U.S. DEPARTMENT OF ENERGY

Energy Storage Systems

Research Program

(DOE / ESS)

Quarterly Progress Report

January 2010 — March 2010

(Fiscal Year 2010 / 2nd Quarter)

Produced By:

DOE Energy Storage Systems Research Program

Sandia National Laboratories

Albuquerque NM

(SNL / ESS)

Projects:

SiC-Based Solid-State Fault Current Control System for Vulnerability Reduction of Power Distribution Networks

Date Project Began: June 30, 2008

Dates for this Project Report: Jan – Mar 2010

Sandia Project Manager (PM): Stan Atcitty

Contractor: Arkansas Power Electronics International, Inc.

Partner(s): University of Arkansas

Project Description:

This Small Business Technology Transfer Research Phase I project seeks to develop high-voltage, high-performance Solid-State Fault Current Controller (SSFCC) technology utilizing Silicon Carbide (SiC) gate-turn-off thyristors (GTOs). The proposed SSFCC technology is able to control the power delivery to all types of faults very rapidly (<< 1ms), allowing for the minimization of power quality issues (i.e., voltage sags, oscillation, voltage and current harmonics, etc.). Moreover, when combined with existing, lower-cost network equipment, such as computer-controller sectionalizers, the proposed technology allows for rapid reconfiguration of the power network. This capability greatly minimizes recovery time and vulnerability of the network in the event of a large-scale, natural disaster. Finally, the proposed solution offers modularity, flexibility, and low operation/maintenance, allowing for widespread adoption and deployment of the technology.

The team has already proven the feasibility of the proposed concept by developing a low-power, low-voltage, SiC-based SSFCC prototype. Research carried out during the Phase I portion of this STTR project demonstrated three ,additional, key points that can be summarized, as follows: a) system scalability [i.e., 4.16 kV to 13.8 kV SSFCC systems using 4.5 kV device technology] , b) system functionality [fast and accurate fault current control] and c) system added value [improved power quality].

For the Phase II portion of this STTR project, the team will focus on demonstrating the benefits of using SiC-based, SSFCC device technology. The team will accomplish this by 1) extensively testing a single-phase 4160V-class, SiC-based, SSFCC hardware prototype that is available to this program, and 2) determining cost benefits associated with the unprecedented level of protection that this new SSFCC technology provides. In addition, during Phase II, the team will target several technical goals ,with the objective of developing a deep understanding of all benefits and capabilities associated with the mass deployment of SSFCC devices. This knowledge will be a key piece of information needed by utility companies and other users before SSFCC devices can be widely accepted.

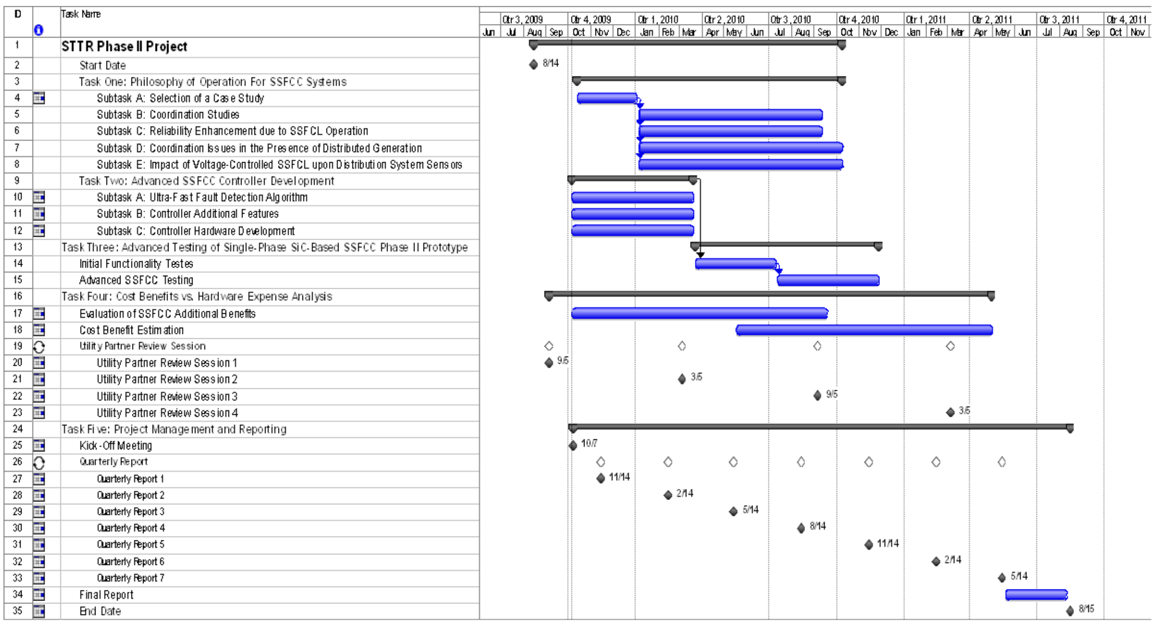
Key Project Events:

This is the third quarterly report of the Phase II STTR. Both the University of Arkansas (UA) and APEI, Inc. researchers have begun to transition from literature review to analytical and/or experimental work.

The UA and APEI have made arrangements to send engineers to the 2010 IEEE Transmission and Distribution Conference in New Orleans, La. Dr. Yongfeng Feng of the UA will be presenting a paper: "Impact of Solid-State Fault Current Limiters on Protection Equipment in Transmission and Distribution Systems," which is directly relevant to this research effort.

Project Status:

University of Arkansas is presently working on Task One, while APEI is working primarily on Task Two. The original high-level program schedule is presented below, and the project is currently on schedule, with the exception of Tasks Two and Three. The SiC, SSFCC prototype development is still being completed (under another research program), which has delayed the beginning of testing, and additional time is needed to complete Task Two. Because the original goals of this research effort are still considered achievable, these deviations from the original schedule are not of great concern. More detail will be provided on project scheduling within the upcoming year.



University of Arkansas researchers are focusing currently on the overall philosophy of operation for the SSFCC (Task 1). The primary objective of this task is to draw conclusions and make recommendations regarding the coordination of the SSFCC with other protective devices (circuit breaker, recloser, fuse, etc). UA researchers have identified the most significant criteria for coordination of the proposed SSFCC with a fuse, and are currently formalizing this design process. Upon completion, it is expected that progress on coordination with other protective devices can proceed more rapidly.

Research on the coordination of the SSFCC with a Schweitzer impedance relay (model SEL-311C) has also been conducted. This work has focused on the effect that an SSFCC will have on impedance values seen by the relay during SSFCC operation. The results from preliminary simulations suggest that, by deliberately controlling the SSFCC, it might be possible to utilize this impedance relay without changing the internal settings of the device. In addition, researchers are planning an experimental study in which the impedance relay operation can be observed in a scaled-down power system.

Under Task 2, APEI's literature review has been largely completed and has been very helpful in understanding the SSFCC application. The review of advanced, fault detection methods (e.g., neural networks, energy methods, etc.) will continue into the next quarter.

Efforts have begun also to compare various fault detection methods in Matlab, using waveforms from Matlab Simulink (using the SimPower library) or from measurements taken from the power grid. APEI contacted engineers from a local electric utility (SWEPCO) and requested fault and other transient waveform measurements from one or more distribution feeders. The utility has indicated that they will provide this information for several system faults and for capacitor inrush events from a feeder in Springdale, AR. APEI will be attending the GRAPES (an NSF funded I/UCRC) semi-annual meeting on May 17-19, and will make similar requests to ConEd representatives at that time.

Large Area, SiC, GTO Thyristor Development

Date Project Began:	FY07 (DE-FG02-07ER84712)
Dates for this Project Report:	Jan. – Mar. 2010
Sandia Project Manager (PM):	Stanley Atcitty
Contractor:	GeneSiC Semiconductor
Partner(s):	Princeton Power Systems & Dow Corning Corporation

Project Description:

This project is focused on developing large area, Silicon Carbide-based Thyristors for ultra-high voltage power conversion applications. In Phase I of this program, the relevant SiC, GTO Thyristor structures were identified; epitaxial design was completed; mask designs were explored; and critical fabrication steps were developed. A novel, sloped sidewall etching was developed to allow the achievement of ultra-high voltages and high breakdown voltage yields. The goals set for Phase II were to achieve the following specifications from a SiC, GTO Thyristor:

- Blocking Voltage > 10-16 kV
- Packaged device on-state Current > 100 A
- Switching frequency > 20 kHz
- Cost effective solution that can be deployed on a large scale

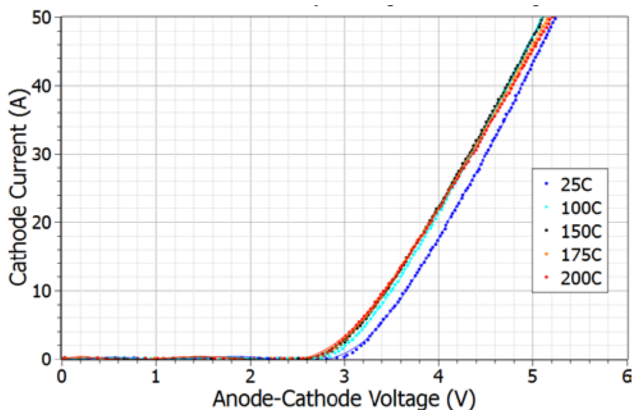
Key Project Events:

- Detailed ,high-temperature, steady-state measurements were performed at currents as high as 50 A, on the recently fabricated 8 kV GTO Thyristors;
- Detailed turn-on and turn-off measurements were performed on the 8 kV Thyristors in a hard turn-off mode ,as well as Anode Switched Thyristor (AST) mode; and
- The fabrication of 12 kV Thyristors was initiated.

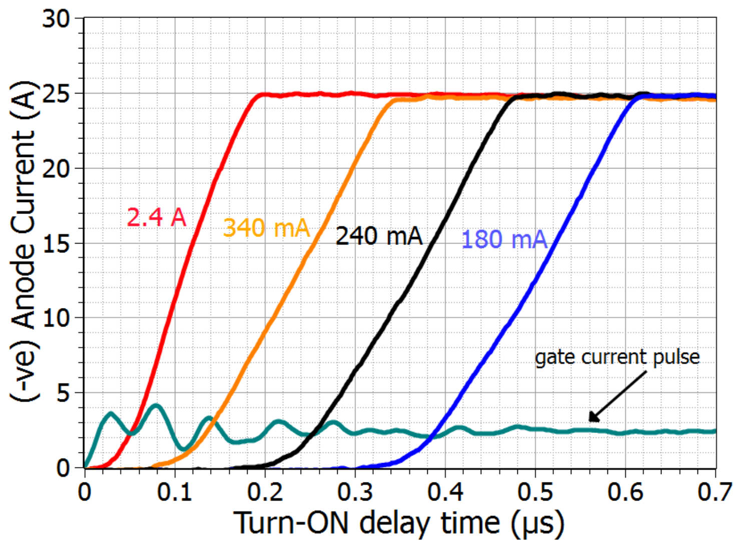
Project Status:

Through a systematic study, Silicon Carbide Gate Turn Off (GTO) Thyristors were characterized, demonstrating record on-state and transient performance. Compared to contemporary, state-of-the-art Silicon GTOs, they were demonstrated to offer an order of magnitude lower differential specific on-resistance of 2.55 m-cm^2. High temperature forward I-V shows that resistance increases to a very modest 2.95 m-cm^2 at 200^{o}C, which promises good paralleling behavior, in contrast to Si GTO Thyristors. Rise-time decreases to 50 nano-seconds when the temperature is increased to 200^{o}C. Hard-turn-off s of 5.5A show 1.8 sec turn-off times at room temperature, which increases to 3.3 sec at 200^{o}C. This is ten times faster than a Silicon GTO. A novel Anode Switched Thyristor (AST) configuration has been introduced, which uses Silicon MOSFETs in series connection with Anode and Gate terminals to switch high currents. The composite device was switched from blocking 2kV to a 16A conduction, and then back to 2kV blocking within ~4 sec, demonstrating a "pulsed" frequency capability of >250kHz.

