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Energy Storage Systems Program

(DOE / ESS)

Quarterly Progress Report

April 2010 — June 2010

(Fiscal Year 2010 / 3rd Quarter)

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Sandia National Laboratories

Albuquerque NM

(SNL / ESS)

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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:	April – June, 2010
Sandia Project Manager (PM):	Stan Atcitty
Contractor:	Arkansas Power Electronics International, Inc.

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), thus 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. The proposed solution offers modularity, flexibility, and low operation/maintenance, allowing for widespread adoption and deployment of the technology.

The team developed a low-power, low-voltage, SiC-based, SSFCC prototype. Research carried out during the Phase I portion of this STTR project demonstrated three key additional points: 1) system scalability (i.e., 4.16 kV to 13.8 kV SSFCC systems using 4.5 kV device technology); 2) system functionality (i.e., fast and accurate fault current control); and 3) system-added value (i.e., 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 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. In this quarter the University of Arkansas (UA) and APEI, Inc. researchers prepared a technical report for submission with the year 2 DOE funding application.

Substantial conclusions were made by the UA regarding the coordination of the SSFCC with conventional protection equipment, including fuses and reclosers, which could be located up- or down-stream of the SSFCC. Their conclusion was that coordination with these devices is possible. A basic method, which can be employed by distribution engineers to ensure coordination, was also presented, as discussed in the year 1 technical report.

APEI, Inc. has also completed initial simulations and MATLAB code for the analysis of fault detection algorithms (we are currently validating our model and code). Initial studies are focusing on a single-phase, differential transformer protection scheme with through-faults, internal winding faults, and inrush events being

considered. This setup is being used to evaluate a proposed harmonic blocking/restraint method, accomplished using a least-squares curve fitting approach for rapid Fourier series decomposition.

UA and APEI, Inc. personnel attended the 2010 IEEE Transmission and Distribution Conference in New Orleans, La. Dr. Yongfeng Feng of the UA presented a paper titled: "Impact of Solid-State Fault Current Limiters on Protection Equipment in Transmission and Distribution Systems," which is directly relevant to this research effort. UA and APEI, Inc. personnel working on this project also attended the semi-annual meeting of the NSF funded GRid-connected Advanced Power Electronics Systems (GRAPES) center in Columbia, SC.

APEI, Inc. has pursued power system data from several utilities (AEP, ConEd, North Little Rock Electric Dept.) for use in fault detection studies. Utilities have expressed a willingness to provide the desired data, but available information has not been sufficient for the required studies (i.e., not enough events captured and/or lack of contextual information). Because of this, it has been determined that simulated fault and transient data will be used for these studies.

Project Status:

APEI, Inc. and the UA submitted a report on technical progress for the year 2 funding applications. This project is considered to be on-schedule at this time.

In the next quarter, UA personnel will be focusing on the coordination of the SSFCC with upstream and downstream sectionalizers, coordination of the SSFCC with other SSFCCs, and authoring an IEEE Transactions paper on the SSFCC coordination studies.

APEI, Inc. will continue with the study of fault detection algorithms over the next quarter. As appropriate, the simulation models and MATLAB code will be extended to cover additional transient phenomenon or three-phase system simulations. A revised setup, which is more applicable to studying line protection, will be specifically pursued. APEI, Inc. will also be looking into options for point and distributed optical sensors (and related system components) for fault detection, using an approach discussed in the year 1 technical report.

APEI, Inc. has hired additional personnel, who will begin conducting a detailed economic analysis of the SSFCC. This analysis will include efforts to quantify the benefits of the SSFCC (e.g., reduced arc flash hazard, increase. It is expected that GRAPES member companies will be surveyed at this time so that the considerations of various utility companies can be reflected in the economic study.

Large Area, SiC, GTO Thyristor Development

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

Project Description:

The goal at the end of Phase II of this program is to achieve the following from a Silicon Carbide based 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

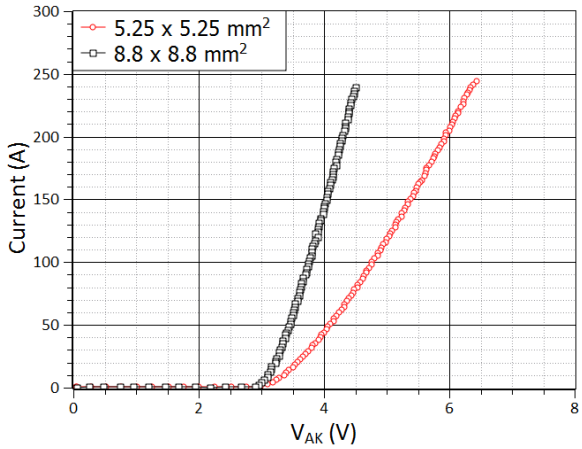
Key Project Events:

- Investigation of on-state characteristics of different sizes of 6.5 kV Thyristors up to 250 A.
- Detailed temperature dependence of forward-blocking characteristics.
- Investigation of Thyristor turn-on performance as a function of gate current and on-state current level.
- Investigation of a forced commutation technique for Thyristor turn-off: impact of on-state current and forward dV/dt on the minimum Thyristor turn-off time (t_Q)
- On-wafer characterization results from recently completed lot of 10.5 kV Thyristors

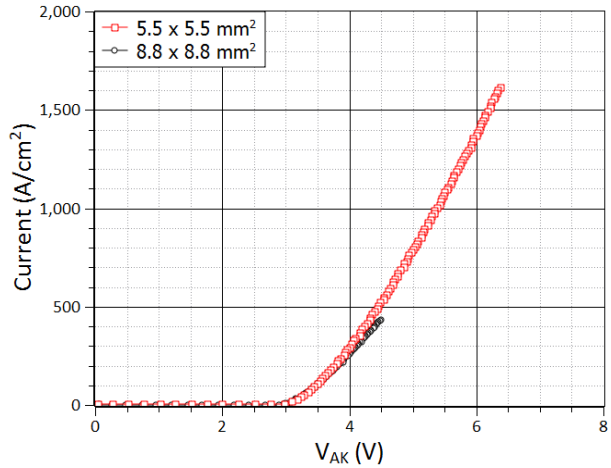
Project Status:

In this reporting period, a detailed, high-current investigation of on-state characteristics of the different sizes of 6.5 kV Thyristors was conducted and the variation of the differential specific on-resistance with current level was studied. The forward blocking characteristics were examined up to 125 °C; and the temperature dependence of breakdown voltage and leakage current were studied. The turn-on performance of the 6.5 kV Thyristors at low and high current densities as a function of gate current level was explored. A forced commutation circuit was designed and constructed to investigate the Thyristor reverse recovery characteristics and minimum turn-off time, t_Q at increasing levels of forward current and dV/dt. On-wafer characterization of the recently completed batch of 10.5 kV Thyristors was also conducted.

