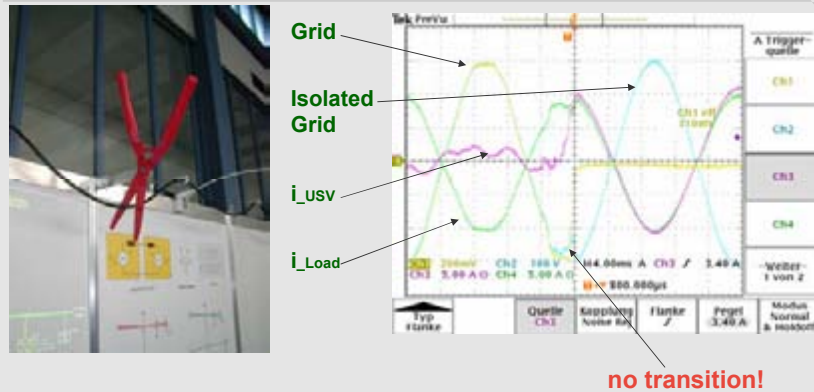


APEI-Workshop, August 2006, Dr. Ing. A. Engler



Selfsync® masters all possible grid faults, even near short circuits. A fast disconnection device is required.

High Impedance Grid fault (selfsync®)



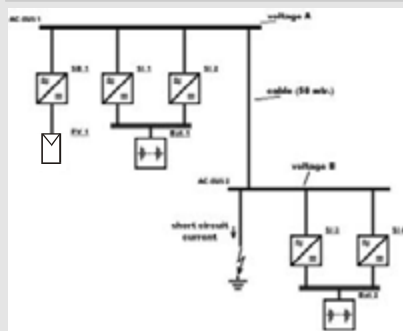
Principally the suggested control mode also continuous operation even in case of a line interruption. A **grid failure** mostly results not in an interruption but in a **short-circuit** and therefore motivates the development of a **disconnection device**!

APEI-Workshop, August 2006, Dr. Ing. A. Engler

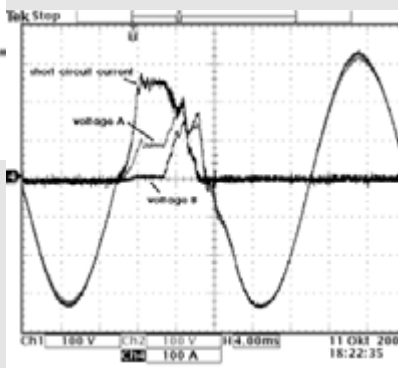


As the operation mode is not changed between island und grid operation, there is almost no transition time.

Increasing short circuit power (selfsync®)



Single phase inverter grid
(DeMoTec, ISET)



Short circuit:
triggering a circuit breaker

APEI-Workshop, August 2006, Dr. Ing. A. Engler



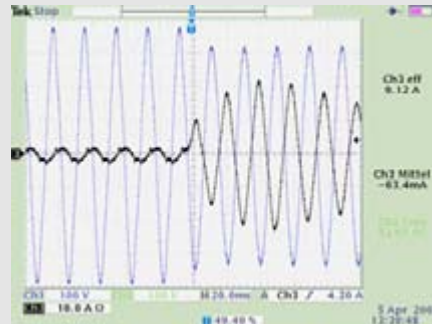
Standard protection devices can be used with Selfsync® .

Parallel operation of an ASG and Sunny Islands (selfsync®)

Load sharing between Sunny Island and genset is possible due to the inherent frequency / active power characteristic of the genset (slip, mechanical controller)



Single phase genset with ASG and capacitor (Fa. Kirsch)