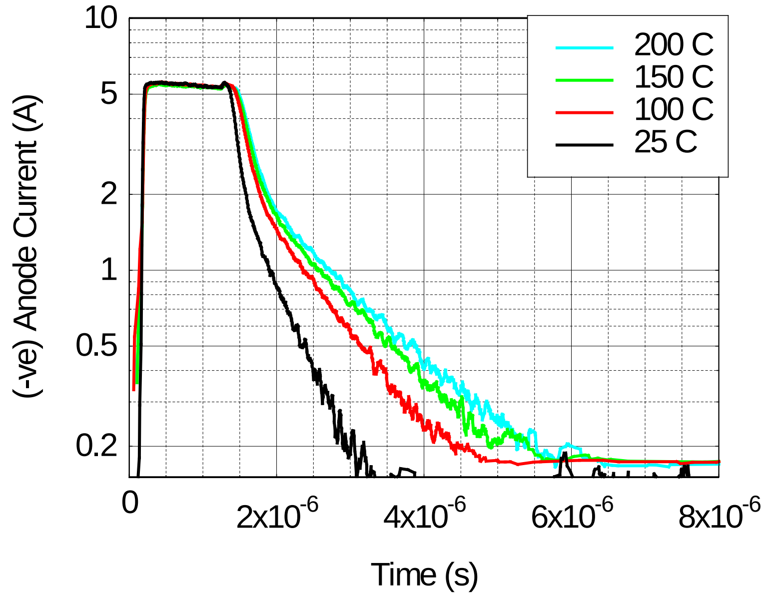
These measurements comprehensively prove the advantage of SiC GTO Thyristors over Si GTO Thyristors.



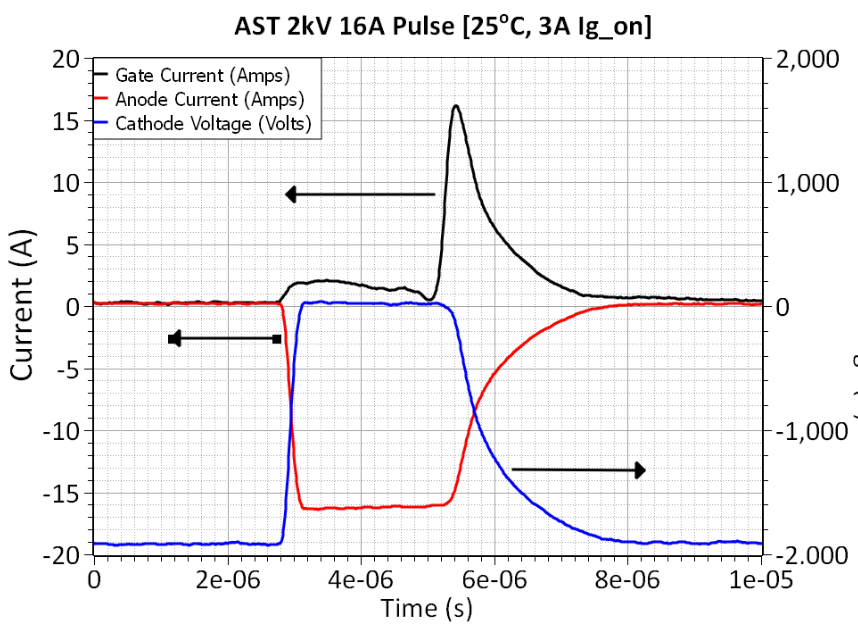
High-current I-V Measurement Performed on a Packaged 8 kV SiC Thyristor



Turn-on Times Measured on a 8 kV Thyristor at Different Gate Currents.



Hard Turn-off Measurements Performed on a Packaged 8 kV SiC Thyristor Fabricated at GeneSiC. An Anode Current of 5.5 A is Turned Off at Different Temperatures.



I-V Characteristics Obtained from a 8 kV SiC Thyristor, Turning Off 16 A of Current in AST Mode at 25 °C.

High Temperature, Fully Programmable, Power Controller for High Density Power Electronics

Date Project Began:	FY2008
Dates for this Project Report:	Jan. – Mar. 2010
Sandia Project Manager (PM):	Stan Atcitty
Contractor:	Joe Henfling
Partner(s):	SJT Micropower, PermaWorks, Honeywell SSEC, SemiSouth, and APEI

Project Description:

This project focuses on the design and development of a high temperature controller that interfaces the High-Temperature Silicon-On-Insulator (HT SOI)-based controller with Silicon-Carbide (SiC) power switches. Using technology developed in America, the high temperature controller creates the basic building block for power converters, motor controllers, and a host of industrial control applications. Sandia will work with Honeywell and other US component manufacturers to design a basic power controller that interfaces HT SOI electronics with SiC power devices that would reliably operate at 240ºC, with the power devices operating at junction temperatures up to 300 ºC. These new systems will be more reliable, more energy efficient, and >30% smaller than existing silicon solutions.

Key Project Events:

- Meeting was held at APEI to discuss collaboration and establish a path forward.
- Ordered power modules from APEI.
- Continuing to work with Honeywell to utilize their Re-configurable Processor for Data Acquisition (RPDA) in the HT controller design.

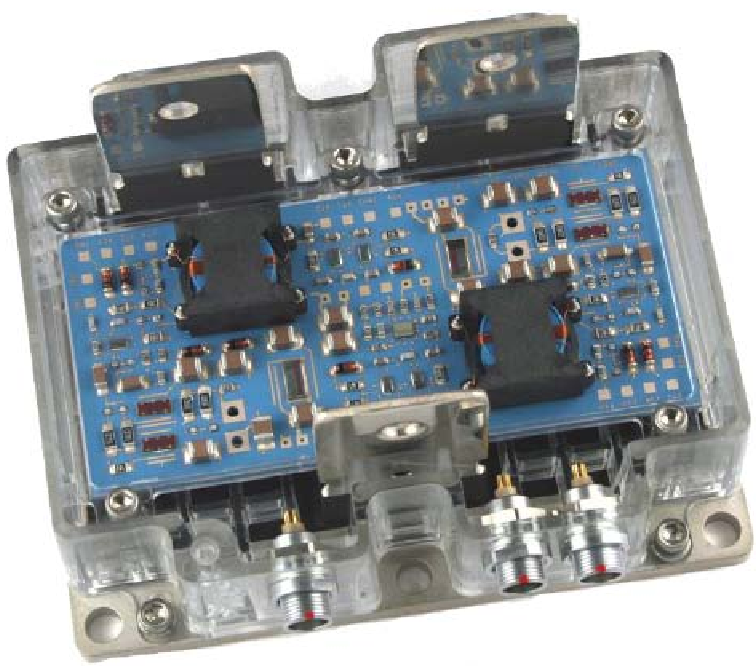
Project Status:

As part of a Phase III effort, Sandia met with Arkansas Power Electronics International (APEI) on February 8 and 9 to establish a partnership that will develop and demonstrate a power controller. Since its inception, the focus of the project has been to fully integrate the HT controller with the gate driver and power stage (co-locate modules onto a common substrate).

Typically, the controller is a separate component operating at lower temperatures. The developed integrated power controller will facilitate higher density designs and better performance. With the remaining funds from Phase II, Sandia has purchased a few of APEI's high-temperature power modules. By combining the power module developed by APEI with the HT controller designed by Sandia, a complete HT power controller can be demonstrated. When the power modules are delivered, Sandia will work with APEI to test the combined system. The delivery date for the modules is April 15, 2010.

Utilizing Honeywell's RPDA would enable the developed system to be fully re-programmable and, as such, could be re-configured for various applications. While other options, including a microcontroller and a non-reprogrammable Field Programmable Gate Array (FPGA), are considered, the desired path forward for this project would be to utilize the newly developed RPDA. The RPDA would provide the greatest flexibility, and the code developed for the module could later be utilized in an Application Specific Integrated Circuit (ASIC). An ASIC is likely the most cost-effective solution in a fully commercialized system.

High Temperature Power Module w/ Integrated Gate Drive



Development and Validation of Advanced Energy Management Control Algorithms for Short- or Long-Term Energy Storage

Date Project Began:	FY2010
Dates for this Project Report:	Jan. – Mar. 2010
Sandia Project Manager (PM):	Stan Atcitty
Contractor:	Missouri University of Science & Technology

Project Description:

Through previous DOE/Sandia support, the Missouri University of Science & Technology (MST) has developed a Hardware-in-the-Loop (HIL) test-bed that mimics the electric power grid. This test-bed will be used to develop the basis for a plug-and-play smart grid.

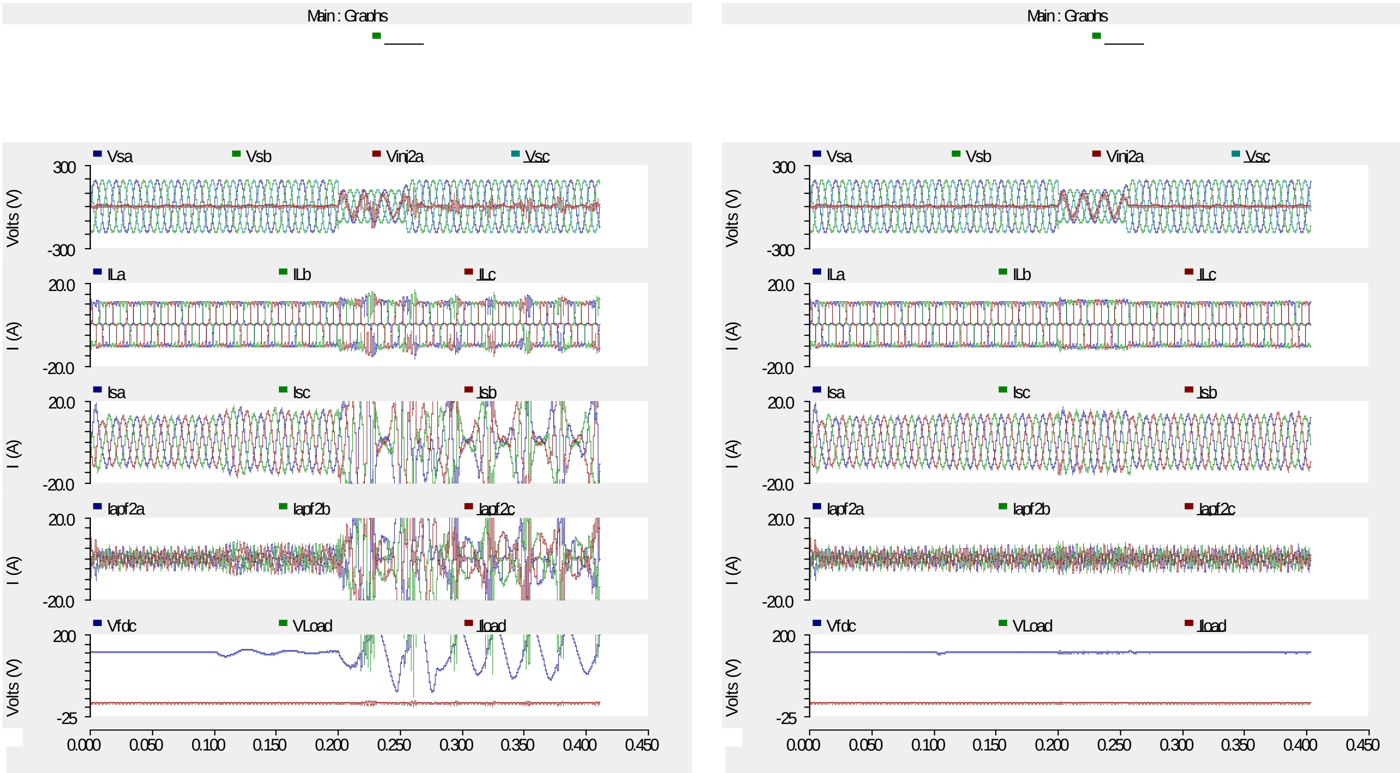
The 2009 project focused on the hardware development of the Unified Power Quality Conditioner coupled with an electrochemical capacitor (ultra capacitor). The laboratory-scale, unified, power quality conditioner with ultra capacitor will be used to experimentally validate improved performance over the same controller without energy storage. This projects builds on the Missouri S&T Flexible AC Transmission System Laboratory developed in previous years.