Project Pictures / Graphs :



(a)



(b)

Figure 1 (a) Forward high current-voltage characteristics measured on representative 5.25 x 5.25 mm2 and 8.8 x 8.8 mm2 SiC Thyristors. When the data shown in (a) is plotted in (b) as current density versus voltage, an almost identical J-V characteristic is obtained for both Thyristor chips. The differential specific on-resistance decreases from ≈ 2.47 mΩ-cm2 at 450 A/cm2 to about ≈ 1.45 mΩ-cm2 at 1600 A/cm2.

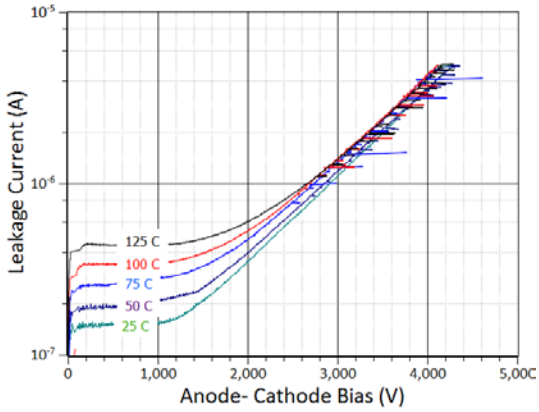
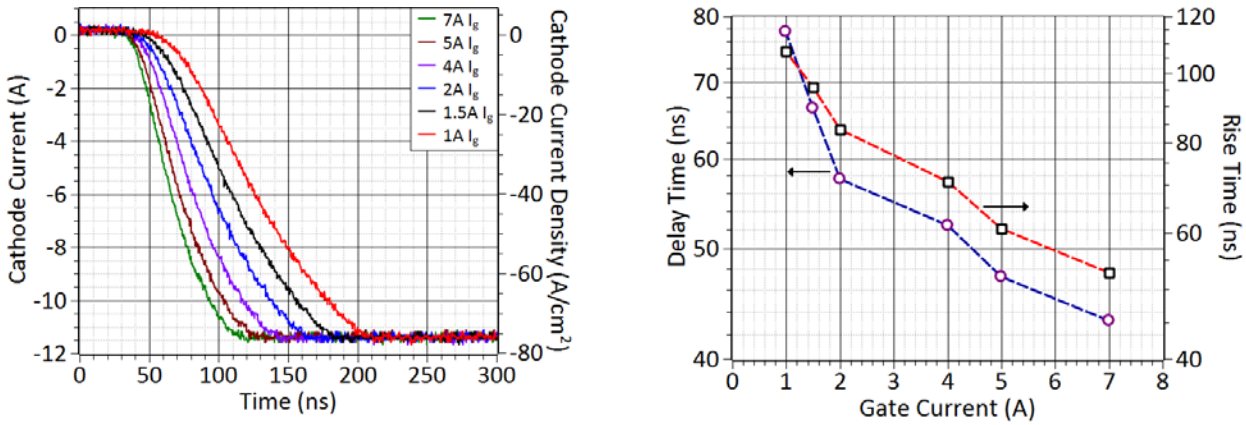
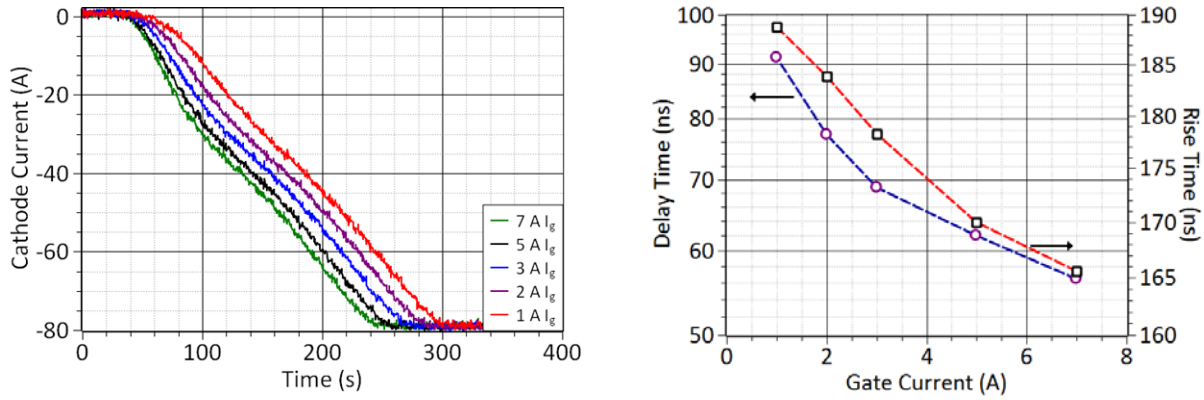


Figure 2: Temperature-dependent forward blocking characteristics measured on a packaged 5.25 x 5.25 mm2 SiC Thyristor. The measurement apparatus limited the maximum applied temperature to 125 °C. The leakage current increases with increasing temperature at lower VAK; but the temperature co-efficient of the leakage current changes from positive to negative at higher VAK. This trend in leakage current indicates that the blocking voltage of the GeneSiC SiC Thyristors is solely limited by avalanche breakdown and not by device design, processing or epilayer defects.



