DISTRIBUTED ENERGY RESOURCES INTEGRATION RESEARCH PROGRAM
Power Electronics Research Assessment

CONSULTANT REPORT

Prepared For:

California Energy Commission
Public Interest Energy Research Program

Navigant Consulting, Inc.

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DER Integration Research Program
Power Electronics
Research Assessment

December 2004

Prepared for the

Public Interest Energy Research (PIER) Program

California Energy Commission

The CEC asked Navigant Consulting to provide input into the Distributed Energy Resources Integration research agenda for power electronics.

- Objective
  - To identify gaps in the research programs being conducted currently and in the near future 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
  - Includes the identification and assessment of research gaps in Power Electronics technologies used in DER applications. The analysis will focus on Power Electronics technologies used in distributed generation systems (e.g., fuel cells, PV and microturbines) and distributed energy applications (e.g., inverters, un-interrupted power supplies and energy storage).
  - Includes recommendations for specific research initiatives and approaches.

NCI recommends 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.
- Consider participation in the Consortium for Advanced Power Electronics and Storage

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

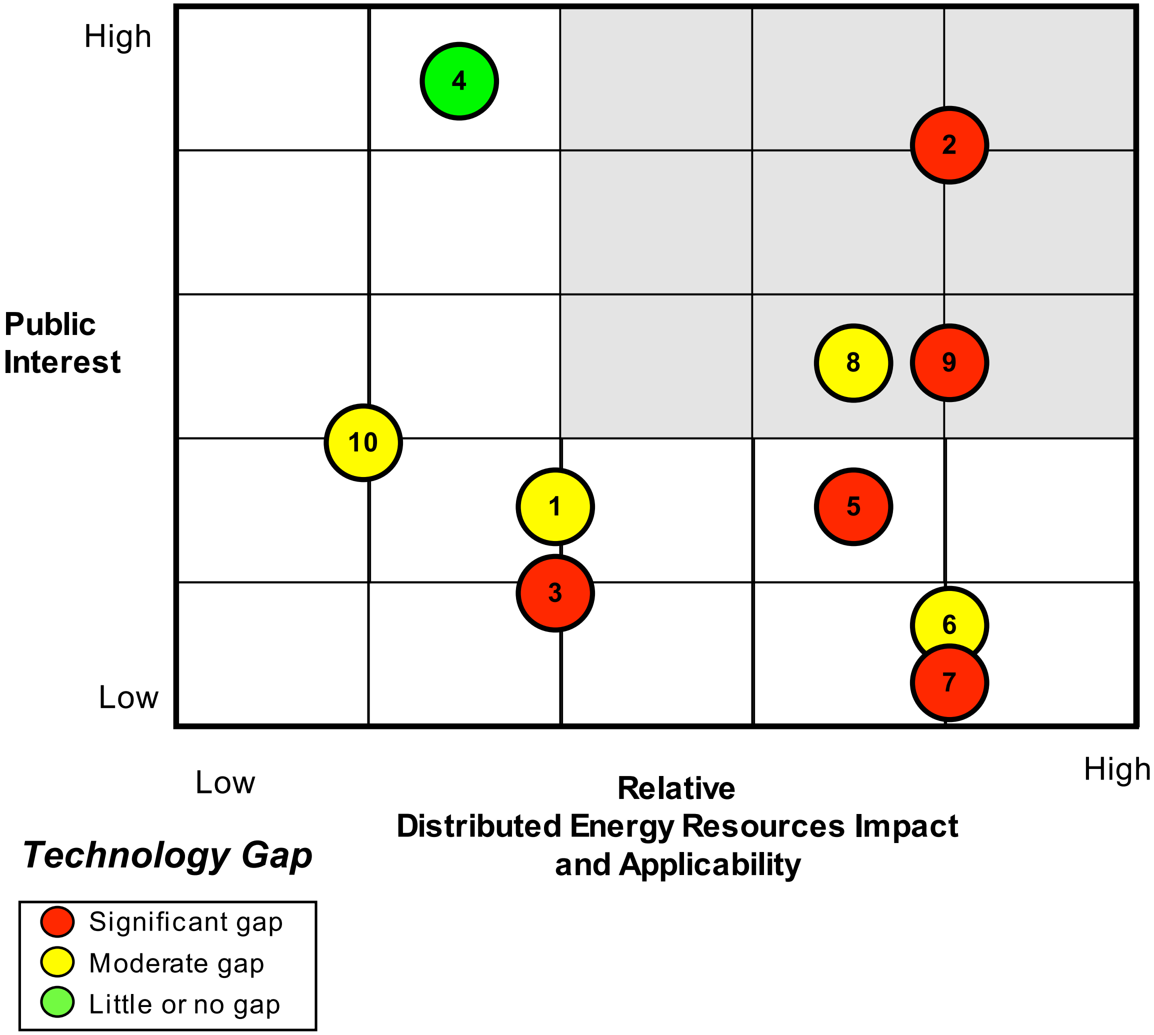
Technology Challenges

- There is a lack of standardization and the inter- and intra-operability of power electronic systems, components and the grid. This increases the cost of manufacturing, impacts reliability, and limits application by system developers.
- Power electronic devices must be modular and scalable. This will simplify applications and designs, leading to increased use; higher production volumes will lower costs and improve performance.
- Current research focuses on power electronic subsystems and component rather than the DER system package. Improvements in the system package are greatest need for DER.

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 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

Priority research initiatives that the CEC should consider are those that have large technology gap, high public benefit and high DER applicability.



Research Initiatives

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  - Includes recommendations for specific research initiatives and approaches.

The fundamental building block of power electronics is the semiconductor-based switch device, a technology that has existed for many decades.

In general, the term power electronics refers to semiconductor-based switching devices (e.g., transistors and thyristors), and the various systems that they comprise (see table below). In power applications, these electronic switches are most often employed to create or convert voltage and current waveforms. The table below shows the names by which common power electronics systems are known.

Benefits of power electronic switches include switching speed, package size, and the ability to be finely controlled by other electronic systems and software.

Power Conversion	Common Names
AC-to-DC	**Rectifier**
DC-to-AC	**Inverter**
DC-to-DC	**“boost”, “buck”, “buck-boost”, “chopper”**
AC-to-AC	**Converters (variable freq. input, fixed freq. output)**

For Distributed Energy Resource applications, the most common power electronics systems are inverters and converters.

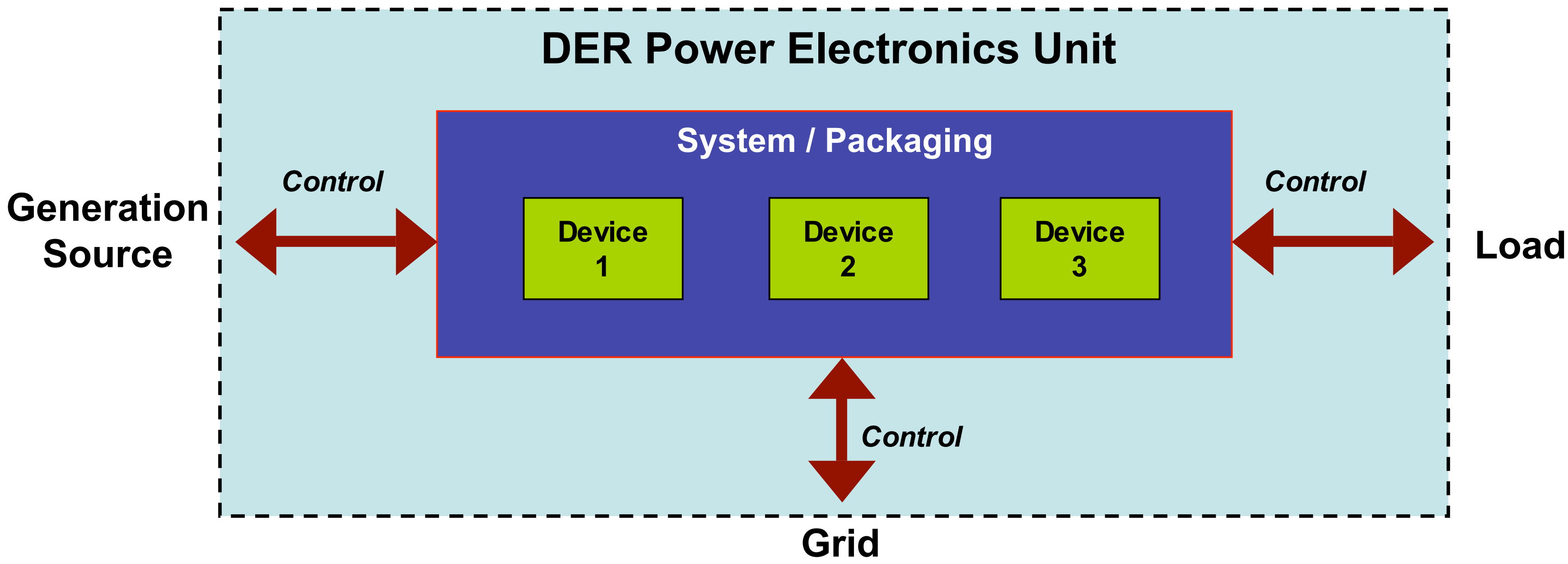
Source: http://www.sandia.gov/ess/Technology/technology.html

In addition to DER, Power Electronics applications are found in a variety of industries ranging from transportation to consumer products.