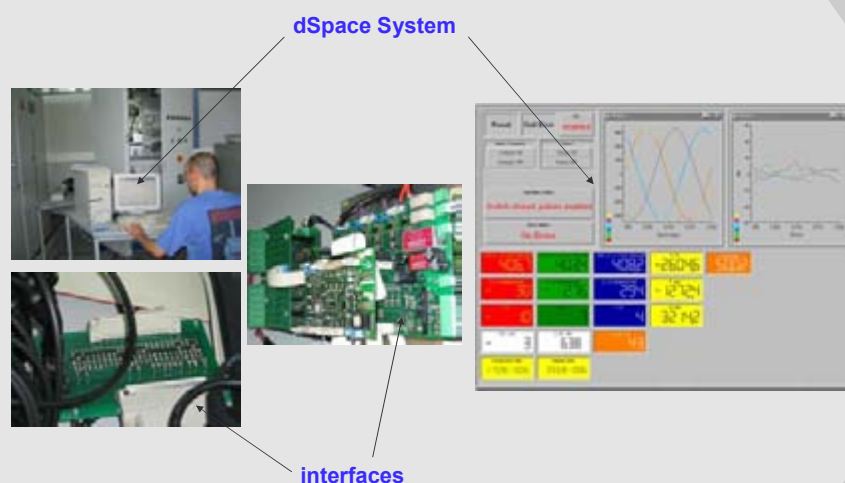
Synchronising a Sunny Island onto the genset (idle frequency set for charging)

APEI-Workshop, August 2006, Dr. Ing. A. Engler



Selfsync® is compatible with standard diesel gensets.

Rapid prototyping of 100kVA inverter control



APEI-Workshop, August 2006, Dr. Ing. A. Engler



ISET develops advanced control algorithms for 100 kVA to 1 MVA inverters.

General Advantages of „Rapid Prototyping“:

- Control algorithms are developed using MatLab/Simulink simulation software. Tested and working models can directly be used in the prototype.
- Automatic code generation for the architecture of the Rapid-Prototyping-System.
- Integration of custom C-code possible
- Quick and effective development even of advanced control algorithms due to high computing power of the Rapid-Prototyping-System.
- Online visualization of all variables
- Adjustment of variables i.e. controller parameters during operation

Development of Power Quality Equipment with rapid prototyping

14

Prototype, 3.3 kVA, 16 kHz switching frequency, usable energy storage 470 Ws



Host PC with integrated Rapid-Prototyping-System

Distorting load, Dimmed light bulbs

Power Quality Monitoring equipment

External interface board of the Rapid-Prototyping-System

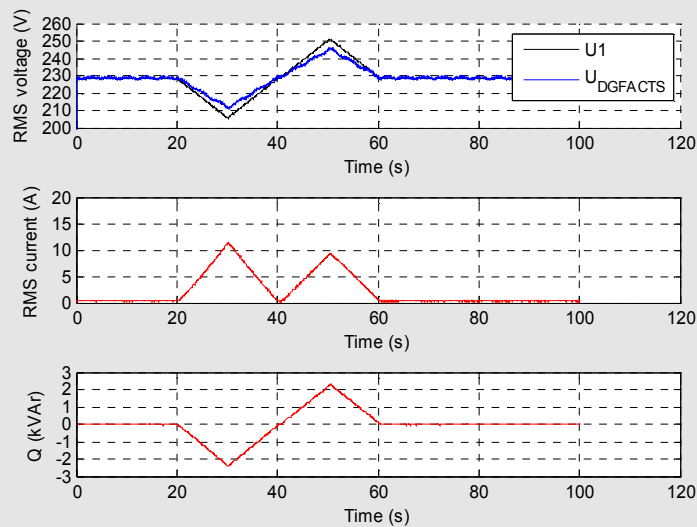
APEI-Workshop, August 2006, Dr. Ing. A. Engler



Realised functions:

- Voltage dependent supply of reactive power (Q droop)
- Dynamic reactive power compensation of dedicated loads
- Dynamic harmonics compensation of dedicated loads
- Flicker reduction
- Local improvement of voltage quality by inductively decoupled sub-networks

Development of Power Quality Equipment: Q-Droop: Grid Support with Reactive Power



Inverter injects reactive power according to the line voltage and supports it depending on the line impedance