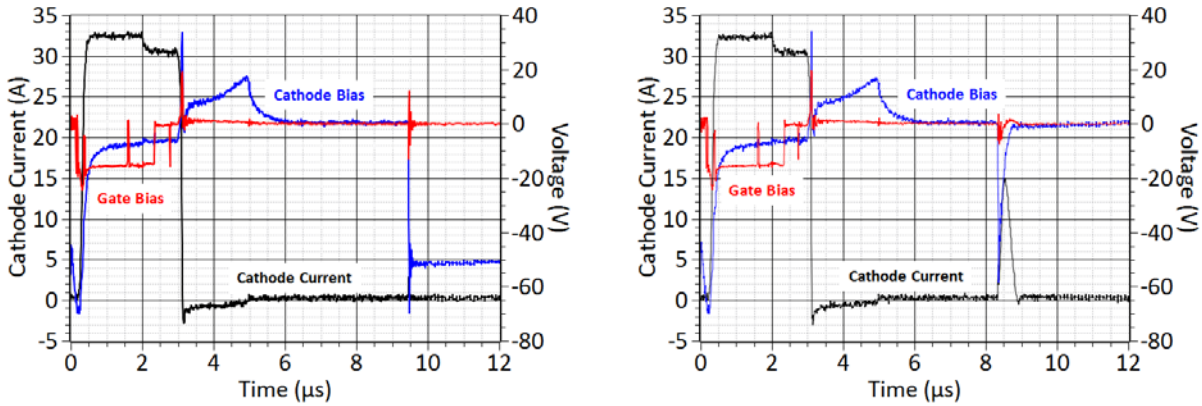
(a) (b)

Figure 3 (a) Turn-on transients measured on a representative four-gate 5.25 x 5.25 mm SiC Thyristor up to a current density of 77 A/cm2 and (b) extracted delay and rise time components of the total current rise time from the data shown in (a). Ultra-low delay and rise times of 44 ns and 55 ns, respectively are observed for a gate current of 7 A. These represent the lowest ever reported delay and rise times for any high-voltage (Si or SiC) Thyristor to-date.



(A) (b)

Figure 4(a): Turn-on transients measured on a representative four-gate 5.25 x 5.25 mm SiC Thyristor up to a current density of 577 A/cm2 and (b) extracted delay and rise time components of the total current rise time from the data shown in (a). At a gate current of 7 A, a rise time of 166 ns and a delay time of 56 ns are observed.



(a) (b)

Figure 5: Representative Thyristor Reverse Recovery characteristics and measured by commutating 32 A of cathode current by applying a reverse bias of ≈ 27 V to the cathode. A subsequent forward bias of 50 V is applied with a dV/dt of 1833 V/µs after (a) a duration of 6.5 µs, which is greater than the minimum turn off time, tq and (b) a duration of 5.5 µs, which is smaller than tq. In (b), the Thyristor spuriously turns on without any gate trigger, when the second forward voltage pulse is applied.

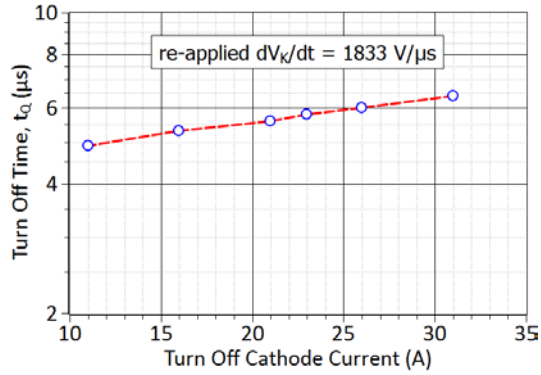


Figure 6: Variation of tq with turned off cathode current for a forward re-applied cathode dV/dt of 1833 V/µs. The value of tq increases from 5 µs for a cathode current of 12 A to 6.5 µs for a cathode current of 32 A at a forward dV/dt of 1833 V/µs.

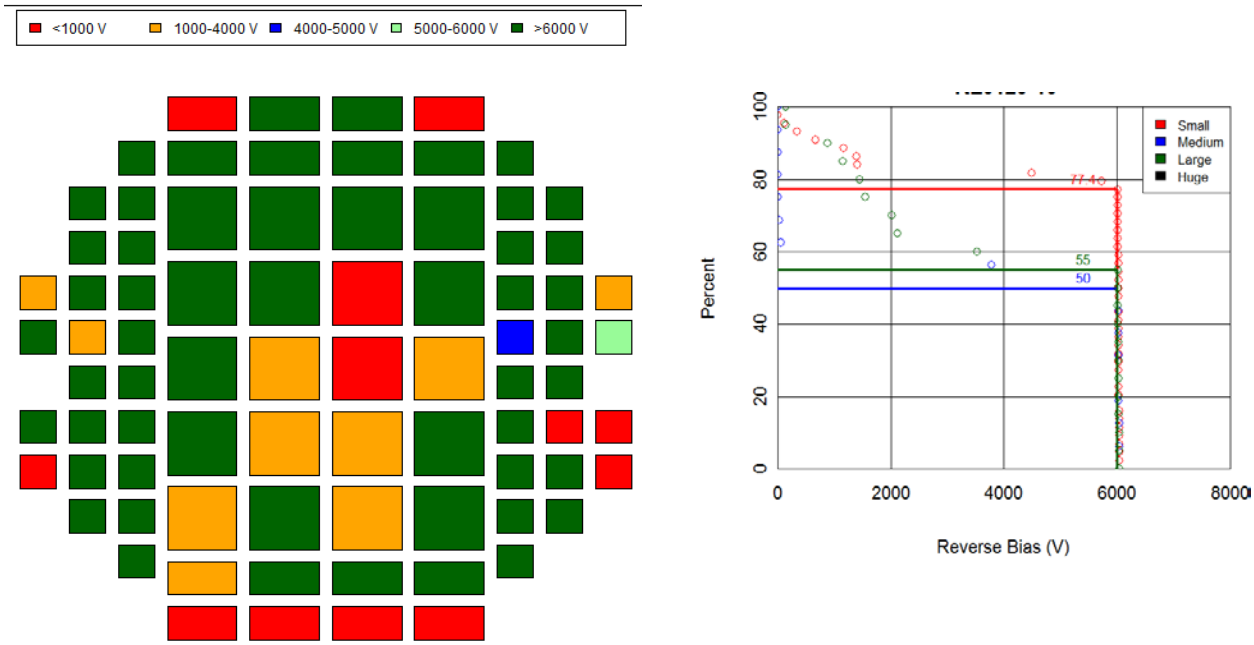


Figure 7(a) Wafer map and (b) probability plot of forward blocking voltages measured on the recently completed batch of 10.5 kV SiC Thyristors. Although a respectable blocking voltage yield was obtained at 6 kV, testing at higher voltages resulted in a sudden and huge increase in leakage current, which destroyed the device (i.e. the device could not even block 50 V subsequent to the failure). Interestingly, this catastrophic breakdown was observed in roughly the same voltage range for both the large and small Thyristors, which exonerates device design and/or processing as the cause of this failure mode.