The primary objective of the 2010 project is to design a power electronic conditioner that will smooth the output power of a 2.5 kW wind turbine using an ultracapacitor. This project will use computer simulation to design the circuit topology and design the controls. The conditioner will also be built to experimentally validate the operation and controls.

Key Project Events:

Project kickoff meeting at Missouri University of Science & Technology in Rolla, on April 6, 2010, with Stan Atcitty (Sandia)

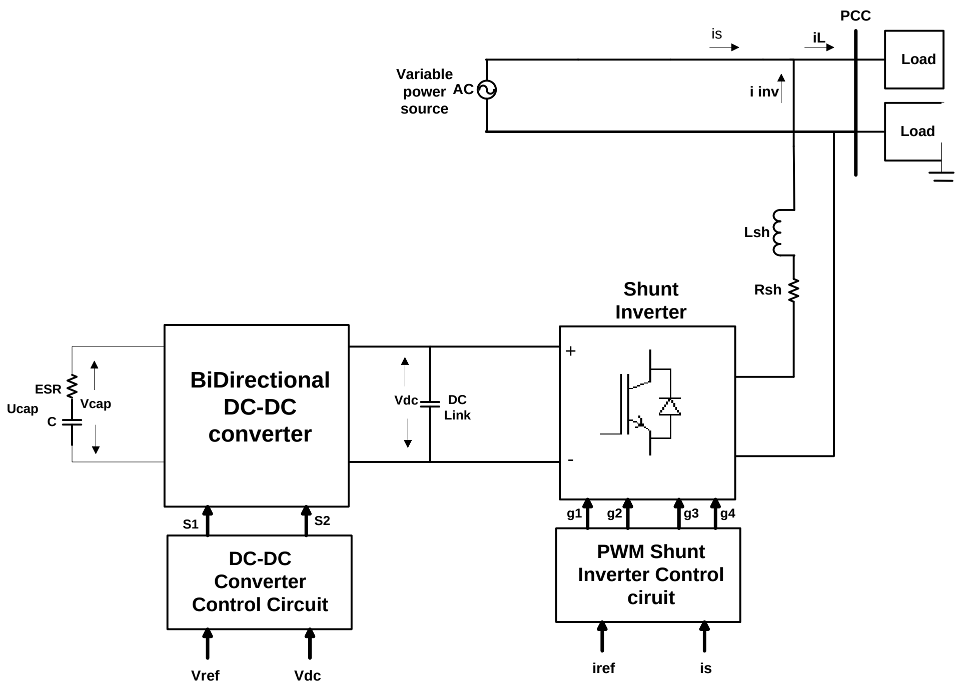
Project Status: ongoing



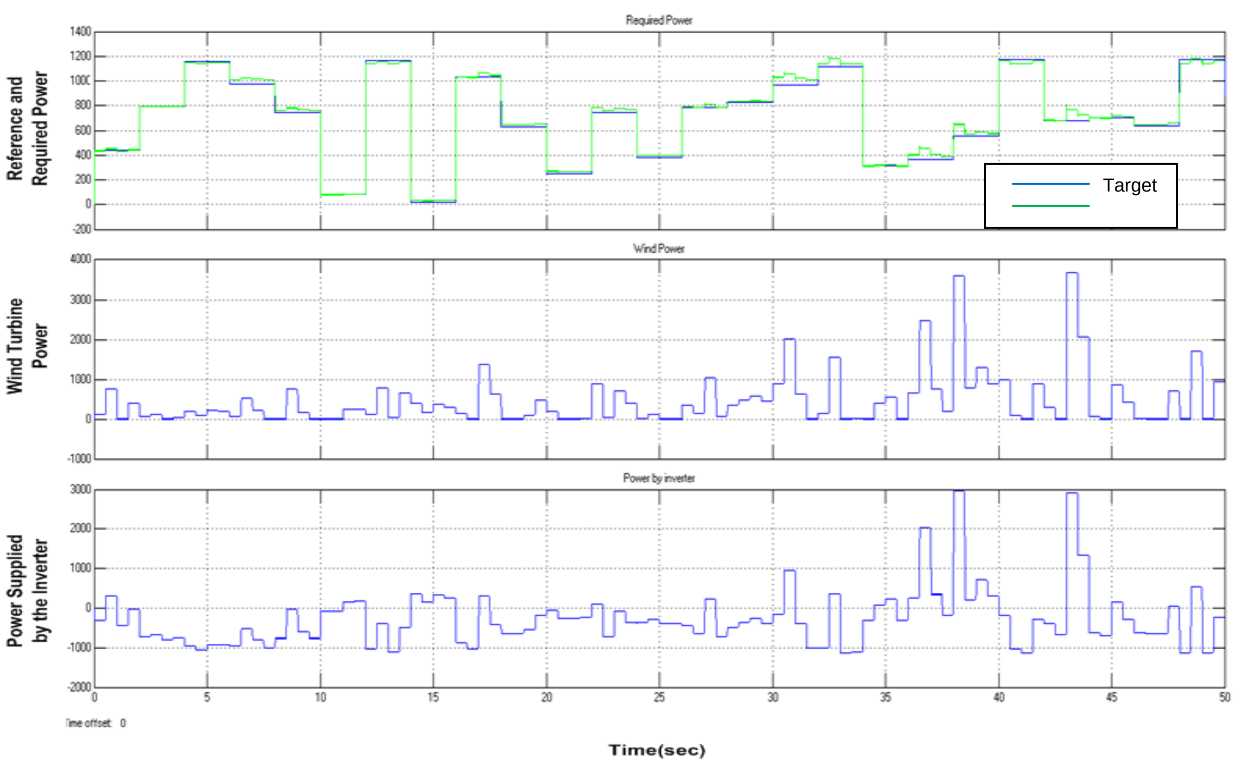
(a) Without ultracapacitor

(b) With ultracapacitor

Comparison of Dynamic Voltage Restorer with and without Ultra Capacitor



Wind Turbine Power Conditioner Topology



Power Conditioner Output

Advanced Power Devices and Converters

Date Project Began:	Nov. 2007
Dates for this Project Report:	Jan 2010 –March 2010
Sandia Project Manager (PM):	Stan Atcitty, satcitt@sandia.gov
Contractor:	NC State University
Partner(s):	SPCO, BPA

Project Description:

With the support of the DOE Energy Storage Program, the Gen-4 Emitter Turn Off Thyristor (ETO) has been developed. In FY 08, the focus was on the development of a Gen-4, ETO-based air-cooled converter as part of the 10 MVA STATCOM hardware development. In FY09, the focus was on the construction and testing of hardware related to the 10 MVA STATCOM. For FY10, the focus is on supporting Silicon Power Corporation (SPCO) and development of the solid-state circuit breaker (SSCB) based on the ETO.

Key Project Events:

- Provided extensive consulting support to SPCO's ongoing project on ETO-based StatCom converter.
- The thermal test on ETO device was conducted. The on-state voltage drop of the ETO at different temperatures was presented. Based on the thermal images, the thermal performance and reliability of the ETO control circuit and power path were analyzed

Project Status:

The conduction loss of the ETO device has been determined by the current passing through the ETO and the voltage drop across the device. In thermal tests, the voltage drop across the ETO was recorded under different temperature conditions, which is shown in Fig. 1.

The thermal performances of the control circuit and power path are the basis of overall reliability of the ETO device. Thermal images of the control circuit and MOSFET captured during tests are shown in Figures 2 and 3, respectively. The thermal images show that when the junction temperature of the GTO approaches 125° C, the maximum temperature of the control circuit and MOSFET is within operating range.