Sample of applications by industry

Industry	Applications		
Transportation	• Electric Vehicles • Electric Locomotives	• Electric Trucks, Buses, Construction Vehicles	
Manufacturing	• Machinery • Power Systems		
Consumers	• Air Conditioners/Heat Pumps • Appliances		
Medical Equipment	• Optical diagnostic equipment • Biotechnology research		
Military	• Naval Systems – Electric Ship – New Surface Ship Power Electronics – New Submarine Power Electronics	• Land Based Systems – "All Electric Tank" – "All Electric Armored Personnel Carrier"	• Aviation Systems – "More Electric" Aircraft
Distributed Energy Resources and Utilities	• Frequency Changes • Motor Controllers • Microcontrollers • Adjustable Speed Drives • Inverters • Breakers • Rectifiers • Converters	• Uninterrupted Power Supplies • Battery Chargers • Switch Gear • Actuators and Actuator Drives • Energy Storage • Pulse Power Systems	• Intelligent Machinery Controls & Network Simulation • Solid State Power Conditioning & Circuit Protection • Motors, Generators, & Motor Drives • Power Conversion - inverters for renewables (solar-hybrid systems, micro-turbines, fuel cells, wind turbines), HVDC • Flexible AC transmission system (FACTS) devices

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



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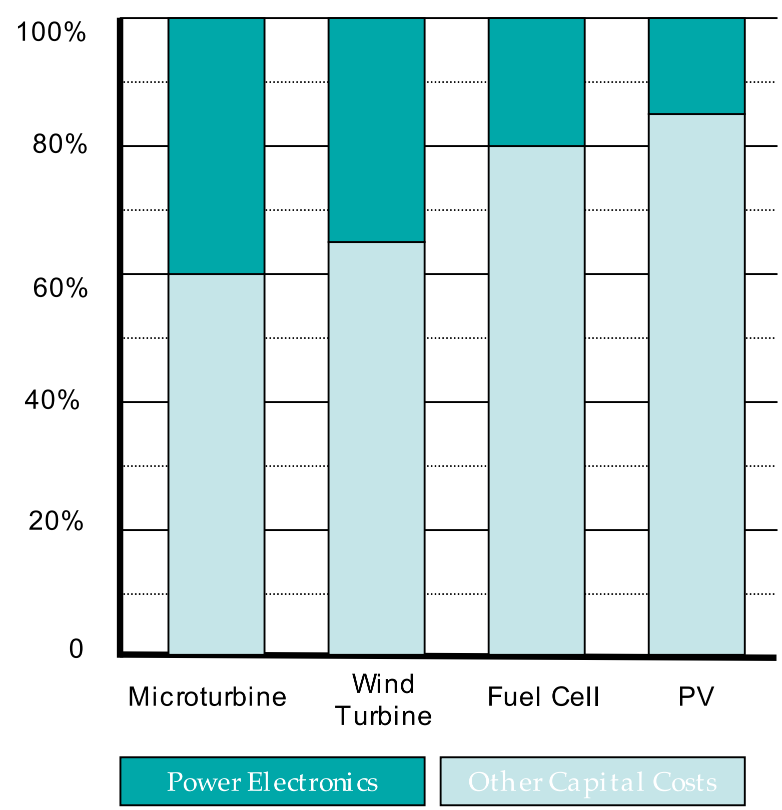
The power electronics activity can be classified into three fundamental areas: Devices, System / Packaging, and Controls.

	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	• The arrangement of devices • Devices can be 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	• 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

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%

DER total capital costs



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

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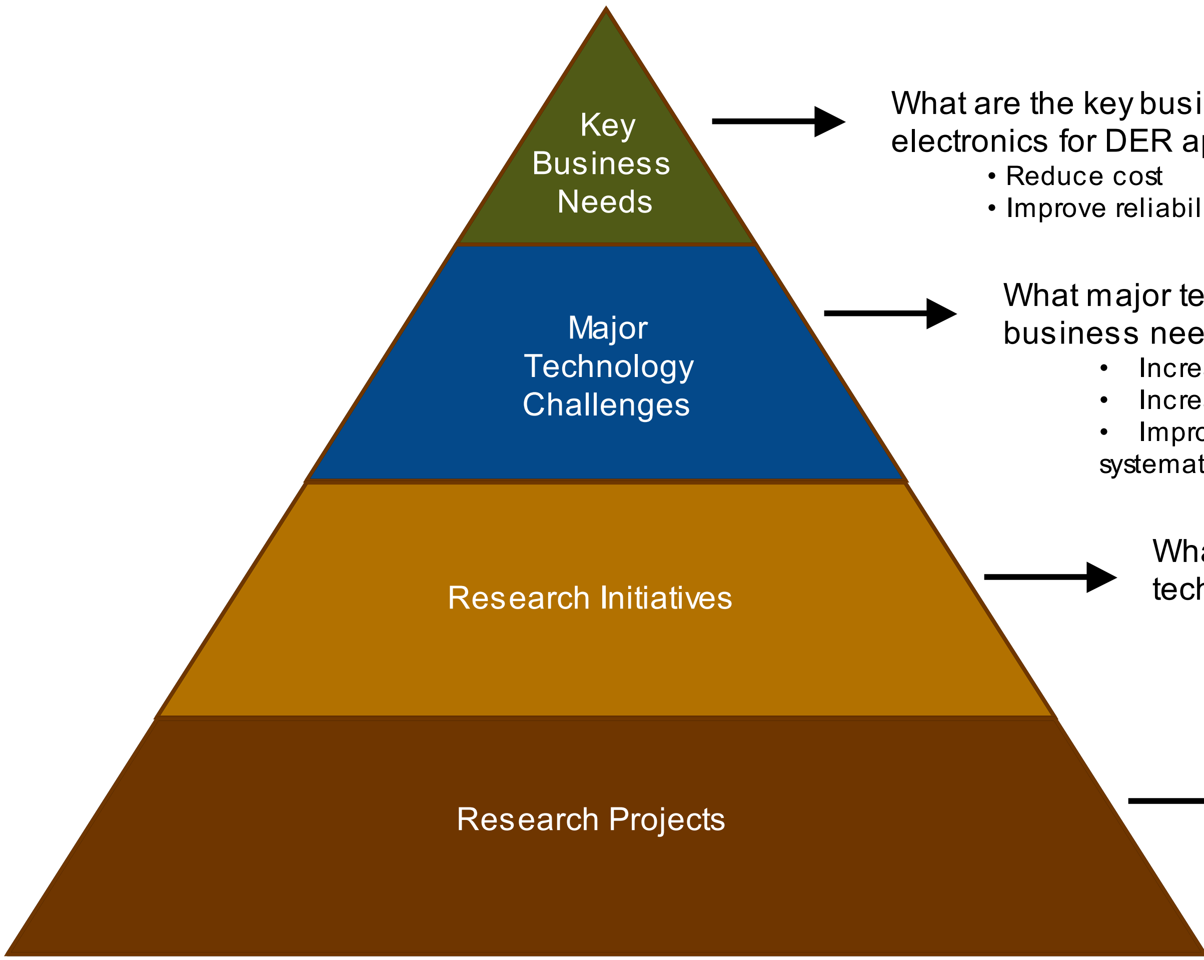
The key business needs surrounding the power electronic industry are to reduce cost and improve reliability, these needs should drive the technology and research agenda.



What are the key business needs surrounding power electronics for DER applications?