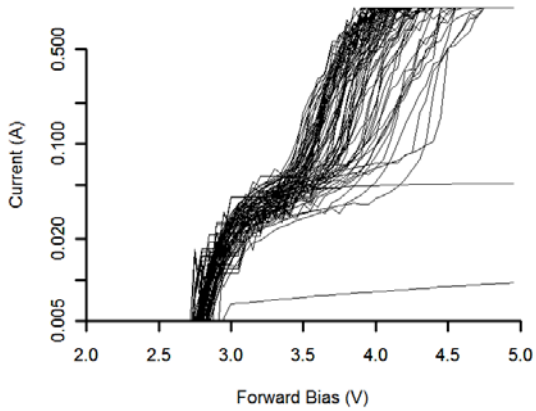


Figure 8: Forward low-current log I-V curves measured on the 10.5 kV Thyristors showing an anomalous two-sloped characteristic close to the turn-on point. These atypical I-V characteristics are believed to be due to a mistake in the epilayer growth which was performed by a world-leading thick SiC epilayer vendor. The same epilayer mistake is believed to result in the catastrophic device failure, when the 10.5 kV Thyristors are tested for blocking at voltages > 6000 V.

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

Date Project Began:	FY2008
Dates for this Project Report:	April – June 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 to Silicon-Carbide (SiC) power switches. The developed high-temperature controller creates the basic building block for power converters, motor controllers, and a host of industrial control applications, using American-developed technology. Sandia will work with Honeywell and other US component manufacturers to design a basic power controller interfacing HT SOI electronics with SiC power devices that would reliably operate in an environment of 240ºC, with the junction temperature of the power devices operating up to 300 ºC. These new systems will be more reliable, more energy efficient, and >30% smaller than existing silicon solutions.

Key Project Events:

- Received power modules from Arkansas Power Electronics International (APEI)
- Meeting held with APEI at Sandia regarding the power
- Ordered and received power supplies required for modules
- Initiated contract with APEI for an additional two modules and to provide a thermal analysis of modules under expected load and operating temperatures conditions
- Optimized Field Programmable Gate Array (FPGA) code to minimize “dead time” between cycles
- Completed preliminary FPGA design to add thermal shut-down capability and feedback control

Project Status:

Sandia met with APEI in May to take delivery of the power modules and to discuss the details required to safely operate them. As a result of the meeting, a path forward was established to ensure compatibility of the Sandia controller with the modules. Two isolated power supplies are required for each module and it was determined that it would be best if APEI provided them during the early stages of the joint program. An RTD (Resistance Temperature Detector) was added to the modules and placed in close proximately to the MOSFET to monitor internal temperature. Sandia will monitor this temperature and, prior to testing the combined system, Sandia will have an automated thermal shut-down capability to ensure the safety of the power module. By combining the power module developed by APEI with the High Temperature (HT) controller designed by Sandia, a complete HT power controller can be demonstrated. While this system will have temperature limits below the initial target, it will help to demonstrate the concept. A contract was placed with APEI for an additional two modules and four power supplies. This will enable us to have adequate spares during the testing of the combined system. Also, a

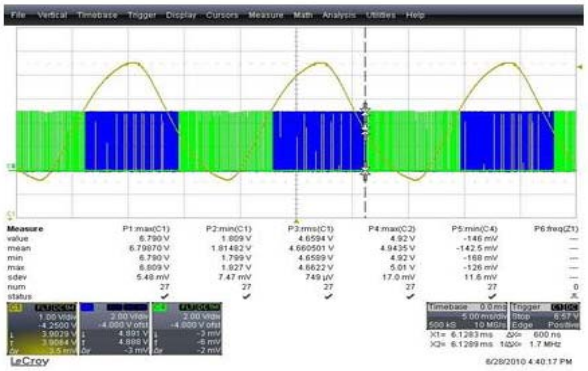
thermal analysis will be performed to properly design the heat sink necessary to meet our programmatic goals of 200 C° ambient temperature (minimum) with a load of 3kW.

During Phase I of this program, a complete system was demonstrated using available discrete components. During this reporting period, the FPGA code was optimized to reduce the “dead time” between cycles from approximately 2 ms to 600 ns. The optimum window for the “dead time” with the APEI module is 200ns - 1us. Figures 1 and 2 show this reduction. Also, a thermal shut down and a preliminary feedback control were developed for the FPGA. Tests are planned to evaluate these functions within the next six weeks.

Pictures / Tables / Graphs:

Figure 1: PWM control with exaggerated “dead-time”

Figure 2: PWM control with optimized “dead-time”



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

Date Project Began: FY2010

Dates for this Project Report: April – June 2010

Sandia Project Manager (PM): Stan Atcitty

Contractor: Missouri University of Science & Technology

Project Description:

From 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 laboratory is used to develop the basis for a plug-and-play smart grid.

The 2009 project focuses on the hardware development of the Unified Power Quality Conditioner coupled with an electrochemical capacitor (ultracapacitor). The laboratory-scale, unified power quality conditioner with ultracapacitor will be used to experimentally validate improved performance over the same controller without energy storage. This project 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 to 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 review meeting at Missouri University of Science & Technology in Rolla on April 6, 2010 with Sandia

Project Status:

At the project meeting, some concern was expressed regarding the amount of total harmonic distortion (THD) and total demand distortion (TDD) with regard to IEEE standard 519. This standard states that individual harmonic components should not exceed 3% of the fundamental and the THD should not exceed 5%. The TDD and THD values found are shown in Fig. 2 and it can be observed that the TDD values are less than 5% during steady state, after the sag and after the load transient. Thus, it is clear that the usage of UCAP in the system significantly reduces the stress on the dc-link capacitor and simplifies its dc voltage regulation.