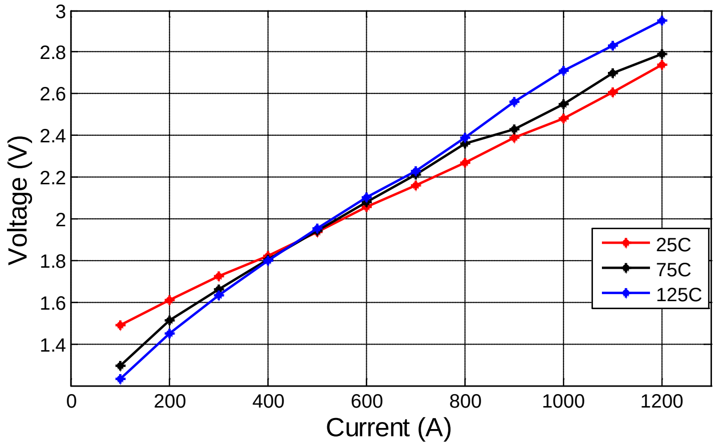


FIGURE 1. ETO ON-STATE VOLTAGE DROP

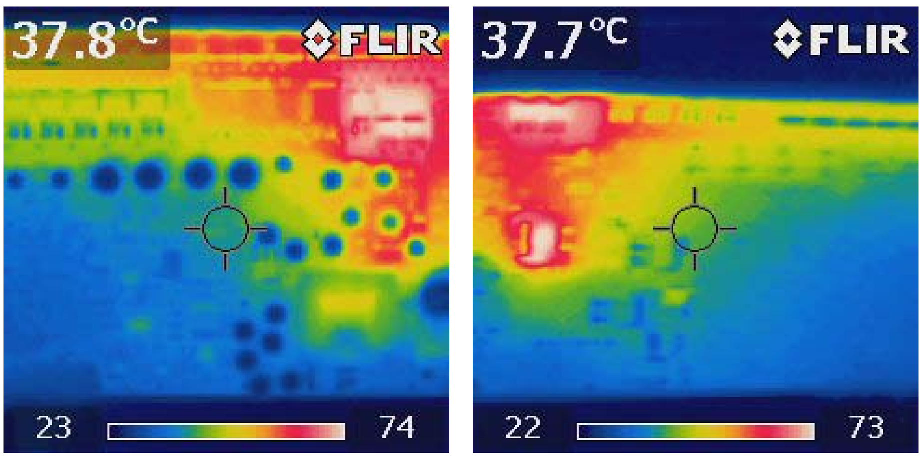


FIGURE 2. THERMAL IMAGES OF CONTROL CIRCUIT

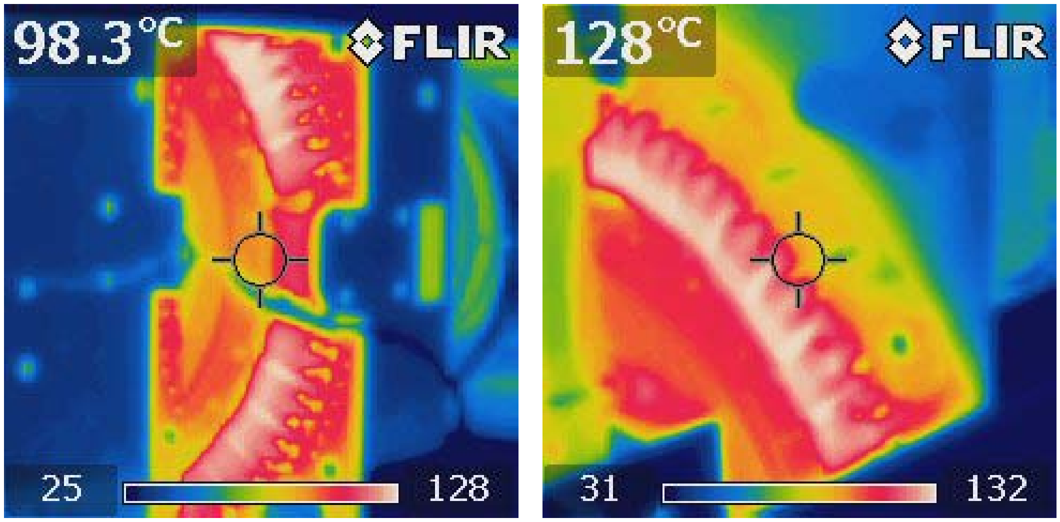


FIGURE 3. THERMAL IMAGES OF MOSFET (POWER PATH)

NMSU Senior Design Project

Date Project Began: FY2008

Dates for this Project Report: Jan – Mar. 2010

Sandia Project Manager (PM): Stan Atcitty

Contractor: New Mexico State University

Project Description:

The Klipsch School of Electrical and Computer Engineering at NMSU requires that all BSEE students complete a six-credit Senior Design class. Students with senior standing must design a reasonably complex system, drawing upon several specialties such as power electronics, computers, control, etc. The class also provides significant experience in teamwork, written and oral communication, and leadership.

Since FY'02, NMSU has developed and offered these design classes in the general area of electrical energy storage systems. Previous projects involved the design of a "Super-capacitor Test System." Design project classes "Photovoltaic System with Storage" were offered in FY'05 - FY'08. Teams successfully designed and installed a 300 W Photovoltaic system with energy storage in an electrochemical capacitor.

Customer-driven microgrids are a paradigm in which customers invest in such generation, and the utility 'enables' microgrid operation. The design task for students is to develop necessary hardware and controls so that the "PV with Energy Storage" system previously developed can participate in an energy market by responding to price signals.

The task given to the 2008-2009 team is to develop a 500 W, 120/208 V, 60 Hz, three-phase inverter (Figure 2). The inverter has been demonstrated on a single-phase basis and the basic control has been developed using discrete logic.

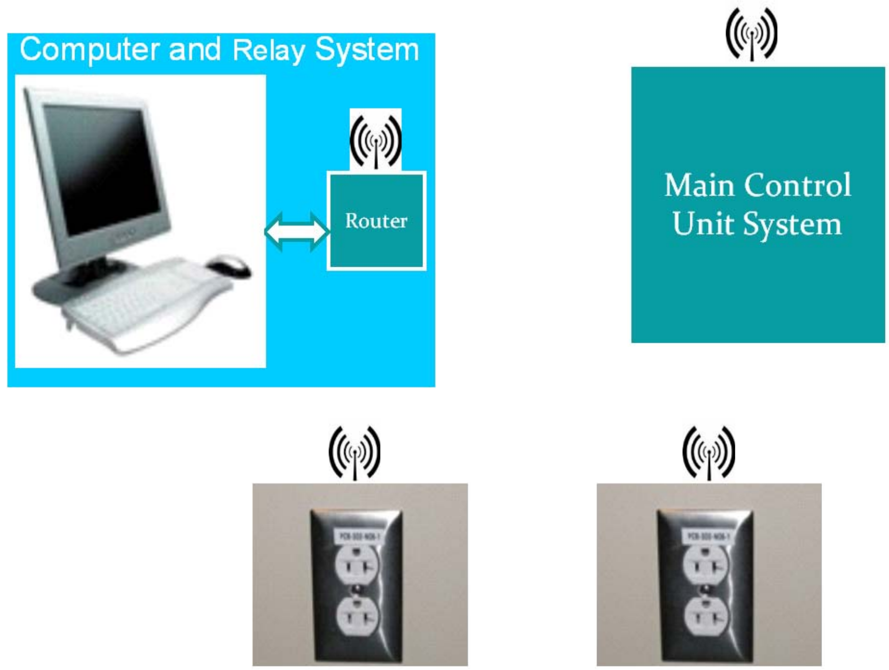
Project Status:

The classes offered have been very well received and the class is again being offered in Spring 2010.

Five students registered for this class. The object is to design wireless-controlled switches to manage load, generation, and storage in residential systems. The concept is illustrated below. In this first phase, it is intended that a smart outlet will be developed that monitors and controls load, with emphasis on turning off loads that consume standby power. In future phases, this smart outlet will act as an agent to manage load, local generation resource, or a storage resource, each of which might be distributed through a residence or a commercial building.

The students have now completed their System Concept and Preliminary and Intermediate Design Reviews. Excellent progress has been made on prototype development.

The students will complete the project in May, 2010.



System Concept

System Concept

Scale Model Demonstration of Storage in Customer-driven Microgrids

---

Date Project Began: FY2008

Dates for this Project Report: Jan.-Mar. 2010

Sandia Project Manager (PM): Stan Atcitty

Contractor: New Mexico State University

Project Description:

It has become abundantly clear that large-scale penetration of renewable-based, distributed resources is impossible without attendant application of centralized and distributed storage. It is, therefore, important to examine the nature and application of small storage systems in so-called *customer-driven* microgrids. The customer-driven paradigm suggests that distribution microgrids with substantial penetration will evolve from the customer side. Small residential and commercial customers, who constitute as much as 35-50% of load, will invest in energy sources. The distribution utility services will include network service, aggregation service for economic benefit, and reliability management for disturbances through islanding.

The El Paso Electric Power Laboratory at NMSU is used to demonstrate the integration of storage-based or storage-supported distributed generation in distribution systems. The goals of this project are to study:

1. The interconnection of sources to a distribution system and the steady state impact,
2. The control and response of sources during disturbances,
3. The role of storage in steady state feeder management and during disturbances, and
4. The role of storage in supporting islanded operation.

The Zigbee-based system to simulate a substation is illustrated in Figure 1. The circuit breakers interconnect utility sources and are controlled by a microprocessor and a communication interface. In turn, the substation is controlled from a SCADA system. Identical controllers will be used for micro-sources such as the laboratory PV Inverter and storage systems.

Key Project Events:

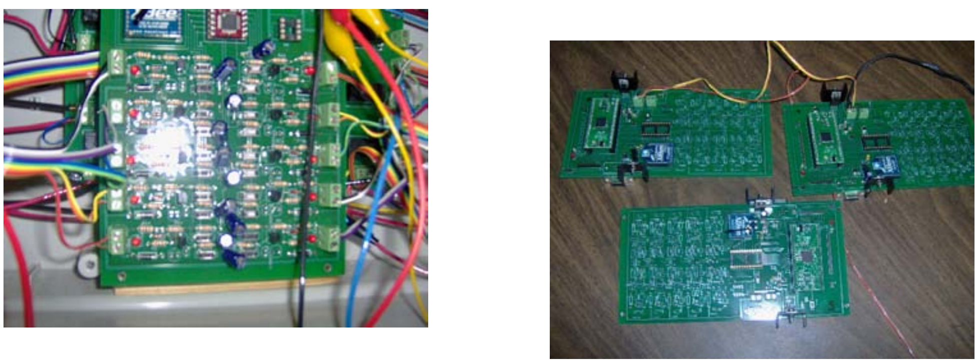
- Wireless communication systems for network control have been completed and bench tested, and the systems are now being installed.
- Work has been initiated on implementing multi-agent systems for microgrid management.
- The prototyping of fundamental, embedded controllers for inverter control has been completed.

Project Status:

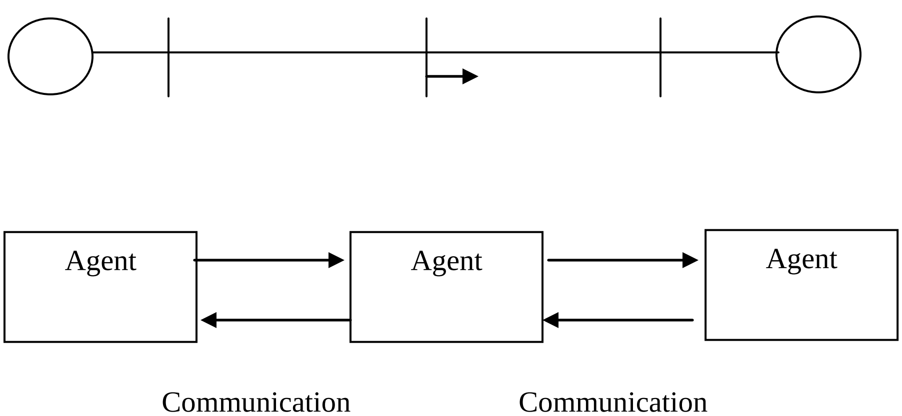
Microgrid control is fundamentally a distributed control problem. Specifically, the work in Q2 focused on implementing decentralized controller agents that rely only on neighbor –to-neighbor communication. In previous work, simulation studies were conducted to demonstrate algorithms for several problems, such as load balancing with such multi-agent systems.

A system with three agents was implemented to solve the classical power flow problem; i.e., the determination of whether acceptable voltages can be established in a microgrid with controllable generation and load. Figure 2 shows a very simple microgrid. Each node has an agent, which can communicate only with its immediate neighbor. Each agent has information regarding the local generation/storage resource and load. Together ,the agents must determine if the microgrid is viable; i.e., whether voltages at all nodes can be maintained at acceptable levels.

In contrast to simulation studies, the hardware implementation is subject to communication errors and multiple attempts are needed for successful communication. For this small system, it was demonstrated that this system correctly solves the power flow problem. The convergence behavior was recorded to provide data that will allow extrapolation performance of larger systems. The system will be expanded to ten agents in Qu3 and integrated with the generation/load hardware.



Microcontroller Boards Implementing Agents



A Three-node Microgrid with a Multi-agent Controller

Design, Development, Testing, and Demonstration of a 10-MVA, ETO-based StatCom

Date Project Began:	FY2009
Dates for this Project Report:	Jan. – Mar. 2010
Sandia Project Manager (PM):	Stan Atcitty
Contractor:	Silicon Power Corporation
Partner(s):	none

Project Description:

The US DOE Energy Storage Program, through Sandia National Laboratories (SNL) and in collaboration with Bonneville Power Administration (BPA), the Electric Power Research Institute (EPRI), the Tennessee Valley Authority (TVA), and North Carolina State University (NCSU), has developed a semiconductor switch known as the emitter turn-off thyristor (ETO), plus the preliminary design for an ETO-based static synchronous compensator (StatCOM) and controls. The ETO is a novel semiconductor switch suitable for high-power and high-frequency applications. The ETO has several advantages over IGBT or GTO technology, including low gate-drive power, high-frequency operation, snubberless operation, a large and safe operating area, and high current and voltage ratings.