- Reduce cost
- Improve reliability

What major technology challenges are effecting the key business needs?

- Increased modularity and scalability
- Increased standardization and interoperability
- Improve performance, yet design power electronics systematically

What research is needed to overcome the technology challenges?

- Ten research initiatives were identified

How well does the current research address the research initiatives?

- 22 research projects were identified and a gap analysis was performed

Three major technology challenges exist when discussing power electronics for DER applications.

1. There is a lack of standardization and interoperability among power electronic components. This increases the cost of manufacturability and reduces volume and reliability.
2. Power electronic devices must be modular and scalable. This will simplify applications and designs, leading to increased use; higher production volumes will lower costs and improve performance.
3. To improve the performance of power electronics, devices, systems and controls should be coordinated, as well as the supporting R&D in each area.

There is a lack of standardization and interoperability among power electronic components and systems. This increases the cost of manufacturability and reduces volume and reliability.

"The market size goes hand in hand with reliability, quality and cost. You get a lot of these one-sies and two-sies out there, and reliability may not be the best using this approach."

National Laboratory

"What we need to do is to bring this [standardization] to the power electronics industry; integrate all channels of the design process. A project that I think is needed would look at the scalability of power electronic components."

University Laboratory

"Power electronics universal interconnect is key. Standardization and the ability to integrate different devices into the system are important."

Equipment Manufacturer

"[The CEC should] design and demonstrate low cost, reliable, cross-platform power electronic converters and interconnection. Standardized inverter requirements and design for cross platform use."

Equipment Manufacturer

"We don't have a plug and play solution and I don't see genset [generation service] manufacturers pre-packaging their units with interconnection systems."

Standards Laboratory

"My personal view is that any advanced circuit topology and controls for grid compatibility and DER compatibility would be worthwhile to achieve better performance, cost and reliability."

Equipment Manufacturer

Power electronic devices must be modular and scalable. This will simplify applications and designs, leading to increased use; higher production volumes will lower costs and improve performance.

"A project that I think is needed would look at the scalability of power electronic components."
University Laboratory

"Modularity [research for power electronics] is very interesting."
National Laboratory

"We need modularity to be able to [economically] size systems – this will help drive cost down."
National Laboratory

"The basic building blocks of power electronics are mature, but what are really needed are low cost, common modules that can be used in multiple markets."
Equipment Manufacturer

Devices, systems and controls should be coordinated, as well as the supporting R&D in each area.

"Getting up to 97%+ efficiency is very difficult, yet seen as critical for widespread DG adoption."

Equipment Manufacturer

"It is valuable to bring together researchers in power electronics, interconnection, and grid-side needs to look at the system as a whole. The value of component research cannot be fully utilized or understood if the problem is only examined at the component level."

University Laboratory

"All the research has been focused on components and new circuits rather than looking at the system to improve the reliability."

University Laboratory

To address these technical challenges, 10 research initiatives were developed and the research projects identified were matched against them.

1. Increase the efficiency of power electronic systems
2. Standardize the interface between power electronics systems and the grid
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A gap analysis was performed on the 10 power electronics research initiatives previously identified.

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Each research initiative was scored based on its relative Public Interest and Applicability and Impact on DER.

		Scoring		
Criteria		1	3	5
Public Interest	Commercial Incentive	Incentives exist	Limited incentives	No incentives
	Accrual of Benefits	Single stakeholder	Multiple classes of stakeholders	All classes, including ratepayers

Stakeholders include: DG customers, DG supplier, and non-DG customer utilities

		Scoring		
Criteria		1	3	5
Applicability & Impact on DER	Applicability	Not applicable to DER	Crosscutting	Specific to DER
	Impact	Negligible Impact	5% cost reduction or reliability improvement	10% cost reduction or reliability improvement

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

Significant gap | Moderate gap | Little or no gap

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	*Compact Diode-Clamped Multilevel Converter*. 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	*Distributed Energy Interface*. 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	*High Reliability Inverter Development*. 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	*ETO Thyristor Development*. 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	*Static Inverter Type Testing*. Improve reliability by developing a procedure type and verification testing of static inverter.

Significant gap **Moderate gap** **Little or no gap**

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

Significant gap   Moderate gap   Little or no gap

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.

Public benefit: There is significant public interest and multiple stakeholder classes will benefit.	5
Relative DER Applicability: 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	*Multilevel Universal Power Conditioner*. Improve the reliability of power electronics through the development of a multilevel universal power conditioner.
I	*Harmonic Elimination Technique and Multilevel Converters:* 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

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.

Public benefit: This initiative benefits primarily manufacturer and customer.	2
Relative DER Applicability: 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

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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	*Soft Switching Snubber Inverter*. Reduce the cost and improve reliability through the development of advanced inverter designs that utilize fewer components and modular electronics.	N	*ETO Thyristor Development*. 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	*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.	O	*Diamond Tip Emitters*. Improve the reliability and efficiency of power electronics through the use of diamond tipped emitters
		P	*Standard Power Electronic Interfaces*. Reduce the cost and improve the reliability of power electronics by developing standardized approaches for integrating power converter components.
M	*PV Inverter Products Manufacturing and Design Improvement*. Design a large number of products based on small number of functional modules to achieve high manufacturing efficiencies and enhanced product reliability		

Significant gap **Moderate gap** **Little or no gap**

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	*Cascade Multilevel Inverter for Utility Applications*. Reduce the manufacturing cost and improve reliability and efficiency of multilevel inverter through the utilization of modular and compact circuit topology
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.
M	*PV Inverter Products Manufacturing and Design Improvement*. Design a large number of products based on small number of functional modules to achieve high manufacturing efficiencies and enhanced product reliability
N	*ETO Thyristor Development*. 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	*Standard Power Electronic Interfaces*. 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**

Research Initiative 8

8	Standardize and 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.

Public benefit: Limited incentives exist, and this initiative could benefit multiple stakeholders.	3
Relative DER Applicability: 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	*Compact Diode-Clamped Multilevel Converter*. 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	*High Reliability Inverter Development*. 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	*ETO Thyristor Development*. 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**

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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.

Public benefit: Limited incentives exist, and this initiative could benefit multiple stakeholders.	3
Relative DER Applicability: 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	*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.
P	*Standard Power Electronic Interfaces*. Reduce the cost and improve the reliability of power electronics by developing standardized approaches for integrating power converter components.
Q	*New Power Electronic Technologies*. Reduce costs and improve reliability by developing power electronics products using cutting edge technology.

Significant gap **Moderate gap** **Little or no gap**

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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