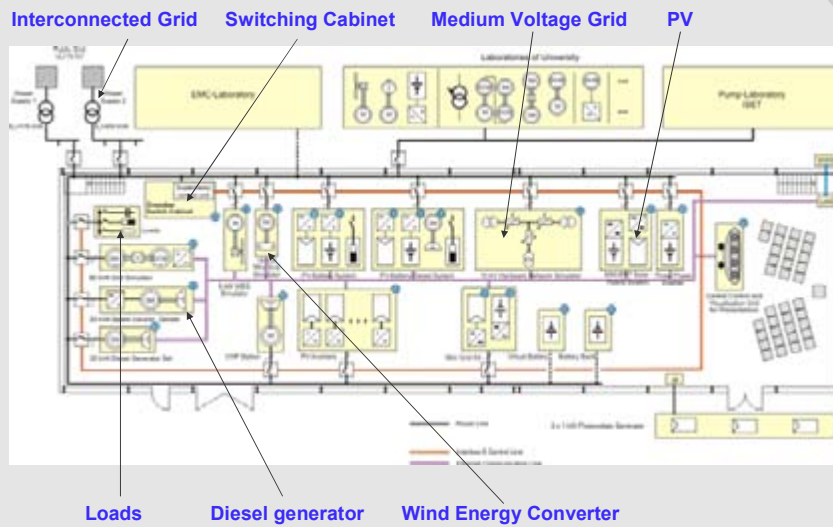
APEI-Workshop, August 2006, Dr. Ing. A. Engler



Realised functions:

- **Voltage dependent supply of reactive power (Q droop)**
- Dynamic reactive power compensation of dedicated loads
- Dynamic harmonics compensation of dedicated loads
- Flicker reduction
- Local improvement of voltage quality by inductively decoupled sub-networks

DeMoTec at ISET

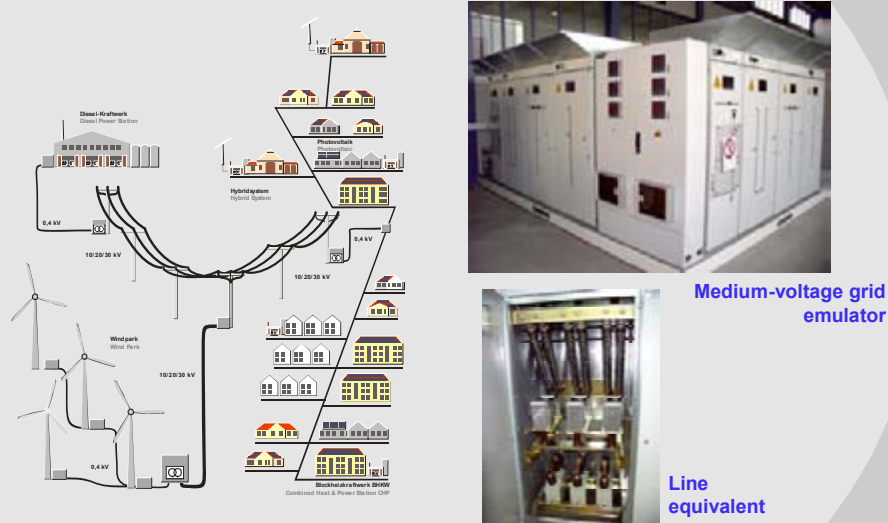


APEI-Workshop, August 2006, Dr. Ing. A. Engler



The design, demonstration and test center (DeMoTEC) at ISET enables a variety of relevant tests for DER-components.

Interconnecting distribution systems (MV- and LV-Grids)

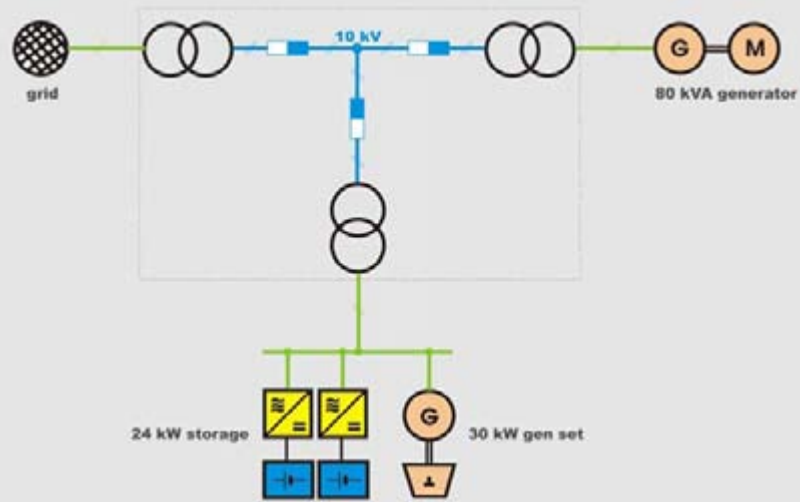


APEI-Workshop, August 2006, Dr. Ing. A. Engler



The Medium voltage grid emulator enables test of equipment for MV-distribution systems.