To purpose of this project is to complete the design, construction, factory testing, installation, and field demonstration of a full-scale, 10-MVA, ETO-based StatCom for installation at a location in the BPA power system. The project is to be arranged in a "phase-gate" approach, in which certain milestones must be met before moving to the next phase. A technical review will be held at the end of each phase. Phase I focuses on design, construction, and factory testing of an ETO-based H-bridge. Once the H-bridge is successfully completed, the second phase will focus on the construction of five additional H-bridges and on the design, construction, and factory testing of the complete 10 MVA StatCOM. In the final phase, the StatCOM will be installed, grid-tied and field tested.

Key Project Events:

- Meeting with Stan Atcitty at American Competitiveness Institute (ACI) Technologies, Inc., Philadelphia, to discuss risk mitigation strategies, readiness, and rework for ETO power devices.
- Weekly teleconferences between Sandia, BPA, SPCO, and NCSU to discuss design/ assembly issues & to provide project and schedule updates.

Project Status:

One of the major milestones for successful completion of Phase 1 of the project is the design of the 1.67MVA H-bridge. This will be followed by assembly and testing. Development tasks have been allocated to the appropriate engineering disciplines and the status of the major schedule tasks are enumerated below.

Major components of the half-bridge, sub assembly have been received from vendors. A mock assembly of the half-bridge circuit was completed to ensure correctness of custom components (Figure 1). A similar process was followed for the Resistor-Capacitor-Diode (RCD) circuit assembly and the resistor bank (Figure 2).

A risk mitigation process was implemented to increase reliability of the final product and significantly reduce chances of malfunction. This was applied to three major components in the power stage:

a. ETO Devices.
b. Enclosure structure, and
c. Thermal management system.

The ETO power devices were inspected by ACI Technologies Inc. and a report (Visual Inspection and Functional Readiness Assessment) summarizing the effectiveness/ reliability of the devices was delivered. The report included recommendations for rework, which is essential for reducing the risk of failure during system operation. Based on this, ACI has been contracted to rework the ETO devices.

A simulation using actual component loads was performed to determine the distribution of stress throughout the enclosure frame. The results (shown in Figure 3) confirm that the minimum factor of safety is 7; i.e., the cabinet can withstand a total stress of approximately six times more than that of the internal components. RFQs for the enclosure have been sent to prospective vendors.

The losses in the power stage were recalculated using an updated electrical model of the system. The efficiency of the system for 1p.u. load is approximately 87% for both the inductive and capacitive modes of operation. Based on these thermal load calculations, a test-bench to validate the novel heat-pipe thermal management system was developed (Figure 4). The test bench incorporates the actual ducts, air mover, and bus-bars to emulate the thermal management system that would be in the final H-Bridge assembly. The thermal loads shall be provided by aluminum blocks clamped in the assembly. This test bench also allows operation and testing of the thermal management system for overloads without actually stressing the power components.

Significant progress has been made in terms of procuring components for the final assembly. The risk mitigation strategies opted for the rest of the course of the project will ensure significant reduction of errors during operation of the unit. The tests/inspections to achieve this are limited by available resources and time remaining in the project.

Figure 1. The RCD Circuit and Half-bridge Assemblies and Fixture to Build the Half-bridge Assembly (L-R)

Figure 1. Section of Resistor Bank for the RCD Circuit

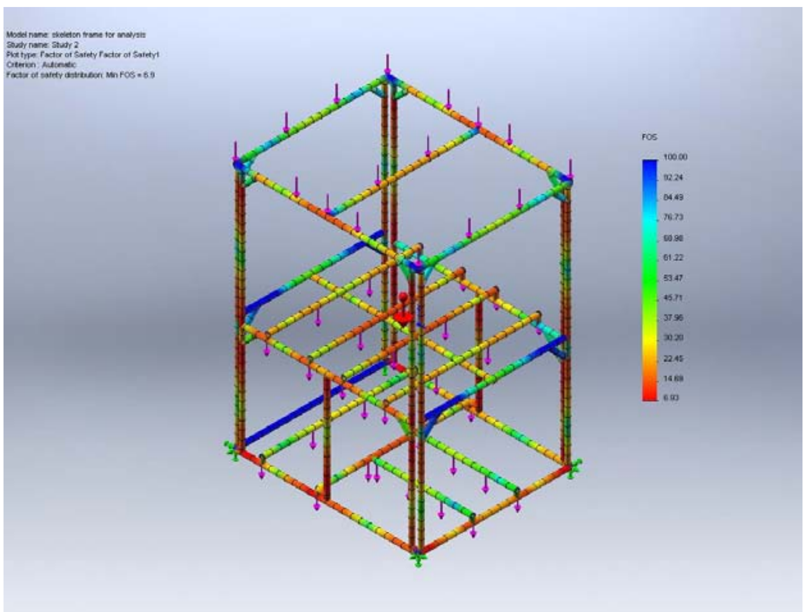


Figure 3. Results of Simulation Using Actual Component Loads

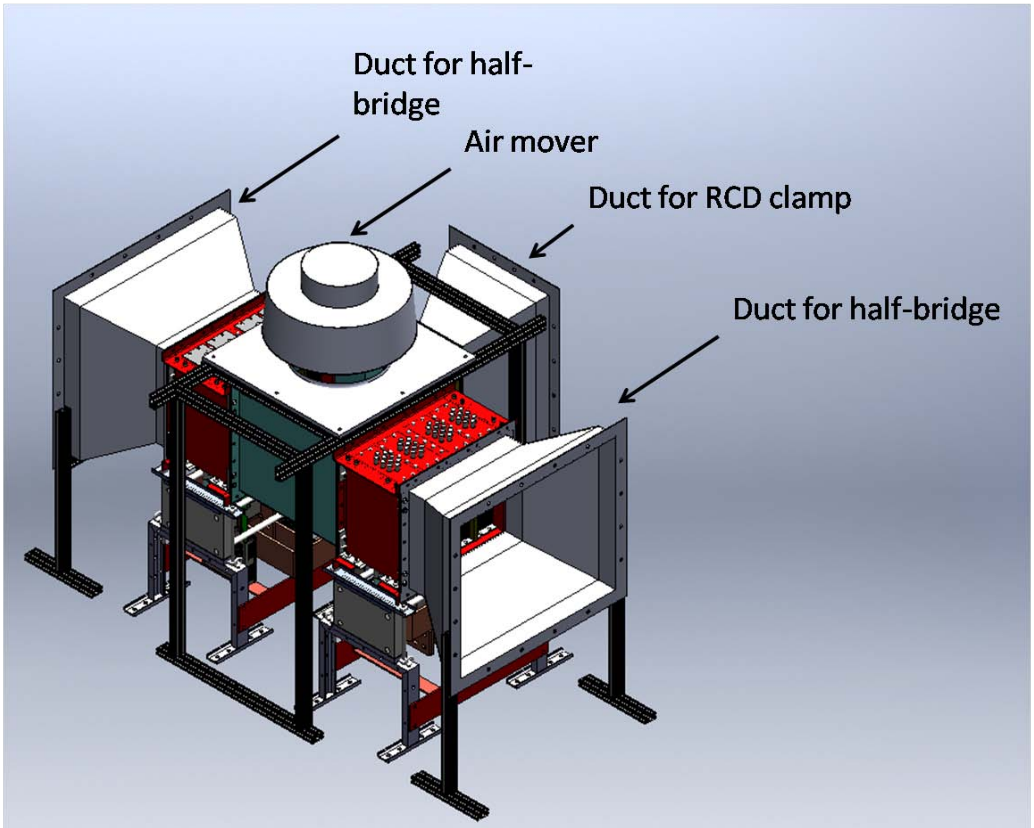


Figure 4. Test Bench Shown in Figure 4 Incorporates the Actual Ducts, Air Mover, and Bus-bars

Power Electronics Reliability

Date Project Began:	FY2008
Dates for this Project Report:	Jan. – Mar. 2010
Sandia Project Manager (PM):	Stan Atcitty
Contractor:	Mark A. Smith
Partner(s):	Silicon Power Corporation (SPCO), others TBD

Project Description:

In Phase I of this effort, Sandia used its modeling, simulation, and optimization capabilities to suggest reliability improvements in components, software, and operations of Silicon Power Corporation's Solid-State Current Limiter. Sandia also developed and documented a general process for analyzing the reliability of any power electronics system.

The goal of Phase II of this project is to use Sandia's semiconductor device reliability measurement and modeling capabilities to investigate and characterize stress-related failure modes of post-silicon devices such as Silicon Carbide SiC and Gallium Nitride switches.

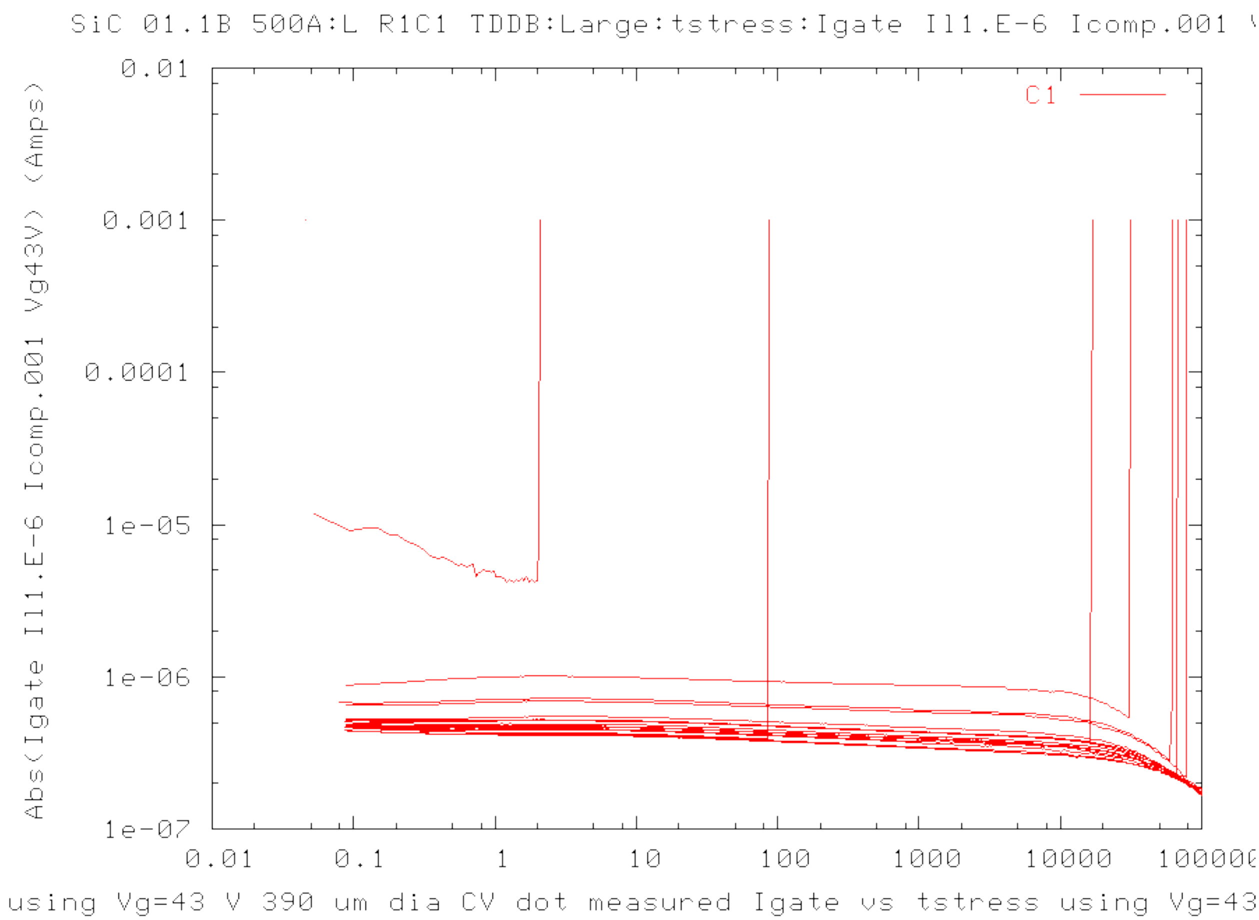
During the reliability characterization, opportunities will be sought for condition monitoring (CM) and prognostics and health management (PHM), to further enhance the reliability of power electronics devices. CM consists of detecting anomalies and diagnosing problems to flag maintenance needs. PHM goes farther by tracking damage growth, predicting time to failure, and managing subsequent maintenance and operations in such a way as to optimize overall system utility against cost.