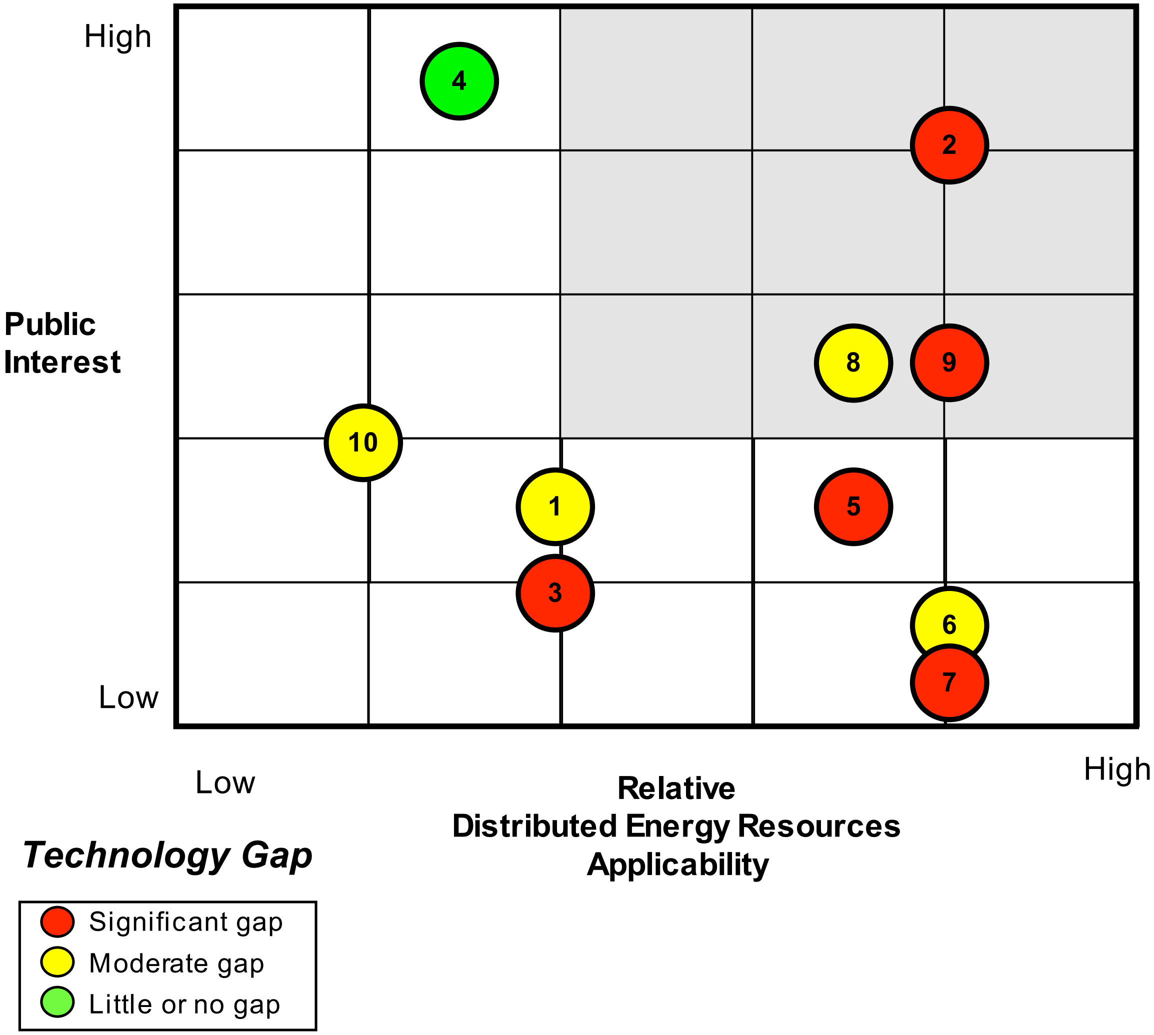
Estimated Total Funding Needed	$5 M	Estimated Current Public Support	$0.8 M

Research Projects That Address Initiative	
A	*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.
B	*Cascade Multilevel Inverter for Utility Applications*. 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**

Priority research initiatives that the CEC should consider are those that have large technology gap, high public benefit and high DER applicability.



Research Initiatives

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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

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 is 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

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NCI recommends 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 modularity and scalability of various power electronics based devices and systems.

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.
- Consider participation in CAPES effort

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B – Research Gap Analysis Approach

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

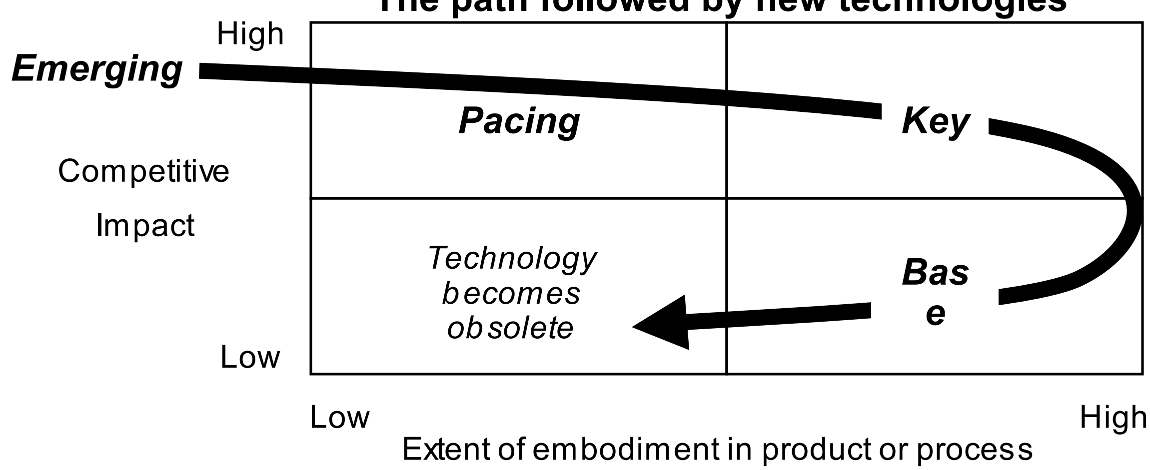
- Literature search of projects and activities by various stakeholders
  - DOE and National Labs
  - State based R&D funding entities (e.g., CEC, NYSERDA, etc.)
  - Universities
  - Manufacturers
  - Industry organizations and standards bodies

- 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 BeaconPower
  - Nag Patibandla of NYSERDA
  - Stan Atcitty 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

The competitive impact of technologies vary by their capabilities.

- **Base**: Although essential to the business, these technologies cannot provide significant competitive advantage
- **Key**: These technologies are critical for today's bases of competition
- **Pacing**: Although they are not fully embodied in current products, they may, if successfully applied, have a substantial impact on the basis of competition in the reasonably near future
- **Emerging**: These technologies may have an impact on competition in the future but this is far from certain

The path followed by new technologies



Appendix B – Research Gap Analysis Approach

Project Type

Project types are determined by the project's state of development.

Research	Development	Demonstration			Commercialization	
		Initial System Prototypes	**Refined Prototypes**	**Pre-Commercial Activity**	**Market Entry**	**Market Penetration**
•General assessment of market needs •Assess general magnitude of economics •Concept and Bench testing •Basic research and sciences (e.g., materials science)	•Research on component technologies •Development of initial product offering •Pilot testing	•Integrate component technologies • Initial system prototype for debugging •Demonstrate basic functionality	•Ongoing development to reduce costs or for other needed improvements • "Technology" (systems) demonstrations •Some small-scale "commercial" demonstrations	• "Commercial" demonstration • Full-size system in "commercial" operating environment •Communicate program results to early adopters/ selected niches •Standards creation • Testing and certification	• Initial commercial orders •Early movers or niche segments • Initial product reputation is established •Business concept implemented •Market support usually needed to address high cost production	• Follow-up orders based on need and product reputation • Broad(er) market penetration • Infrastructure developed • Full-scale manufacturing

Gap Terminology

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.