Pictures / Tables / Graphs:

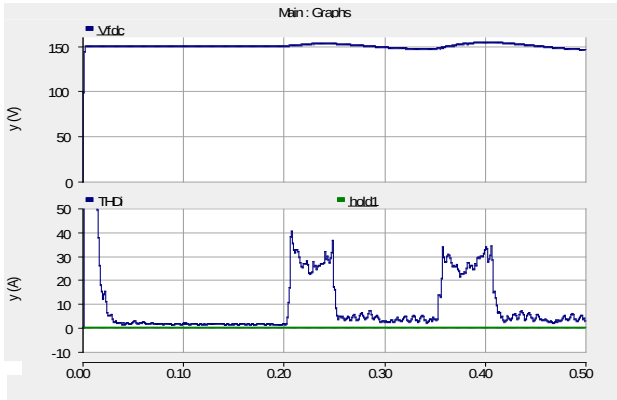


Fig. 1: V_{dc} and THDi waveforms for step change in load from 3kW to 4.5kW at 0.2s and back at 3.5 s (*Without UCAP*)

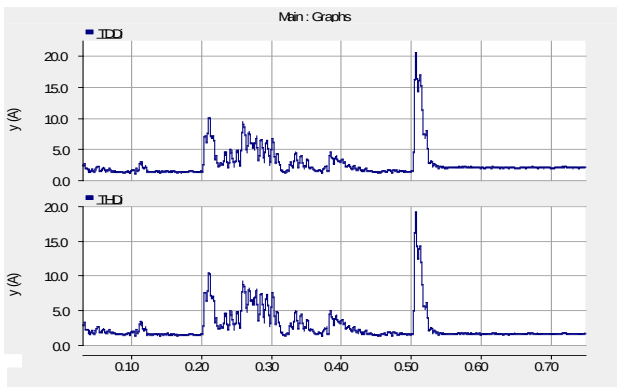


Fig 2: THD_i and TDD_i values for the system with UCAP for a voltage sage at 0.2s and a load change at 0.5 s

Figure 3 shows the output of the model developed to simulate the wind turbine output. This output is consistent with the actual measured data from the installed Skystream wind turbine.

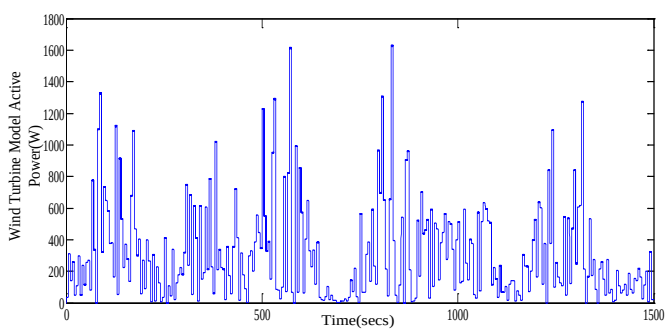


Fig 3. Modeled, active power output of the wind turbine

Figure 4 shows the same waveform of Figure 3, but passed through a low pass filter. This signal will be used as the reference signal to alleviate spikes due to gusts and stalls in the actual wind turbine electrical output.

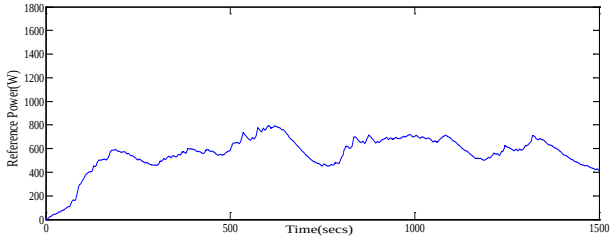


Fig 4. Reference power obtained from the low pass filter.

Figure 5 shows an expanded version of Figure 3 and Figure 6 shows the response of the conditioner. Note that the conditioner very closely tracks the active power output, less the reference signal of Figure 5.

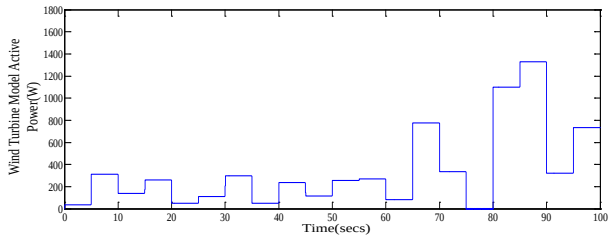


Fig 5. Active power output of the wind turbine model

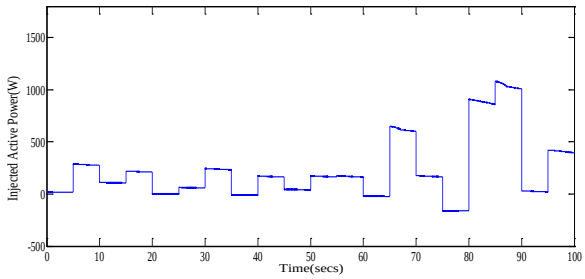


Fig 6. Conditioner active power

Figure 7 shows the expanded version of the smoothed electrical power output after the conditioner. This output tracks Figure 4 very well.

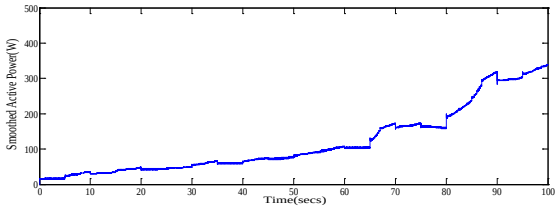


Fig 7. Smoothed power at the grid interconnection point

Advanced Power Devices and Converters

Date Project Began: Nov. 2007

Dates for this Project Report: April - June 2010

Sandia Project Manager (PM): Stan Atcitty

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. The ETO is is an inexpensive, high power/high speed, semiconductor switching tool that can be used in systems requiring elevated current and reverse voltage blocking, such as the nation's power infrastructure. In FY08, the focus was on the development of the 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 SPCO and on developing the solid state circuit breaker (SSCB) based on the ETO.