Key Project Events:

- January 2010 – Phase II authorization received. Initial calls and meetings to identify potential, internal Sandia data sources relevant to power conversion systems.
- February 11, 2010 – Initial meeting to explore complementary synergies with Sandia's overall photovoltaic systems reliability project.
- February 21-25, 2010 – Attendance at Applied Power Electronics Conference in Palm Springs, CA, to understand the state of the power electronics technology industry, as well as to learn from decades of experience in power converter design for reliability.
- March 2010 – Initiated collaboration with Sandia's micro fabrication group to test reliability of key inverter components to be supplied by industry.

Project Status:

A number of sources of reliability data related to power conversion technologies have been explored. The phase II focus has settled on the reliability of SiC devices that are key to future high-efficiency power converters for both alternative power generation and energy storage. Sandia will conduct accelerated failure testing by measuring changes in device characteristics over time and under conditions of high stress, such as high voltage, current density, and/or temperature. An example of the induced failure data that Sandia can collect is shown in Figure 1. The changes will be correlated with the onset of failure for purposes of CM and PHM. We are working with our contacts in industry to obtain samples of SiC devices to test.



Example Data Showing Oxide on SiC Leakage Current and Breakdown Over Time.

Electrochemical Solution Growth of Bulk GaN for Power Electronics Substrates

Date Project Began:	FY2008
Dates for this Project Report:	Jan. – Mar. 2010
Sandia Project Manager (PM):	Stan Atcitty
Contractor:	Karen Waldrip
Contractor Contact:	knwaldr@sandia.gov
Partner(s):	GNOEM Systems, Inc.

Project Description:

This project is focused on developing a novel, scalable, economical growth technique for bulk Gallium Nitride (GaN), a critical material for next-generation, high-temperature power electronics.

Large area, high quality bulk GaN is required as a substrate material for growth of high efficiency bipolar transistors for inverters and power conditioning. Attempting to grow GaN in bulk by traditional precipitation methods forces extreme thermodynamic and kinetic conditions, putting these techniques at the extremes of experimental physics, which is unsuitable for large area, cost-effective substrate growth. The Electrochemical Solution Growth (ESG) technique is a novel concept that addresses these issues in a unique way, and is being proven out at Sandia National Laboratories under this program. Its final step in demonstrating feasibility is to deposit high quality GaN on a seed crystal. Initial experiments have shown that it is important to first understand auto nucleated growth from solution, in order to better choose the experimental conditions for seeded growth. The current activities are focused on understanding the conditions of saturation of nutrients in the molten salt electrolyte solution and the impact of growth conditions on crystal size, growth rate, and quality.

Key Project Events:

Near-term milestones have shifted to reflect a discovery of what is believed to be a high-quality crystal growth by autonucleation from a saturated molten salt electrolyte solution and investigate the growth conditions that yield the highest quality and largest area or volume crystals. If/when successful, these crystals can be used both as substrates for device growth and as high quality seed crystals in the larger rotating-seed boule growth experiments.

Project Status:

The project is on track.

- All work this quarter was performed by the contractor, with the exception of characterization work, which was performed by SNL. Much of the contractor's focus this quarter was on electrochemical characterization of lithium tetrachlorogallate ($LiGaCl_4$)—the species that we suspect the gallium forms in solution upon oxidation in the LiCl salt.
- Understanding the electrochemistry in detail is now becoming more important for experimental design to produce high quality auto nucleated seeds in solution:
    - Electrochemical experiments were performed to determine diffusion rates of gallium and nitride species in the molten salt. Data have been collected and are being evaluated by electrochemists at SNL.
    - Additional electrochemical experiments have been performed to evaluate, in closer detail, the number of electrons transferred during the reduction and oxidation of both the gallium and nitride species. These experiments entail some level of difficulty. Again, the resulting data are being evaluated by electrochemists at SNL.

Superconducting Flywheel Development

Date Project Began: June 2006

Date of This Project Report: Jan - Mar 2010

Sandia Project Manager: Nancy Clark

Contractor: Boeing

Project Description:

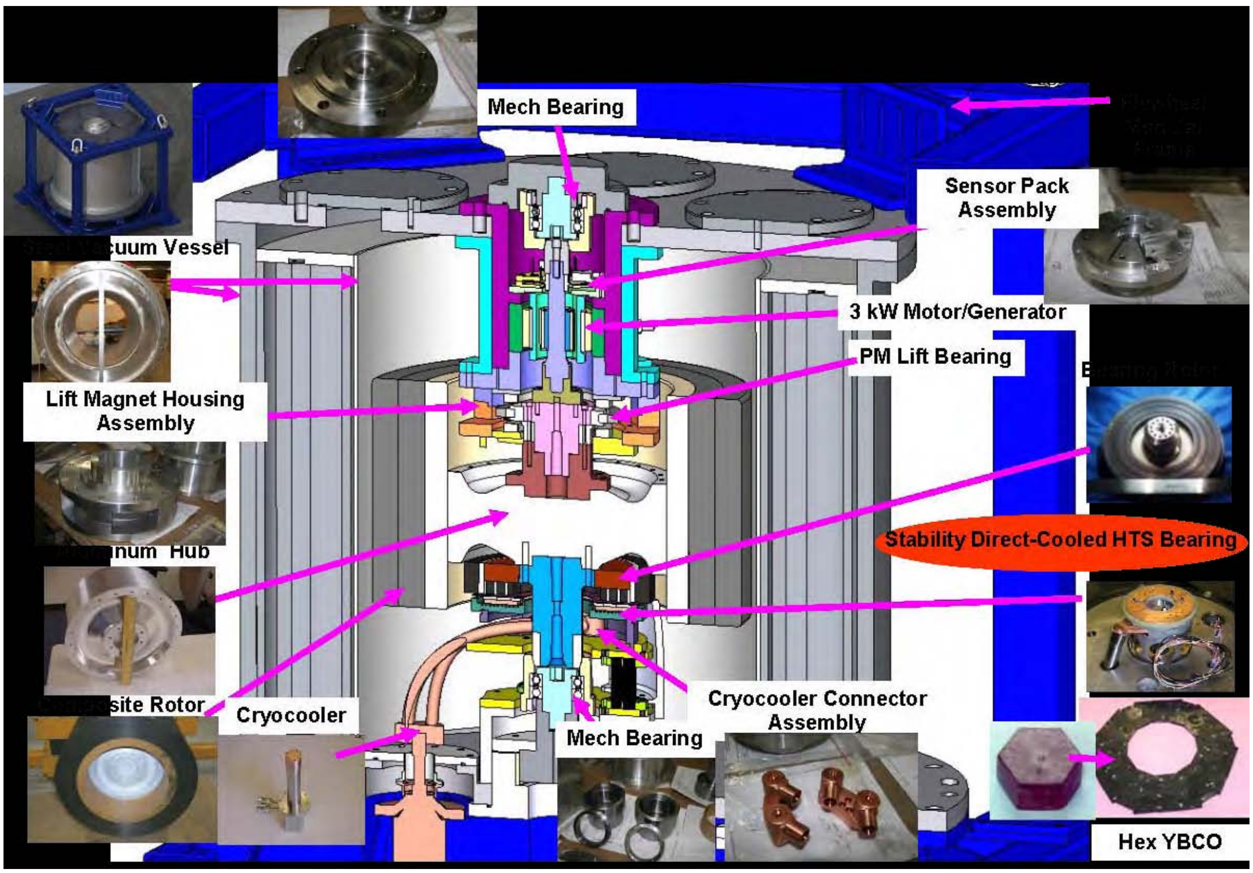
This report culminates an ongoing design and development effort between the ESS Program and Boeing to mature a new class of flywheel systems with multi-hour storage capabilities. The overall goal of this project was to produce a 3- to 5-kWh flywheel ESS for use in a hybrid wind/diesel generation application. This research offers the potential for significant benefits for future large flywheel systems in terms of system efficiency, as well as capital and operating costs.

Key Project Events:

- Prior to FY07 - Design, assembly & testing of three key components: the rim/hub ass'y, stability magnet ass'y (SMA), and the high-temp. superconducting (HTS) bearing.
- By end of FY07 - Work completed on the 5-kWh rotor and successful testing of HTS bearing to approx. 15,000 rpm. Additional capability to HTS bearing for passive damping of sub synchronous vibration anticipated due to previous experience with the DOE SuperConducting Flywheel Program.
- In FY09 – Study of permanent magnet arrays for hall sensor on motor/generator encoder was conducted.
- In FY09 – New motor/generator encoder design tested.
- 5 kWh rotor completed & fully tested at 105% speed.
- Direct-cooled, high-temp superconducting bearing was successfully tested at ~15,000 RPM.
- Two US patents were issued on Dec 15, 2009
  - 7, 633,202 B2 "Damping in high-temperature superconducting levitation systems"
  - 7,633,203 B2 "Damping and support in high-temperature superconducting levitation systems"

Project Status

The 5 kWh rotor was completed and fully tested at 105% speed. The direct-cooled, high-temperature Superconducting bearing was successfully tested at ~ 15,000 RPM, including measured losses, thermal modeling, and measurements of the cryocooler performance. Therefore, the design, development, and system integration of the Boeing Superconducting Flywheel is now complete and this project has closed.



5 kWh Flywheel energy storage system.
Schematic diagram with locations of parts and sub-assemblies.

Carbon-Enhanced Lead-Acid Battery and EC Testing

Date Project Began:	December 2005
Date of This Project Report:	Jan. – Mar. 2010
Sandia Project Manager:	Tom Hund
Contractor:	(SNL In-house Project)
Partner(s):	none

Project Description

In a cooperative effort with Mead-Westvaco, NorthStar Battery, and Battery Energy, the ESS Program was working to enhance the high-power cycle performance of valve-regulated, lead-acid (VRLA) batteries for utility cycling applications. The goal of this work was to evaluate the effect of different carbon formulations when used in the negative electrode of the battery. The carbon additions can significantly improve battery performance in high-power, partial-SOC cycling and prevent hard sulfation in the negative electrode, which can lead to capacity loss and premature battery failure. NorthStar Battery, Battery Energy, CSIRO/Furukawa, and East Penn Battery have produced a number of VRLA batteries containing carbon additives. All of the above batteries were or are under test at SNL. The goal of the current testing on the second series of carbon-enhanced VRLA batteries is to identify a carbon formulation and/or manufacturer that can build a battery that will maintain a low gassing current, while providing the high-power, intermediate-SOC cycle performance with a long cycle-life, in utility applications.