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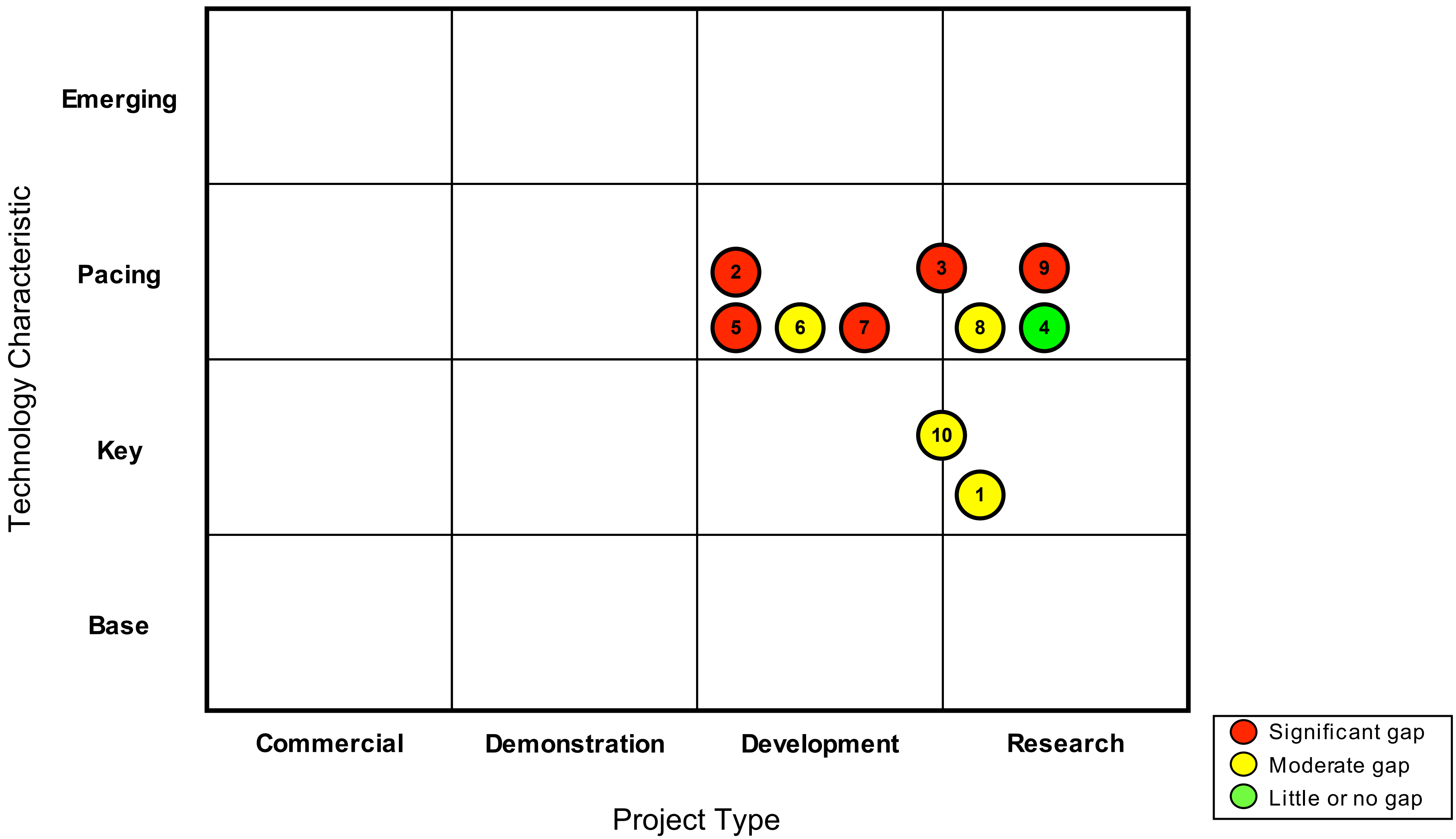
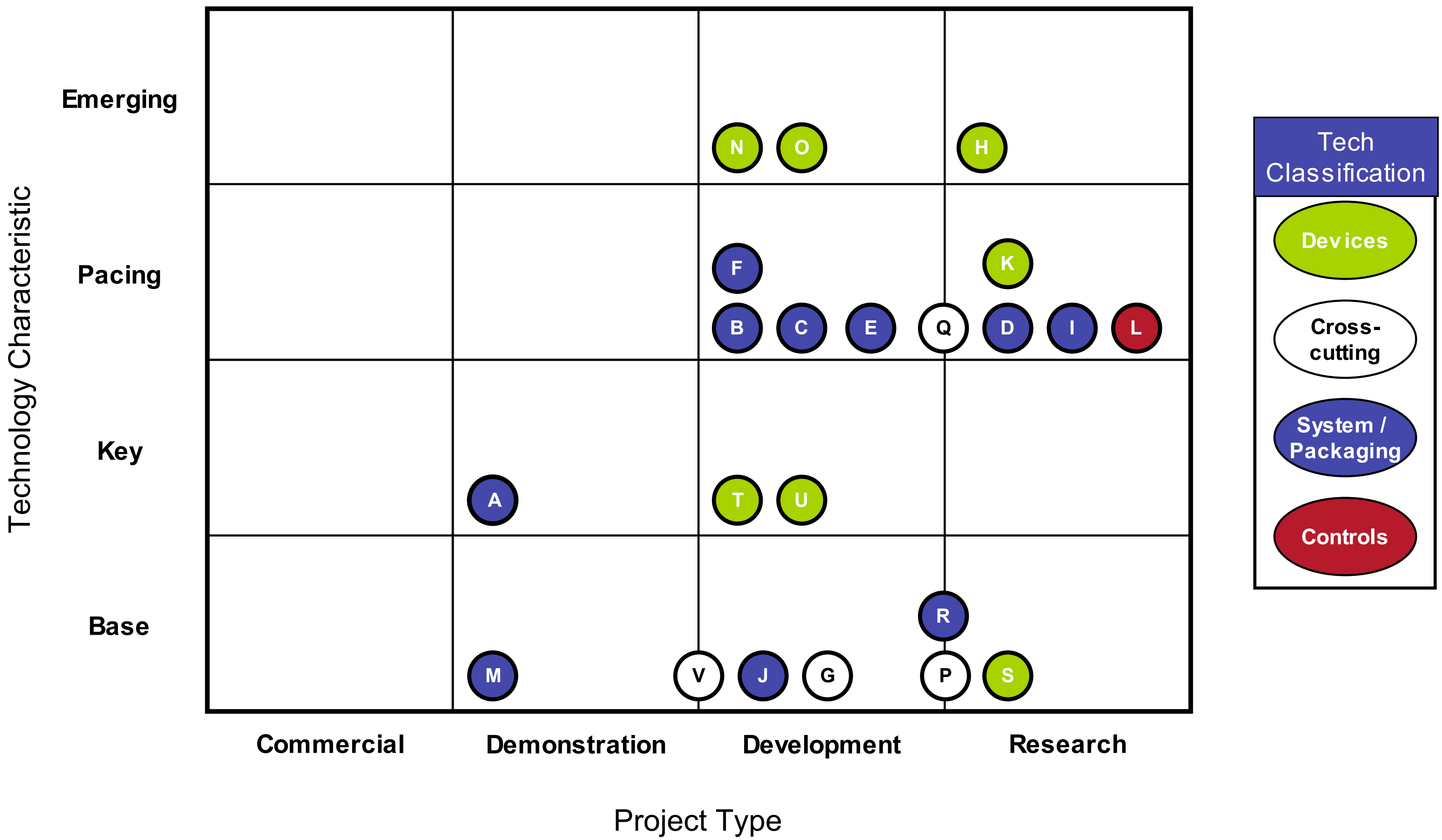
Five of the ten research initiatives are rated as having significant gaps.



Research Initiatives Mapping   Mapping by Tech Classification



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Applicability of R&D Funds to DER Power Electronics and Research Initiatives

Project	Total Funds*	DER PE Applicability	Applicable Funds	Applicability to Research Initiatives										
				1	2	3	4	5	6	7	8	9	10	Total
A	$ 750,000	100%	$ 750,000	50%									50%	100%
B	$ 750,000	100%	$ 750,000							50%			50%	100%
C	$ 750,000	100%	$ 750,000	50%	40%						10%			100%
D	$ 250,000	100%	$ 250,000				100%							100%
E	$ 500,000	0%	$ -											0%
F	$ 500,000	100%	$ 500,000						100%					100%
G	$ 250,000	100%	$ 250,000		100%									100%
H	$ 500,000	50%	$ 250,000	50%		50%								100%
I	$ 250,000	100%	$ 250,000				100%							100%
J	$ 4,550,000	90%	$ 4,095,000	10%	20%				20%	10%	20%	20%		100%
K	$ 300,000	0%	$ -											0%
L	$ 250,000	100%	$ 250,000	100%										100%
M	$ 250,000	100%	$ 250,000						20%	80%				100%
N	$ 255,000	100%	$ 255,000		10%				50%	10%	30%			100%
O	$ 2,000,000	50%	$ 1,000,000	40%		30%			30%					100%
P	$ 500,000	100%	$ 500,000						40%	30%		30%		100%
Q	$ 750,000	50%	$ 375,000									100%		100%
R	$ 1,785,000	90%	$ 1,606,500			100%								100%
S	$ 300,000	0%	$ -											0%
T	$ 2,045,000	0%	$ -											0%
U	$ 1,843,000	0%	$ -											0%
V	$ 116,586	100%	$ 116,586		100%									100%
Total			$ 12,198,086											