Example for laboratory installation

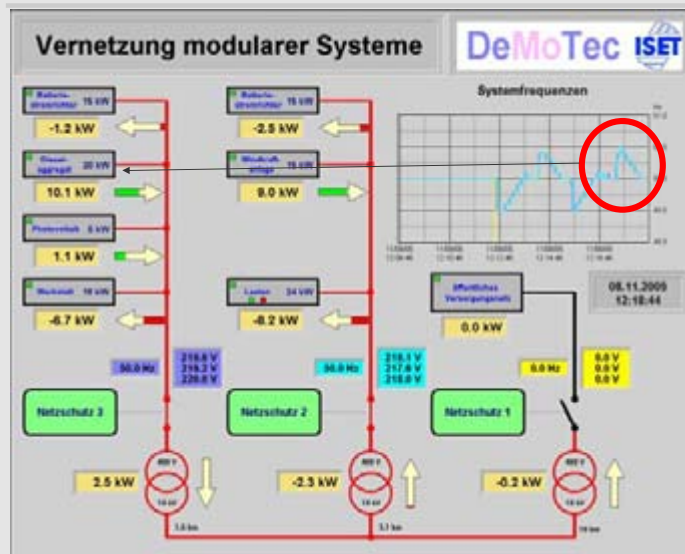


APEI-Workshop, August 2006, Dr. Ing. A. Engler



Laboratory demonstration
- Starting diesel genset (tertiary control) -

19



Screenshot
Of
SCADA-System

APEI-Workshop, August 2006, Dr. Ing. A. Engler



The development of SCADA-Systems and supervisory control algorithms enables energy management of grid connected or remote hybrid systems.

Greek Island Kythnos



APEI-Workshop, August 2006, Dr. Ing. A. Engler



Example of small hybrid system installed by ISET and SMA.

Greek Island Kythnos



APEI-Workshop, August 2006, Dr. Ing. A. Engler



Example of small hybrid system installed by ISET and SMA.

Conclusion

- ISET develops power electronics for commercial production
- ISET develops advanced control algorithms for grid interfacing
- ISET is able to test equipment in laboratory and field tests
- ISET is a non-profit organisation

ISET e. V
Königstor 59
34119 Kassel
Germany

APEI-Workshop, August 2006, Dr. Ing. A. Engler



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE (DD-MM-YYYY) October 2006			2. REPORT TYPE Proceedings		3. DATES COVERED (From - To) 08/24/06	
4. TITLE AND SUBTITLE Advanced Power Electronics Interfaces for Distributed Energy Workshop Summary: August 26, 2006, Sacramento, California					5a. CONTRACT NUMBER DE-AC36-99-GO10337	
					5b. GRANT NUMBER	
					5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) B. Treanton, J. Palomo, B. Kroposki, and H. Thomas					5d. PROJECT NUMBER NREL/BK-581-40480	
					5e. TASK NUMBER WW88.2005	
					5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Renewable Energy Laboratory 1617 Cole Blvd. Golden, CO 80401-3393					8. PERFORMING ORGANIZATION REPORT NUMBER NREL/BK-581-40480	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S) NREL	
					11. SPONSORING/MONITORING AGENCY REPORT NUMBER	
12. DISTRIBUTION AVAILABILITY STATEMENT National Technical Information Service U.S. Department of Commerce 5285 Port Royal Road Springfield, VA 22161						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT (Maximum 200 Words) The Advanced Power Electronics Interfaces for Distributed Energy Workshop, sponsored by the California Energy Commission Public Interest Energy Research program and organized by the National Renewable Energy Laboratory, was held Aug. 24, 2006, in Sacramento, Calif. The workshop provided a forum for industry stakeholders to share their knowledge and experience about technologies, manufacturing approaches, markets, and issues in power electronics for a range of distributed energy resources. It focused on the development of advanced power electronic interfaces for distributed energy applications and included discussions of modular power electronics, component manufacturing, and power electronic applications.						
15. SUBJECT TERMS power electronics; distributed energy; DER; workshop; advanced power electronics initiative; California Energy Commission; CEC; National Renewable Energy Laboratory; NREL						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UL	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER (Include area code)	

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18