Key Project Events

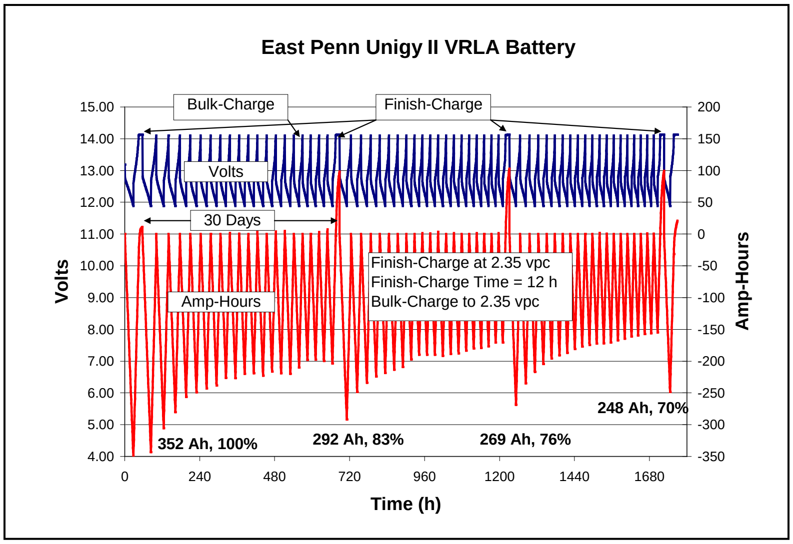
- MeadWestvaco and NorthStar Battery team to evaluate carbon formulations in the negative electrode of NorthStar VRLA batteries for utility applications. Two series of MeadWestvaco carbon formulations have been evaluated to date. This battery is designed for telecommunications systems.
- MeadWestvaco includes Battery Energy SunGels in their carbon formulation testing. This battery is designed for motive power and remote area power supplies.
- CSIRO/Furukawa provides Sandia with an Ultrabattery for utility cycle testing. This battery is designed for hybrid electric vehicles (HEVs).
- Sandia purchases an East Penn carbon enhances large format VRLA battery for testing. This battery is designed for utility cycling and wind farm power smoothing.
- The CSIRO/Furukawa Ultrabattery test results are published at the **18th International Seminar on Double Layer Capacitors and Hybrid Energy Storage Devices 12/08.** The results show a high rate partial state of charge cycle performance increase of at least 13 to 1 over conventional VRLA batteries.
- Sandia has purchased 24 1,000 Ah Ultrabattery cells in January of 2009 from Furukawa Battery for high-rate-partial-state-of-charge testing and for photovoltaic energy storage applications.
- The East Penn ALABC carbon enhanced wind farm energy smoothing battery test report was presented and published at the **EESAT 2009** conference. This was the first large format (1,000 Ah Cell) battery manufactured using the ALABC carbon technology.
- The East Penn version of the Ultrabattery was purchased in October 2009 and with the Furukawa version of the Ultrabattery photovoltaic hybrid power system testing is underway. This is the first large format Ultrabattery (1,000 Ah Cell) testing for solar and utility applications.

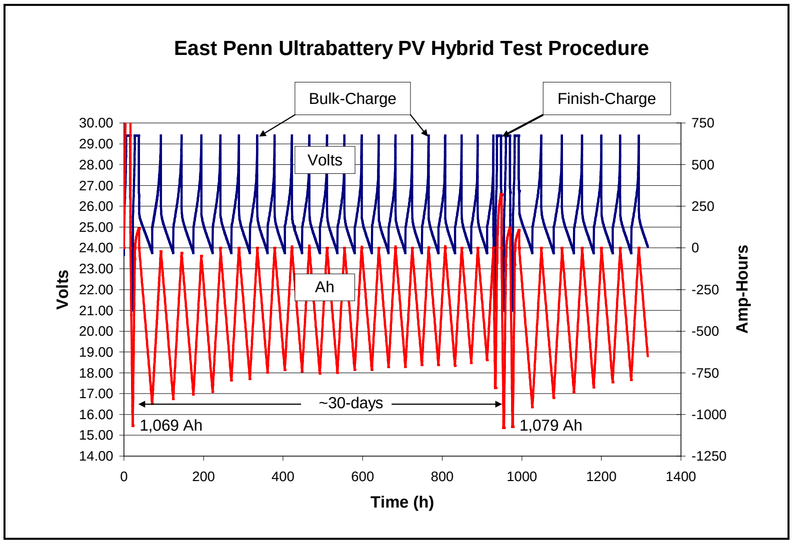
Project Status

Testing for FY10 Qt.1 is currently focusing on the new large format East Penn and Furukawa Ultrabattery. This is a valve regulated lead-acid battery with a carbon supercapacitor in parallel with the lead-acid cell. Initial test results using a PV hybrid power system test procedure is showing very positive test results with the capacity increasing from 1,069 to 1,079 Ah, a slight increase. This compares with a conventional VRLA battery where capacity dropped 17% after the first 20 PV hybrid cycles. Preliminary test results look very encouraging.

Project Pictures / Graphs / Tables

Furukawa 1,000 Ah Ultrabattery





East Penn 1,000 Ah Ultrabattery

Iowa Stored Energy Park

Date Project Began:	FY05
Date of This Project Report:	Jan. – Mar. 2010
Sandia Project Manager:	Georgianne Peek
Contractor:	Iowa Stored Energy Plant Agency (ISEPA)
Partner(s):	Iowa Association of Municipal Utilities (IAMU)

Project Description:

The Iowa Stored Energy Park (ISEP) is a DOE-supported effort of municipal utilities in Iowa, Minnesota, and the Dakotas to develop 13,400 MWh (268 MW for 50 hours, continuous operation) of compressed air energy storage (CAES) that utilizes wind generation resources to the highest degree possible. ISEP will satisfy the municipal utilities' need for intermediate generation and will support the development of wind energy by making it dispatchable, producing ancillary services to support the transmission grid, and encouraging further expansion of wind resources. In addition, ISEP will demonstrate the transferable processes of evaluating aquifer storage, site identification, and CAES design and operation for grid integration of wind.

Key Project Events:

- 2002 – IAMU study completed
- 2003 – Completed conceptual design and began search for geological sites
- 2005 – Conducted seismic surveys; Completed feasibility analysis
- 2006 – Found suitable geologic formation
- 2007 – Public announcement of site and solicitation of municipal partners
- Jan. 2008 – Complete MISO market analysis
- May 23, 2008 – First modeling results of MRES
- Sept. 2008 – Iowa Power Fund approved forgivable loan of $3.2M
- Mar. 2009 – Modeling of MRES completed with favorable results
- Feb 2010 – Test well drilling/coring begun

Project Status:

The land rights were secured this quarter. It was determined that the test well(s) can be completed without EPA approval.

During this quarter, the drilling/coring was started on the first exploratory test hole. However, based on geophysics, it was discovered that the geologic structure is not the geometry of what was expected (the target horizon was about 100 feet lower than anticipated from the seismic interpretation). Based on this, the recommendation was made to change course somewhat and, as opposed to production wells, drill the next two holes as exploratory efforts to better define the geologic structure and, thus, reduce risk. The rationale for the exploratory holes is to develop some geologic ground truth to the seismic work to better constrain the models.

The test cores will be transported to the Sandia National Laboratories Geophysics laboratory for analysis. In addition, water samples will be collected from the pump tests for chemical analyses by Sandia.

Project Pictures / Graphs / Tables:

Truck mounted drill rig

Bottom of target reservoir horizon (Cambrian Mt Simon sandstone)

NYSERDA / DOE: Joint Energy Storage Initiative: Advanced Sodium-Sulfur (NaS) Battery Energy Storage System (BESS) Project at MTA Long Island Bus

Date Project Began:	FY 2006
Date of This Project Report:	Jan.- Mar. 2010
Sandia Project Manager:	Georgianne Peek
Contractor:	EnerNex
Partner(s):	NYSERDA, NYPA NYPA negotiated cost share partners: Metropolitan Transportation Authority Long Island Bus (LIB) (customer) American Public Power Association's DEED Program (APPA) CEA Technologies, Inc. (CEATI) Electric Power Research Institute (EPRI) Natural Resources Canada (NRCan) New York Independent System Operator (NYISO) New York State Energy Research and Development Authority (NYSERDA) United States Department of Energy (US DOE) Consolidated Edison, Inc. (Con Ed) FirstEnergy Corp. Hydro One Hydro-Québec Long Island Power Authority (LIPA) New York Power Authority (NYPA) (project developer) Public Service Electric and Gas Company (PSE&G) San Diego Gas & Electric (SDG&E) Southern Company Tennessee Valley Authority (TVA)

Project Description:

As part of the Joint NYSERDA/DOE Energy Storage Initiative, this project will demonstrate the ability to shift a compressor peak load to off-peak capacity, and provide emergency backup power using a 1 MW, 6.5 MWh, NaS BESS at a major Long Island Bus (LIB) depot facility in Garden City, Long Island, NY. The LIB depot chosen as the site for this demonstration is a natural gas refueling station for 220 buses. Three 600-horsepower, natural-gas compressors comprise the load that is served by a dedicated line from the Long Island Power Authority (LIPA). The load operates 24 hours per day, seven days per week over three shifts, and incurs high, on-peak demand charges for four months of the year (approximately May 15 through September 15). The project will demonstrate the ability of a NaS battery system to enhance the reliability of the local grid by shifting load from on-peak to off-peak.

Key Project Events:

- NAS™ Battery modules (developed jointly by NGK and Tokyo Elec. Power Co., of Japan) arrived in New York on July 24, 2006.
- Battery module installation occurred over three days, August 3 – 7.
- LIPA confirmed on Feb 9, 2007 that they had accepted all of the mark-ups made by LIB on their Jan 17th Interconnection Agreement (IA) submission.
- The 1 MW, 7.2 MWh, sodium-sulfur battery and PCS installation were completed on June 22, 2007.
- December 2007: NGK determines that battery cycling will not restore batteries to full capacity and the batteries were returned to Japan for analysis.
- January 2008: NYPA and NGK meet to confirm a recovery plan and timeline.
- May 2008: New battery modules arrived and complete system restart was completed.
- June 2008: Data acquisition system installed.
- Aug. 2008: Batteries completed approximately 30 cycles.
- March 2009: 18 month operating test program begun to monitor performance of the system.

Project Status:

During this quarter, data collection was conducted for the consumption of the three electric compressors. However, the system DAS is still plagued with problems and is currently down. The NAS Battery is on standby until the large gas compressor is back online. NYPA might put the NAS battery back into service, when data collection system is up and running. The gas compressor is expected to be back online by June 1, 2010, when peak summer tariff goes into effect; the NAS battery to be put back into service by this date.

Project background information and system monitoring data are available at http://www.storagemonitoring.com/nyserdadoe/storage-home.shtml.