Key Project Events:

- Provide extensive consulting support to Silicon Power Corporation's ongoing project on ETO converter
- Based on the proposed solution for dynamic voltage imbalance issue, two ETOs were revised and the test was conducted, and the experimental results are presented in this report.

Project Status:

On-going in FY10

Pictures / Tables / Graphs:

The test setup is shown in Fig. 1 and circuit configuration is shown in Fig. 2. In Fig. 2, a 100k ohm resistor is paralleled with each ETO to obtain static voltage balance, a Resistor Capacitor (RC) snubber consisting of 2 ohm resistor and 1.5uF capacitor is utilized to assist dynamic voltage balance.

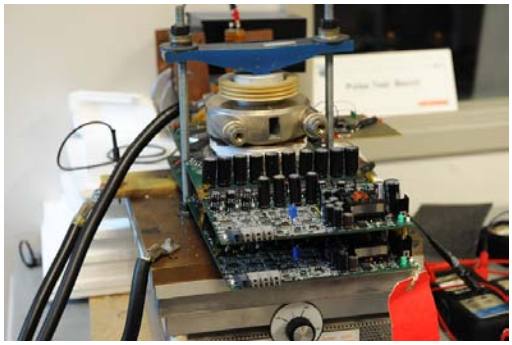


Fig 1. Test setup

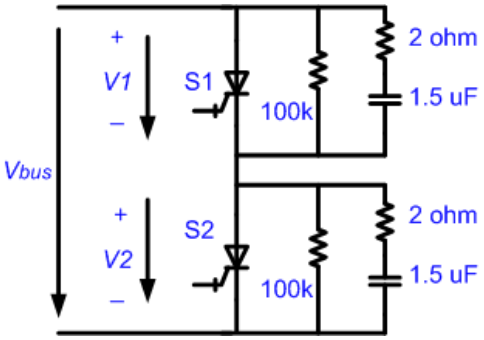


Fig 2. Circuit configuraton

When two ETOs are connected in series, there are a total four situations during turn-off period. The experimental results of all four situations are shown below.

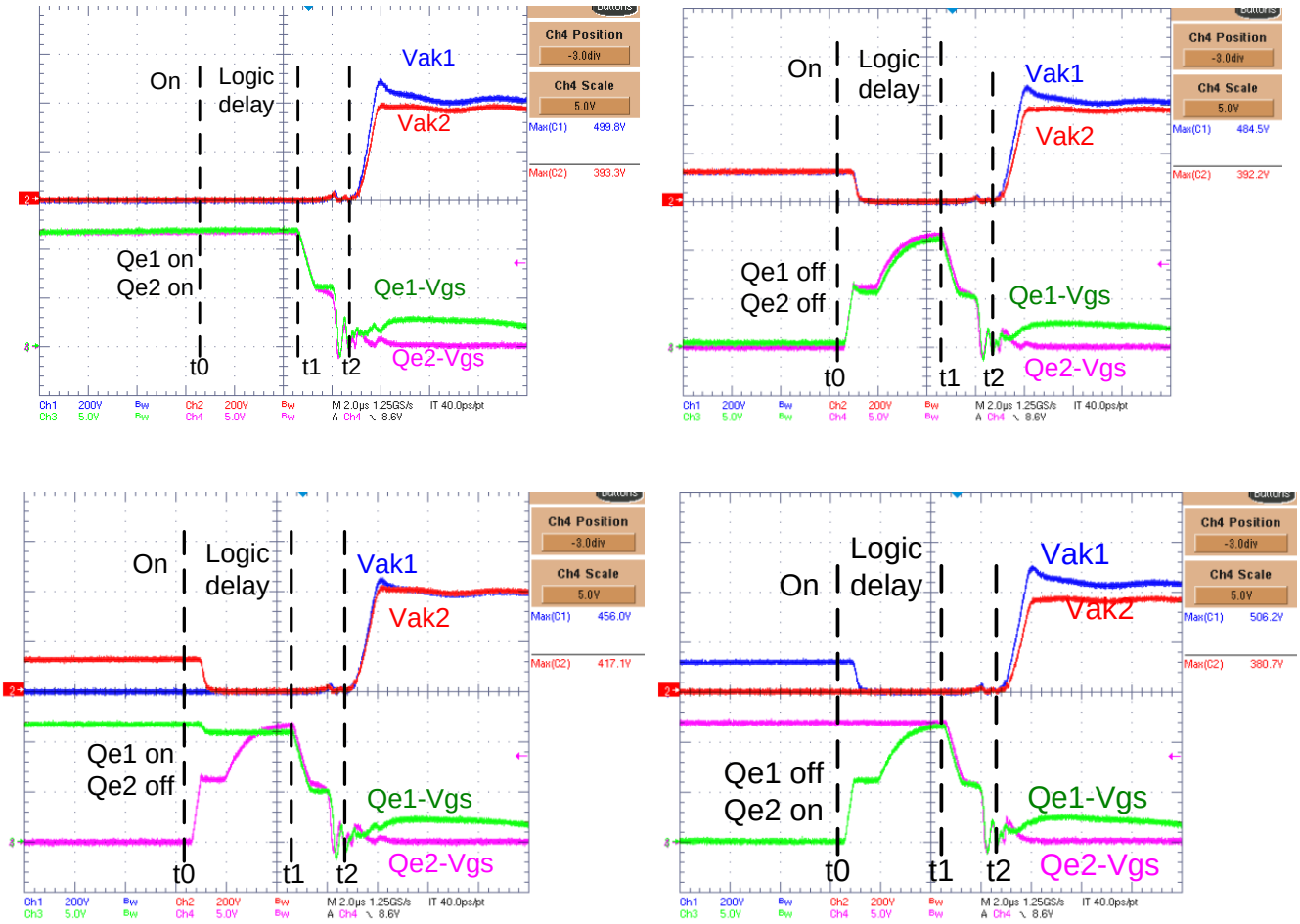


Fig 3. Turn-off waveforms of two ETO in series connection

From the experimental results, it could be seen that, in any situation, the gate-source voltage of the MOSFET in both ETOs starts to fall at the same time, which reveals that the real turn-off operation of both ETOs happens simultaneously.