* Estimated in some cases

Appendix B – Research Gap Analysis Approach

Estimate of Funds Applicable to Research Initiatives

Estimated R&D Funds Applicable to Research Initiatives

Project	Estimated Funds Applicable to Research Initiatives									
	1	2	3	4	5	6	7	8	9	10
A	$ 375,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 375,000
B	$ -	$ -	$ -	$ -	$ -	$ -	$ 375,000	$ -	$ -	$ 375,000
C	$ 375,000	$ 300,000	$ -	$ -	$ -	$ -	$ -	$ 75,000	$ -	$ -
D	$ -	$ -	$ -	$ 250,000	$ -	$ -	$ -	$ -	$ -	$ -
E	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
F	$ -	$ -	$ -	$ -	$ -	$ 500,000	$ -	$ -	$ -	$ -
G	$ -	$ 250,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
H	$ 125,000	$ -	$ 125,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -
I	$ -	$ -	$ -	$ 250,000	$ -	$ -	$ -	$ -	$ -	$ -
J	$ 409,500	$ 819,000	$ -	$ -	$ -	$ 819,000	$ 409,500	$ 819,000	$ 819,000	$ -
K	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
L	$ 250,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
M	$ -	$ -	$ -	$ -	$ -	$ 50,000	$ 200,000	$ -	$ -	$ -
N	$ -	$ 25,500	$ -	$ -	$ -	$ 127,500	$ 25,500	$ 76,500	$ -	$ -
O	$ 400,000	$ -	$ 300,000	$ -	$ -	$ 300,000	$ -	$ -	$ -	$ -
P	$ -	$ -	$ -	$ -	$ -	$ 200,000	$ 150,000	$ -	$ 150,000	$ -
Q	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 375,000	$ -
R	$ -	$ -	$ 1,606,500	$ -	$ -	$ -	$ -	$ -	$ -	$ -
S	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
T	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
U	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
V	$ -	$ 116,586	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total	**$ 1,934,500**	**$ 1,511,086**	**$ 2,031,500**	**$ 500,000**	**$ -**	**$ 1,996,500**	**$ 1,160,000**	**$ 970,500**	**$ 1,344,000**	**$ 750,000**

Project A: Airak – Optically Isolated 5MW Inverter

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
With DOE funding, Airak is developing a high-power, utility-scale, optically isolated power conversion systems. The goal of this effort will be to develop a pre-production full-bridge 5 MW inverter system based upon the Company's demonstrated technologies.	Increase efficiency Improve reliability	• Increase the efficiency of power electronic systems • Minimize the system package size of power electronics	This inverter system will utilize a new generation of optical sensing and control, innovative DSP control algorithms, and the newest form of HVIGBT devices to produce a complete inverter system with greater than 99% efficiency, that exhibits higher reliability, and that occupies a smaller footprint.

Funding/Source	Participants	Point of Contact
DOE: $750,000 awarded in 2002 for 24-month program	Sandia National Lab, CPES, AEP, Thermacore, Deltronic, PPI and Airak	Paul Duncan Airak, Inc. pduncan@airak.com (703) 330-4961

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Key	Demonstration

Source: https://buffy.eecs.berkeley.edu/PHP/resabs/resabs.php?f_year=2004&f_submit=one&f_absid=100299

Appendix C – Project Details

Project B: ORNL – Cascade Multilevel Inverter for Utility Applications

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
This research effort is developing cascade multilevel inverters that use single-phase H-bridges and separate DC sources to synthesize single-phase or polyphase ac waveforms. This research is important because: •Circuit topology is modular and compact, which leads to lower manufacturing costs. •Operation of multilevel inverter with fundamental frequency switching enables higher efficiency and lower EMI •Easy to incorporate redundant levels into design to significantly increase	Reduce cost Improve reliability	• Improve the manufacturability of power electronic systems and components • Minimize the system package size of power electronics	This technology is applicable to the interface between distributed generation sources such as PV or fuel cells and an ac utility. It can also be used in VAR, sag, and harmonic compensation or power flow control on a medium or high voltage ac utility.

Funding/Source	Participants	Point of Contact
DOE (Estimated at $750K)	Oak Ridge National Laboratory	Don Adams Oak Ridge National Laboratory (865) 946-1321 adamsdj@ornl.gov

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Pacing	Development

Source: http://www.ornl.gov/sci/engineering_science_technology/peemrc/

Project C: ORNL – Compact Diode-Clamped Multilevel Converter

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Diode-clamped multi-level inverters can synthesize a desired waveform from several levels of DC voltages. Their unique structure allows them to span high voltage without the use of transformers and with no voltage sharing problems. All three phases share a common DC bus, which can minimize system capacitance requirements. The diode-clamped multilevel converter provides high efficiency (99%) because a fundamental frequency switching frequency can be used for individual devises.	Increase efficiency Improve scalability	• Increase the efficiency of power electronic systems • Improve interface standardization of power electronic systems	This technology can be applied in the interface between DC distributed generation sources and AC utility. Other applications include static VAR compensation, interface between high voltage DC and AC electrical systems, and medium-voltage active filter to improve power quality,.

Funding/Source	Participants	Point of Contact
DOE (Estimated at $750K)	Oak Ridge National Laboratory	Don Adams Oak Ridge National Laboratory (865) 946-1321 adamsdj@ornl.gov

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Pacing	Development

Source: http://www.ornl.gov/sci/engineering_science_technology/peemrc/

Project D: ORNL – Multilevel Universal Power Conditioner

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
The project seeks to develop multilevel PWM strategies for active filtering by a back-to-back diode-clamped multilevel inverter connected in a series-parallel arrangement to the utility. The objective is to improve the power quality of both the utilities and their customers at the point of common coupling (PCC).	Improve power quality	• Minimize the harmonic distortions of power electronic systems	A multilevel universal power conditioner can improve the quality of the voltage delivered by a utility to the customer and reduce the harmonic and reactive current demanded by customers from the utility.

Funding/Source	Participants	Point of Contact
DOE (Estimated at $250K)	Oak Ridge National Laboratory	Don Adams Oak Ridge National Laboratory (865) 946-1321 adamsdj@ornl.gov

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Pacing	Research

Source: http://www.ornl.gov/sci/engineering_science_technology/peemrc/

Appendix C – Project Details

Project E: ORNL – Voltage Sag Supporter

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
The sag supporter under development seeks to have the following characteristics: •Supports voltage sags of 30% for 30 seconds •Approximately 90% of problem sag will be eliminated •Suppression of voltage harmonics and distortion. •Applicable from 4.6kV to 25.7 kV •Unit is modular, transportable, and has self-control and protection. •Economical solution for most of a customer's power quality needs.	Improve power quality	• Improve the durability of power electronic systems and components • Reduce the complexity of power electronic systems • Improve the modularity / scalability of power electronic systems and components	The goal of this project is to improve the quality of service for electric power users such that they are not as susceptible to voltage harmonics or sags. The major power quality problem facing industry today remains voltage sags. Although infrequent in nature, a voltage sag can cause plant outages and equipment malfunction that cost industry millions of dollars in lost product and restart time.

Funding/Source	Participants	Point of Contact
DOE (Estimated at $500K)	Oak Ridge National Laboratory and Southern States, Inc.	John McKeever Oak Ridge National Laboratory (865) 946-1316 mckeeverjw@ornl.gov

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Pacing	Development

Source: http://www.ornl.gov/sci/engineering_science_technology/peemrc/

Project F: ORNL – Soft Switching Snubber Inverter

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
This project seeks to develop an inverter that can be operated like a conventional hard-switched inverter with no limitations on switching timings or additional control complexity. Only passive components are needed to achieve soft switching with no additional control needed. Any traditional PWM methods can be used with the inverter	Reduce cost Improve reliability	• Reduce the complexity of power electronic systems	The ultimate goal of this project is to create an inverter that minimizes the additional cost required to achieve soft-switching The simulation and proof of concept work has been completed. A 100 kW prototype is currently being assembled and tested.

Funding/Source	Participants	Point of Contact
DOE National Transportation Research Center (Estimated at $500K)	Oak Ridge National Lab	Gui-Jia Su Oak Ridge National Laboratory (865) 946–1330 sugs@ornl.gov

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Pacing	Development

Source: http://www.ornl.gov/sci/engineering_science_technology/peemrc/pess5.html

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Project G: University of Tennessee – Distributed Energy Interface

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Renewable energy resources, such as solar cells, wind mills, fuel cells, are playing a more and more important role in power energy systems. This project is developing the power electronics based interfaces between these distributed energy resources and power grid.	Improve reliability	• Improve interface standardization of power electronic systems	The interfaces developed by this project will help control the power flow between energy resources and power grid, conduct the optimal operation of the energy resources, and communicate with the control center to realize remote control and operation.

Funding/Source	Participants	Point of Contact
National Science Foundation Oak Ridge National Laboratory (Estimated at $250K)	University of Tennessee	Leon Tolbert 311 Ferris Hall, University of Tennessee, Knoxville, TN 37996-2100 (865) 974-2881 tolbert@utk.edu

Classification Category	Project Focus	Technology Characteristic	Project Type
Cross-Cutting	Hardware	Base	Development

Source: http://powerelec.ece.utk.edu/

Project H: Univ. of Tennessee – Silicon Carbide Power Electronics for Utility Application

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
This project involves modeling and design of silicon carbide devices and the study of device benefits at the system level. Gate turn-off (GTO) thyristors are investigated in a HVDC system.	Increase efficiency Improve thermal management	• Increase the efficiency of power electronic systems • Improve the thermal management characteristics of power electronic systems	The project provides a comparison between silicon and silicon carbide devices in terms of efficiency, costs, operating temperature and thermal management, and the corresponding effect on system performance.