Project Pictures / Graphs / Tables:

Completed installation – 2008

NYSERDA / DOE: Dispatchable Photovoltaic System with Electric Energy Storage for Commercial Buildings in NYC Area Network

Date Project Began:	FY 2008
Date of This Project Report:	Jan. – Mar. 2010
Sandia Project Manager:	Georgianne Peek
Contractor:	EnerNex
Partner(s):	NYSERDA, CUNY, LaGuardia Community College (LGCC)

Project Description:

This project will install a 100 kW PV system, coupled with a 150 kW/150 kWh Gaia Power Technologies PowerTower storage system, on the roof of LGCC in Queens, NY. The storage system will provide the firming and dispatch capabilities for facility peak demand. The PV/ESS system will be modeled using "PV Planner" software developed by the University of Delaware, with support from the National Renewable Energy Laboratory (NREL), for the purpose of analyzing dispatchable, peak-shaving PV. The technical and economic performance will be monitored and analyzed for 18 months. The specific project objectives are to:

- Demonstrate EES for firming electrical capacity of renewable energy;
- Demonstrate dispatchable PV for managing demand charges;
- Evaluate grid reliability improvement through the commercialization and widespread deployment of dispatchable peak shaving PV; and
- Evaluate if dispatchable, peak-shaving, PV technology can be used to defer the need for a reverse power relay to interconnect with network electricity grids.

Key Project Events:

- Oct. 2, 2008 Project Kick-off Meeting

Project Status:

This project is currently on hold. The manufacturer of the BESS filed bankruptcy. CUNY and LGCC are developing a contingency plan and determining what storage technology to move forward.

Project Pictures / Graphs / Tables:

Proposed Site for PV Installation.

NYSERDA / DOE: Long Island RR Trackside FESS

Date Project Began:	FY 2008
Date of This Project Report:	Jan. – Mar. 2010
Sandia Project Manager:	Georgianne Peek
Contractor:	EnerNex
Partner(s):	NYSERDA, NYPA (NY Power Auth.), LIRR (Long Island Rail Road)

Project Description:

The New York Power Authority (NYPA) will install and demonstrate a high-speed Flywheel Energy Storage System (FESS) at the Long Island Rail Road (LIRR) Deer Park station on Long Island, NY. The scope of the project is a turn-key installation of a 2.5 MW/15 sec FESS to provide traction power voltage support for LIRR to mitigate voltage sag problems, reduce power peak demand charges, and offset costly electric distribution upgrades.

Key Project Events:

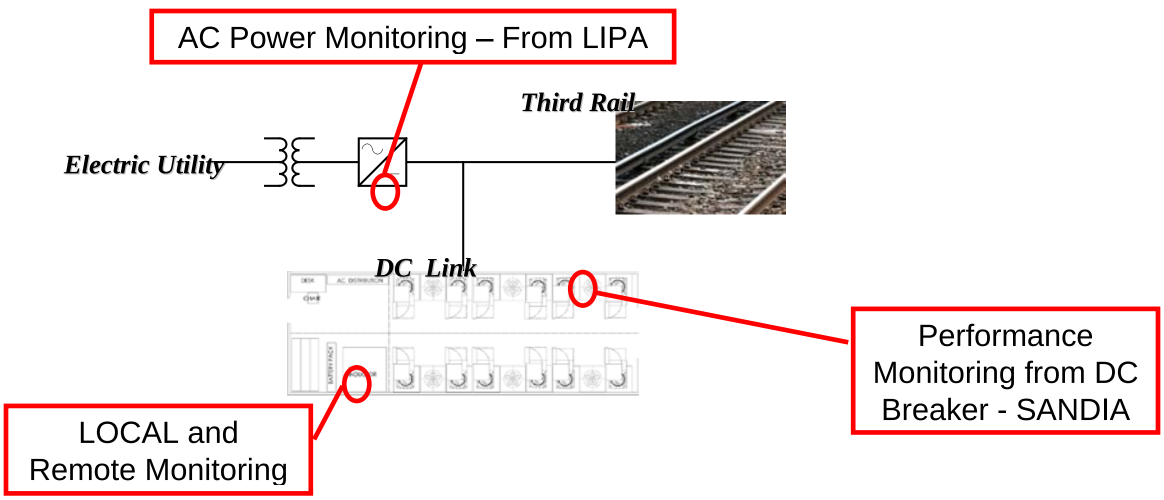
- Project kick-off meeting on January 8, 2008
- Turn-key FESS re-bid due July 11, 2008
- FESS contract awarded to Pentadyne July 2009
- Kick-off meeting with FESS contractor Aug. 2009

Project Status:

Currently, the project is in the specification phase. Documents are exchanging hands among Pentadyne, NYPA, and LIRR for approval. The site preparation work is scheduled to begin in April. The foundation work is scheduled for May, and the building and flywheel assembly are scheduled to be installed in August.

Project Pictures / Graphs / Tables:

Future FESS Site



Proposed Monitoring Locations

NYSERDA / DOE: Energy Storage System Demonstration at Niagara Falls State Park

Date Project Began:	FY09
Date of This Project Report:	Jan. – Mar. 2010
Sandia Project Manager:	Georgianne Peek
Contractor:	EnerNex
Partner(s):	NYSERDA, Premium Power Corp., NYS Parks

Project Description:

This project will demonstrate the technical and economic performance of a 100kW/ 150kWh, Zinc-Flow PowerBlock®150 (PB150) energy storage system (ESS) in conjunction with a 30 kW PV system, and interconnected with National Grid's distribution feeder at the Niagara Falls State Park maintenance facility. The ESS is a commercially available product manufactured, distributed and serviced by Premium Power Corporation (PPC), which is based in North Reading, MA.

The specific objectives of this project are to demonstrate and evaluate one Premium Power Corporation PB150, fully integrated mobile ESS to:

- Provide capacity firming of renewable energy generation (~30kW of PV), that will be installed on the roof of the Niagara Falls State Park Maintenance Facility;
- Provide up to 150kWh of backup energy to the maintenance facility for Niagara Falls State Park;
- Reduce daily energy demand by up to 150kWh and peak power by up to 100kW on the heavily-loaded grid during peak load periods;
- Demonstrate the mobility of the ESS's, which can be deployed in emergencies, for backup power or to relieve congestion at critical "load pockets" in NYS;
- Demonstrate long-term, commercial-scale operation of a high-efficiency peak shift energy storage system, with the capability to withstand daily deep discharge cycling and maintain a 30+ year design life, as opposed to today's VRLA battery systems, which have limited cycling capability and life.

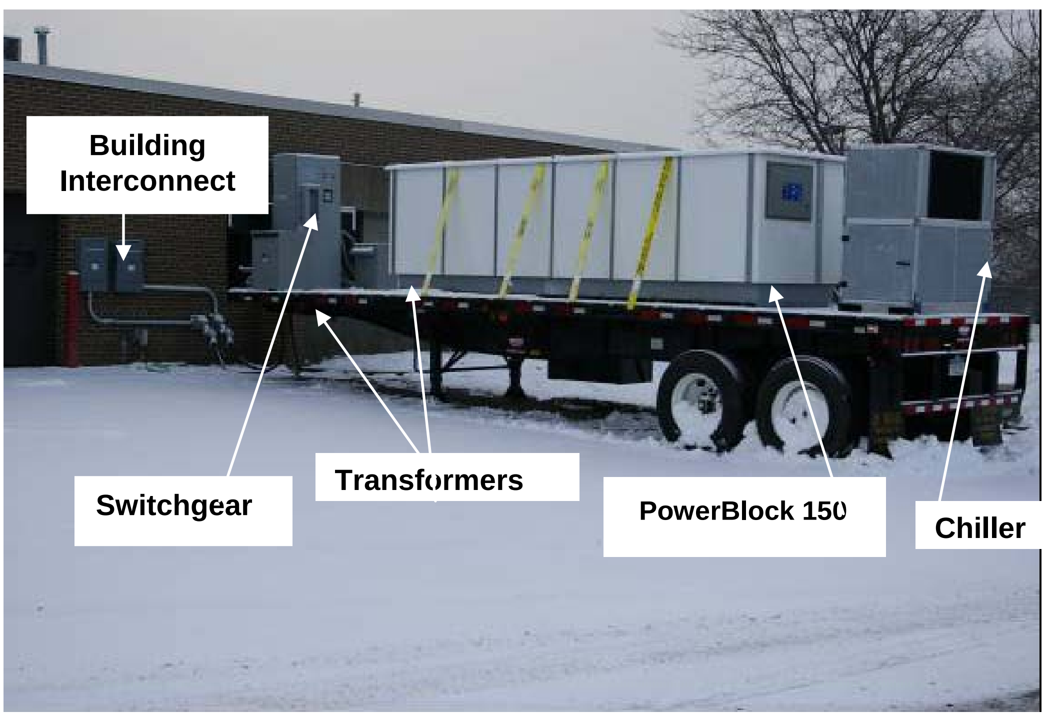
Key Project Events:

- Kick-off meeting held April 17, 2009.
- PB150 unit installed February 2010

Project Status:

PB150 unit was installed and commissioned. Unit is operating and ready to be exercised and tested. On-site personnel were trained in its operation. DAS installation and collection of data to begin next quarter.

Project Pictures / Graphs / Tables:



NYSERDA / DOE: Stephentown Flywheel Frequency Regulation Demonstration

Date Project Began:	FY 2010
Date of This Project Report:	Jan. – Mar. 2010
Sandia Project Manager:	Georgianne Peek
Contractor:	EnerNex
Partner(s):	NYSERDA, Beacon Power, NYSEG, National Grid, NYISO

Project Description:

This project will install, test, and demonstrate the performance of a 20 MW, 5 MWhr, flywheel energy storage plant in response to a NYISO signal for grid regulation service. The plant might be deployed such that all, or part, of the plant capacity will be interconnected with a 115 kV National Grid transmission line, with the balance connected to a NYSEG 34.5 kV distribution feeder, both located in Stephentown, NY. Beacon Power Corporation anticipates a staged deployment of the facility in 2 MW blocks.

Key Project Events:

- Contract award expected March 2010

Project Status:

NYSERDA expects to issue the contract to Beacon Power in March 2010. Beacon Power owns the site in Stephentown, NY, and has begun clearing and leveling the site, in anticipation of the contract award.

Project Pictures / Graphs / Tables: (none at this time)

Improved Properties of Nano-composites for Flywheel Applications

Date Project Began: FY 2010

Date of This Project Report: Jan. – Mar. 2010

Sandia Project Manager: Georgianne Peek

Contractor: Internal Sandia

Partner(s): Beacon Power

Project Description:

This project is a collaboration between Sandia and Beacon Power, Inc. The purpose is to develop nano-composite materials for tailored mechanical behavior and operational performance optimization in flywheel energy storage systems. Current composite flywheels have significant obstacles in their makeup, including transverse strain behavior, long-term mechanical creep and micro-fracture propagation, composite processing/manufacturing, and other system requirements. This has resulted in limits to the operational efficiency of the flywheels, both in terms of leading edge technology and overall system costs. Because the kinetic energy stored in these devices is based on a 'squared' relationship with speed, even incremental improvements will result in substantial additional energy storage and more attractive operational dynamics.

Several approaches will be used to identify novel material solutions and system enhancements, including the systematic exploration of resin requirements, nano-filler features, interfacial properties and processing optimization. The material selection criteria and manufacturing improvements from this study will allow US-based companies to position themselves as global leaders in this evolving technology, and to develop their own supply of higher quality and better understood materials by removing the current dependency on foreign sources.

Key Project Events: (none at this time)

Project Status:

During this quarter, the Sandia project team of Tim Boyle, Mat Celina, John Bell, and Ben Anderson met with Beacon Power and began some of the baseline studies. These studies include fundamental observations on the fiber and the resin. The impact of nano-particle (NP) material will be determined. In addition, material from Beacon was received. Preliminary measurements are currently being taken on the NP and the other material supplied by Beacon. The team is also working on the potting motor issue**.**

Project Pictures / Graphs / Tables: (none at this time)