During the turn-off period, there is a light voltage imbalance between two ETOs. This could be caused by the variance of gate-drive delay and the GTO device. In real applications, a snubber is still needed to parallel with each ETO to obtain good dynamic voltage balance.

NMSU Senior Design Project

Date Project Began: FY2008

Dates for this Project Report: April - June, 2010

Sandia Project Manager (PM): Stan Atcitty

Contractor: New Mexico State University

Partner(s): None

Project Description:

The Klipsch School of Electrical and Computer Engineering at NMSU, requires all BSEE students to 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 communications, and leadership.

Since FY02, NMSU has developed and offered such design classes in the general area of electric energy storage systems. Previous projects involved the design of a “Super-capacitor Test System.” Design project classes, “Photovoltaic System with Storage,” were offered in FY05 through FY08. 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 given to the 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 was 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. The basic control has been developed using discrete logic.

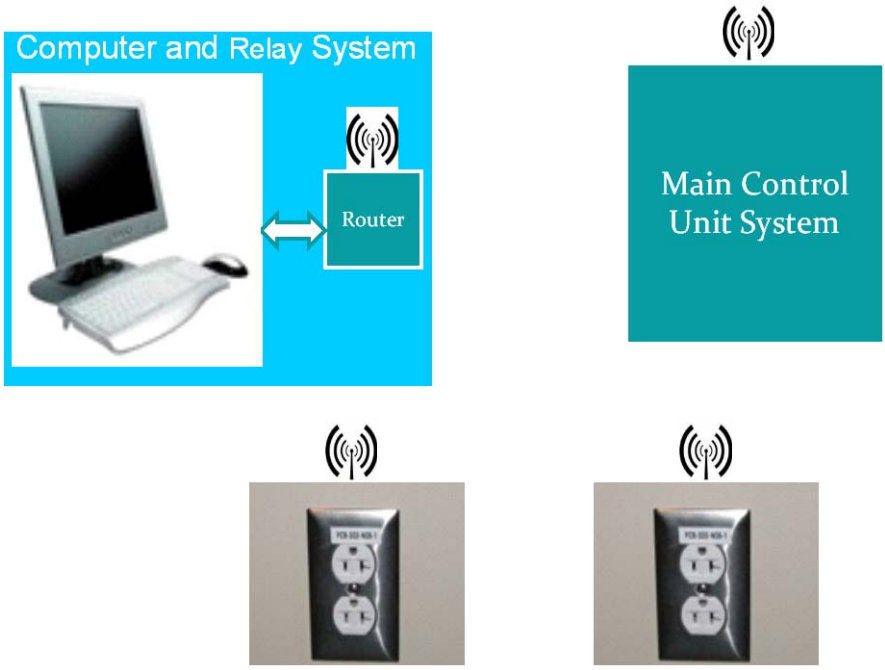
The FY10 project, called “The Smart Outlet,” was set up as a 6-credit class for the Spring 2010 academic year. The goal of this class is for the students to develop central and local electric outlet controllers to manage customer load/generation/storage.

Programmed from the central master, the local controls are implemented in the form of ‘smart’ outlets that directly replace the conventional 120 V US-type electrical outlets.

Project Status:

Wireless-controlled switches and standard wall outlets were constructed and the students demonstrated how management of the load and, ultimately, generation and storage in residential systems can be managed. The concept is illustrated in Figure 1.The outlets monitor and control load, with emphasis on turning off loads that consume standby power. In a future phase, this smart outlet will act as an agent to manage load, local generation resource, or a storage resource, each of which can be distributed through a residence or a commercial building. Two students, who completed the BSEE in May 2010, will continue to work on the project towards a possible patent disclosure. New Projects are being developed for Fall 2010.

Project Pictures / Graphs / Tables:



System Concept

Scale Model Demonstration of Storage in Customer-driven Microgrids

Date Project Began: FY2008

Dates for this Project Report: April - June, 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 now include, network service, aggregation service for economic benefit, and reliability management through islanding for disturbances.

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
4. The role of storage in supporting islanded operation

Wireless communication systems for network control were completed and bench tested. The systems are now being installed. The Zigbee-based system to simulate a substation is illustrated in Figure 2. 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. In the second direction, work was initiated on implementing multi-agent systems for microgrid management. Finally, 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 Qu2 focused on implementing decentralized controller agents that rely only on neighbor-to-neighbor communication. In previous work, simulation studies were used 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 classic power flow problem; i.e., the determination of whether acceptable voltages can be established in a microgrid with controllable generation and load. Specifically, Figure 1 shows a very simple Microgrid. Each node has an agent and 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. Further, the convergence behavior was recorded to provide data that will allow extrapolation performance of larger systems.

Figure 2 displays the convergence time of the capacity-discovery algorithm for a three-node microgrid and an extrapolation to several agents. Convergence is always achieved and the convergence time appears linear with the number of agents. In a practical distribution feeder it is expected that the number of agents communicating with each other form clusters of roughly 10 nodes. With more advanced communication, cycle time of less than 10 seconds should be achievable for microgrid management.