Funding/Source	Participants	Point of Contact
National Science Foundation Oak Ridge National Laboratory (Estimated at $500K)	University of Tennessee	Leon Tolbert 311 Ferris Hall, University of Tennessee, Knoxville, TN 37996-2100 tolbert@utk.edu (865) 974-2881

Classification Category	Project Focus	Technology Characteristic	Project Type
Devices	Hardware, Materials	Emerging	Research

Source: http://powerelec.ece.utk.edu/

Project I: Univ. of Tennessee – Harmonic Elimination Technique and Multilevel Converters

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
In this work, techniques are given that allow one to 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	Improve power quality	• Minimize the harmonic distortions of power electronic systems	Multilevel inverter design that determines the switching angles (times) so as to produce the fundamental voltage and not generate specific higher order harmonics.

Funding/Source	Participants	Point of Contact
National Science Foundation Oak Ridge National Laboratory (Estimated at $250K)	University of Tennessee	John Chiasson chiasson@utk.edu (865) 974-0627 Leon Tolbert tolbert@utk.edu (865) 974-2881

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Modeling, Power Quality	Pacing	Research

Source: http://powerelec.ece.utk.edu/

Appendix C – Project Details

Project J: DOE – High Reliability Inverter Development

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
The objective of this DOE project include: •Double inverter lifetimes (MTFF) to beyond 10 years •Develop transportable designs for multiple technologies (storage, PV, and DER) and multiple power sizes (<10kW to MW) •Employ advanced designs with fewer components •Apply new inverter technologies such as DSP, modular electronics and software, and advanced power flow •Expanded markets •Increase public confidence	Improve reliability Increase efficiency Reduce cost	• Increase the efficiency of power electronic systems • Reduce the complexity of power electronic systems • Improve the manufacturability of power electronic systems and components • Improve interface standardization of power electronic systems • Improve the modularity / scalability of power electronic systems and components	In addition to the MTFF improvements, the DOE seeks achieve efficiency levels >94%, cost of less than $0.90/watt (assuming production at 10,000 per year), and compliance with various standards including UL1741, IEEE 929, IEEE C62.41, IEEE 519, NEC, and FCC Part 15, Class B.

Funding/Source	Participants	Point of Contact
Cost share at a minimum of 50% for all industry partners: Phase 1- Xantrex, Satcon, and GE. DOE funding as follows: Phase 1 (Project Formulation): $550,000 ($300k for PV, $150 for DER, $100k for storage); DOE Phase 2 (Detailed Design FY03 and FY04): $3,000,000; DOE Phase 3 (Prototype Hardware-FY05): $1,000,000	U.S. Department of Energy (Energy Storage, DER Electric Systems Integration, and Photovoltaics programs), Phase 1 Industry Participants: Xantrex, Satcon, GE	Russell Bonn Sandia National Lab (505) 844-6710

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Base	Development

Source: http://www.sandia.gov/ess/Publications/Conferences/2002/BONN%20-%20HiReliabInvStatus.pdf
http://www.sandia.gov/pv/docs/PDF/Symposium2003/Gonzalez.pdf

Appendix C – Project Details

Project K: Dartmouth College – Advanced Magnetics for Power Electronics

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
This project will develop magnetic component design methods and software to improve accuracy, accessibility, and computational efficiency compared to analytical methods and to numerical methods in use today. This will be accomplished through the use of strategic combinations of analytical and numerical calculation	Increase efficiency Reduce cost Improve reliability	• Increase the efficiency of power electronic systems • Minimize the system package size of power electronics	This project should result in improvements in specific aspects of magnetics design as well as the integration of these methods into optimization of complete magnetic components, and joint optimizations of circuit designs and their magnetic components. Magnetic components have tended to be the largest and most expensive components in a power circuit, and they are often responsible for the highest power losses

Funding/Source	Participants	Point of Contact
DOE (Estimated at $300K)	New England Electric Wire Corp, West Coast Magnetics, AeroVironment, Dartmouth College	Charles Sullivan Thayer School of Engineering Dartmouth College Hanover, NH 03755 Charles.R.Sullivan@dartmouth.edu (603) 646-2851

Classification Category	Project Focus	Technology Characteristic	Project Type
Devices	Modeling	**Emerging** / Pacing	Research

Source: http://thayer.dartmouth.edu/other/inductor/doeproject.shtml

Appendix C – Project Details

Project L: UC Berkeley – Digital Control of PWM Converters

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
The focus of this project is to develop online power optimization techniques for a digital pulse-width modulation (PWM) controller. The idea is to minimize 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	Improve reliability	• Increase the efficiency of power electronic systems	This work can result in robust, self-optimizing power converters, and can offer new approaches to automatic mode switching (e.g., between continuous and discontinuous conduction mode in PWM converters).

Funding/Source	Participants	Point of Contact
NSF MICRO (Estimated at $250K)	UC Berkeley	Angel Vladimirov Peterchev UC Berkeley, EECS Department 211 Cory Hall #1772 Berkeley, CA 94720-1772 peterch@eecs.berkeley.edu (510) 643-5895

Classification Category	Project Focus	Technology Characteristic	Project Type
Control	Control	Pacing	Research

Source: https://buffy.eecs.berkeley.edu/PHP/resabs/resabs.php?f_year=2004&f_submit=one&f_absid=100299

Project M: Xantrex – PV Inverter Products Manufacturing and Design Improvement

Project/Technology Development/Product	Final benefit	Research Initiatives	Expected Results
The approach is to design a relatively large number of products based on a relatively small number of functional modules to achieve high manufacturing efficiencies and to enhance product reliability. The specific emphasis is on new products designed for high-volume manufacture. Three prototypes have been developed, three-phase 10kW and 25kW inverters and a 2kW single-phase inverter, all using new Digital Signal Processor (DSP) controllers.	Reduce cost Improve reliability	• Reduce the complexity of power electronic systems • Improve the manufacturability of power electronic systems and components	The cost of the 10kW inverter was reduced by 56% and the cost of the 25kW inverter was reduced by 53%. The 2kW inverter has no basis for comparison but should benefit equally form this design approach. Conversion loss was reduced by 50% and the size and weight of the equipment was reduced.

Funding/Source	Participants	Point of Contact
DOE (PV Manufacturing R&D Project) (Estimated at $250K)	Xantrex and Distributed Power Technologies	R. West Distributed Power Technologies 3547-C South Higuera Street, San Luis Obispo, CA 93401

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware, Cost Reduction	Base	Demonstration

Source: http://www.nrel.gov/ncpv_prm/pdfs/33586076.pdf
http://www.eere.energy.gov/solar/pdfs/sda_dave_mooney.pdf

Project N: Virginia Tech – ETO Thyristor Development

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
The Emitter Turn-Off (ETO) Thyristor was developed as part of the CPES program to reduce the cost of power electronics technology by using integrated power electronic modules (IPEMs) composed of standardized components instead of custom designed and manufactured systems. ETO technology integrates commercial, low-cost GTO devices with low voltage power Metal-Oxide Semiconductor Field Effect Transistors (MOSFET) in a low inductance housing arrangement.	Reduce cost Improve reliability	• Reduce the complexity of power electronic systems • Improve the manufacturability of power electronic systems and components • Improve interface standardization of power electronic systems	ETO has the highest power handling capabilities of all solid-state switches. It is also expected to provide lower cost and higher reliability than competing power switching technologies. ETO has twice the switching speed of Gate Commutated Thyristor (GTO) counterparts and should cost significantly less than Integrated Gate Commutated Thyristors (IGCTs).

Funding/Source	Participants	Point of Contact
DOE Energy Storage Program $150K Naval Surface Warfare Center (Performance testing) $105K	Sandia National Lab Virginia Tech Naval Surface Warfare Center	Dr. Alex Huang Virginia Tech (540) 231-8057 huang@vt.edu

Classification Category	Project Focus	Technology Characteristic	Project Type
Devices	Hardware	Emerging	Development

Source: http://www.ece.vt.edu/news/fall03/rd100.html

Project O: Vanderbilt University – Diamond Tip Emitters

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Nanometer scale diamond tip emitters for cold cathodes are being developed as (a) vertical and (b) lateral diamond vacuum field emission devices. These diamond field emission devices, diode and triode, were fabricated with a self-aligning gate formation technique from silicon-on-insulator wafers using variations of silicon micropatterning techniques. High emission current, > 0.1A was achieved from the vertical diamond field emission diode with an indented anode design.	Improve power capability Improve scalability	• Increase the efficiency of power electronic systems	Development of CVD Diamond and Power Electronic Devices for high power resistors and capacitors, energy density storage system, power thyristor, power emission device

Funding/Source	Participants	Point of Contact
TVA / DOD $1-2M / year	TVA DOD Vanderbilt University	Dr. Jim Davidson Microelectronics Group Vanderbilt University Nashville, TN 37235 jim.davidson@vanderbilt.edu (615) 343-7886

Classification Category	Project Focus	Technology Characteristic	Project Type
Devices	Hardware	Emerging	Development

Source: http://www.ioffe.rssi.ru/nanodiamond/2004/abstr/Davidson_inv.pdf
http://www.vuse.vanderbilt.edu/~jld/persinfo.htm

Project P: University of Wisconsin – Standard Power Electronic Interfaces

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
This report presents the results of ongoing investigations on development of high power electronic systems for distributed generation systems using standardized approaches for integrating the components that comprise a power converter. The investigations have focused on developing a modular architecture that would allow using pre-engineered and mass-produced components to develop power electronic solutions in a systematic manner.	Reduce cost Improve reliability	• Reduce the complexity of power electronic systems • Improve the manufacturability of power electronic systems and components • Improve interface standardization of power electronic systems	• A new framework for realization of power converter is presented called Bricks-&-Buses •A hardware prototype is presented to demonstrate proof of concept and explore properties of the proposed approach. •A concept design review meeting with a number of participants from the power electronics industry was held to disseminate the ideas and solicit inputs.

Funding/Source	Participants	Point of Contact
CEC NSF (Estimated at $500K)	CERTS PSERC WisPERC	Giri Venkataramanan College of Engineering University of Wisconsin-Madison 1415 Engineering Drive Madison, WI 53706 (608)262-4479

Classification Category	Project Focus	Technology Characteristic	Project Type
Cross-Cutting	Hardware, Modeling	Base	Research, Development

Appendix C – Project Details

Project Q: EPRI – New Power Electronic Technologies

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
- Provide new power-electronic components to aid in design and control of more flexible electrical infrastructure for the distribution system of the future - Assess the current state of the art in distribution components that incorporate or could incorporate power electronics - Assess the cutting edge trends in both power electronic circuits and power semiconductor technology - Apply the cutting edge technology to evolve a new generation of power electronic equipment for ADA	Identify new power electronic technologies	• Improve the modularity / scalability of power electronic systems and components	The results of this project should lead to new power electronic products for the distribution system of the future.

Funding/Source	Participants	Point of Contact
EPRI Members (Estimated at $750K)	EPRI	Frank R. Goodman, Jr. Technical Leader, Distribution Systems EPRI 3412 Hillview Avenue Palo Alto, California 94304 fgoodman@epri.com 650-855-2872

Classification Category	Project Focus	Technology Characteristic	Project Type
Cross-Cutting	Hardware	Pacing	Research, Development

Source: http://www.epriweb.com/public/FrankGoodman.html

Appendix C – Project Details

Project R: NREL / ORNL – Thermal Management for Power Electronics

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Improve thermal characteristics of power electronics and motors with combination of high--temperature materials and advanced cooling strategies. • Model and validate spray-cooling and jet impingement for high heat flux heat removal • Model spray cooling and jet impingement cooling of an actual hardware	Reduce cost Improve reliability	• Improve the thermal management characteristics of power electronic systems	• Demonstrate enabling technologies to improve heat rejection from power electronics ~ 250 W/cm2 • Reducing system cost, increasing reliability, specific power, power density, and efficiency • Demonstrate the viability and advantages of two-phase cooling techniques such as spray cooling, and jet impingement

Funding/Source	Participants	Point of Contact
DOE NREL $175K ORNL $1,610K	ORNL, NREL, ISR, Rockwell Scientific, Georgia Tech	Desikan Bharathan, Keith Gawlik, Dr. Bill Kramer NREL 1617 Cole Boulevard Golden, CO 80401 (303)-384-7418 Desikan_Bharathan@nrel.gov

Classification Category	Project Focus	Technology Characteristic	Project Type
System / Packaging	Hardware	Base	Research, Development

Source: http://www.nrel.gov/vehiclesandfuels/powerelectronics/pdfs/program_review_6-7-04_thermal_mgmt.pdf
http://www.nrel.gov/vehiclesandfuels/powerelectronics/pdfs/advanced_power_electronics_thermal_mgmt.pdf

Project S: Ames National Labs – Permanent Magnets

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Determine magnetic properties of bonded isotropic powder samples as a function of loading fraction, powder size, annealing schedule, coating treatment, and temperature, up to a maximum of 200°C. Polymer-bonded particulate magnets offer the benefit of greatly simplified manufacturing — but at a more moderate level of stored magnetic energy that is still compatible with innovative PM motor designs. To exploit the potential of bonded PM materials for such motors, researchers need to develop magnet material with high-temperature properties that can be loaded to a high-volume fraction in an advanced polymer binder	Reduce cost Improve reliability	• Minimize the system package size of power electronics	• Reduce cost, increase maximum operating temperature to 200°C. Increase energy product of NdFeB permanent magnets by 25%

Funding/Source	Participants	Point of Contact
DOE $300K	Ames National Labs Magnequench International Argonne National Laboratory Oak Ridge National Laboratory	Susan Rogers Power Electronics & Electrical Machines OFCVT EERE, U.S. Department of Energy Washington, D.C.

Classification Category	Project Focus	Technology Characteristic	Project Type
Devices	Hardware	Base	Research

Source: http://www.eere.energy.gov/vehiclesandfuels/technologies/materials/improved_powder.shtml?print

Appendix C – Project Details

Project T: NREL – Small Wind Turbine Project I

NAVIGANT CONSULTING

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Develop and test a direct grid-tied inverter for a 1.8-kW wind turbine. Single-phase, 120-Vac inverter is integrated into the tower-top turbine nacelle.	Scalability		• NREL will review inverter design, support inverter testing and conduct prototype wind turbine field testing (w/ inverter) •Southwest Windpower and Integrid will develop / supply turbine design and manufacturing experience

Funding/Source	Participants	Point of Contact
$2.045M from 1997 - 2004	NREL Southwest Windpower Intergrid	National Wind Technology Center 18200 State Hwy 128 Golden, CO 80403 303-384-6900

Classification Category	Project Focus	Technology Characteristic	Project Type
Devices	Hardware	Key	Development

Source:

Project U: NREL – Small Wind Turbine Project II

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Preliminary design of a direct grid-tied inverter for a 10-kW wind turbine. Multiple voltage and phase configurations.	Scalability		• NREL will provide a technical review of the inverter design. • Abundant Renewable Energy will provide the wind turbine design • Outback will provide the inverter design and manufacturing experience

Funding/Source	Participants	Point of Contact
$1.843 M from 1997 - 2005	NREL Abundant Renewable Energy Outback	National Wind Technology Center 18200 State Hwy 128 Golden, CO 80403 303-384-6900

Classification Category	Project Focus	Technology Characteristic	Project Type
Devices	Hardware	Key	Development

Source:

Appendix C – Project Details

Project V: NYSERDA – Static Inverter Type Testing

Project/Technology Development/Product	Final Benefit	Research Initiatives	Expected Results
Develop and demonstrate a procedure for type and verification testing of static inverters for use in utility grid interconnections.	Improve reliability	• **Improve interface standardization of power electronic systems**	This project has applications for numerous emerging technologies which utilize static inverters such as fuel cells, photovoltaics, microturbines and wind power.

Funding/Source	Participants	Point of Contact
Funding NYSERDA $28,168 – total cost $116,586 (solicitation 493-99)	Plug Power and UL	James M. Foster NYSERDA (518) 862-1090 ext 3376

Classification Category	Project Focus	Technology Characteristic	Project Type
Cross-Cutting	Testing Certification	Base	Development/ Demonstration

Source: http://www.eere.energy.gov/de/pdfs/der_conf_01/jm_foster.pdf