Project Pictures / Graphs / Tables:

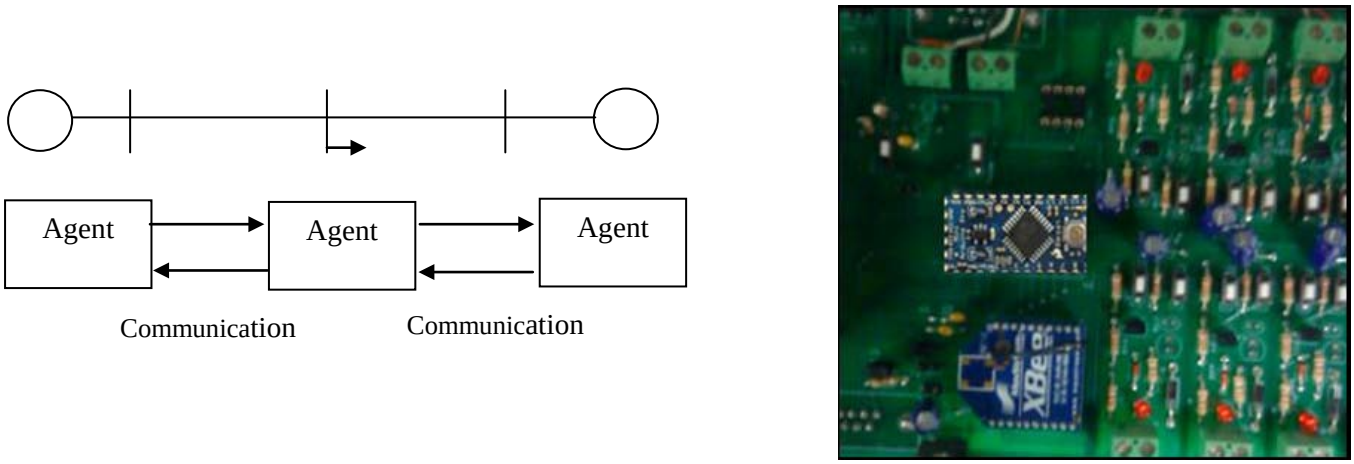


Figure 1. A three node Microgrid with a multi-agent controller

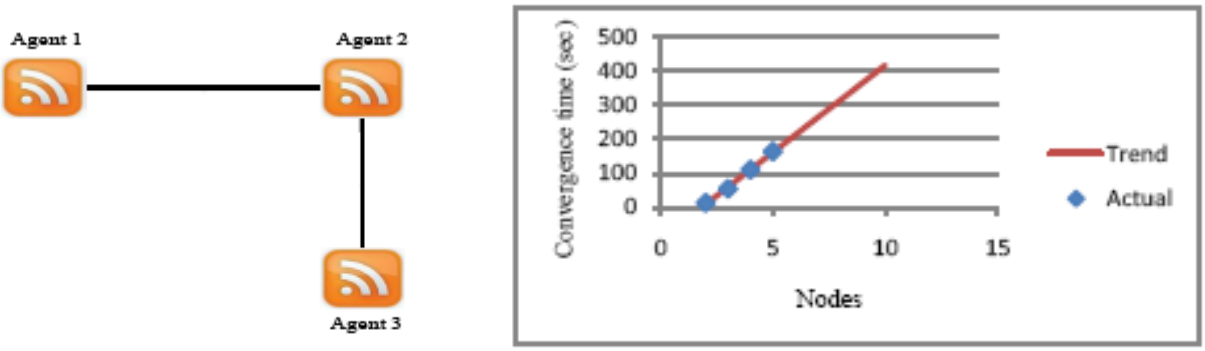


Figure 2. Example performance of a three-node network.

References

Karunakar Gampa, S. J. Ranade, Palak Jain, *Student Member*,, Manikanden Balakrishnan and Sandeep Yemewar "Performance Analysis of Capacity Discovery Algorithm on Hardware Platform", Submitted to the 2011 North American Power Symposium.

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

Date Project Began: FY2009

Dates for this Project Report: April – June 2010

Sandia Project Manager (PM): Stan Atcitty

Contractor: Silicon Power Corporation

Project Description:

The US DOE's Energy Storage Program through Sandia National Laboratories (SNL) in collaboration with Bonneville Power Administration (BPA), Electric Power Research Institute (EPRI), Tennessee Valley Authority (TVA), and North Carolina State University (NCSU) has developed a semiconductor switch known as the emitter turn-off thyristor (ETO) and the preliminary design for an ETO-based static synchronous compensator (StatCom) and controls.

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. This project will be arranged in a "phase-gate" approach, where 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 a complete StatCom. In the final phase, the StatCom will be installed, integrated, and field tested.

Key Project Events:

- Completed testing of 4 ETO modules in preparation for H-Bridge assembly.
- Weekly Teleconferences between Sandia, BPA, SPCO, and NCSU to discuss design/ assembly issues and to provide project and schedule updates.
- SPCO requested a no-cost extension to August 31, 2010 to compensate for unexpected delays due to NCSU module quality.

Project Status:

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

ETO Test

ETO's specifications were reviewed and the acceptance tests were developed**.** Modules received from NCSU were reworked and tested to determine compliance.

Results:

- Each of the ETO modules has been tested in a static high voltage test and in a boost converter configuration (see figure 1).

- Four out of eight ETO modules provided by NCSU and reworked by K&L have passed module level testing and are ready for H-bridge assembly.
- Three of the failed modules have been evaluated and are under repair. These will be part of three spares. The 8th unit was an earlier ETO version, and has been used for parts.

H-bridge and Control System Design

The assembly of the two half bridges is progressing and the scheduled completion date is 7-19-2010.

Mechanical and Thermal

The final enclosure design has been completed and key components have been received. Work has started on the assembly into the main mechanical structure; but was delayed by the ETO rework efforts required for half-bridge subassembly completion.

During this quarter, there was significant progress implementing this design. All major, commercially available components, such as the air-movers and dampers, were received. Custom fabricated parts, such as the air flow ducts, air filters, and related assemblies, were received. An H-Bridge thermal management test was performed to evaluate, quantify, and verify that the performance of the STATCOM system meets all its desired performance parameters, and that it is form, fit, and function compatible with the STATCOM switch modules. A test bench set-up was built to perform a sequence of tests and the information obtained is validated for sufficient airflow & uniform heat dissipation through the system. The mechanical layout of the thermal management test bench is shown in Figure 2.

Summary:

This project involved the transition of an ETO-based StatCom design from an academic to a commercial product. During this effort, SPCO's development team performed both internal and third party inspections of the government-furnished ETO modules from NCSU to validate concerns of potential failure of these limited resources under full power conditions. SPCO then undertook extensive rework to enhance reliability of the ETO modules, increasing mechanical, electrical, electronic and thermal margins. Now that the bulk of the ETO rework is complete, progress has resumed at an accelerated pace on the bridge assembly, with a revised completion of contract milestones by end of August.

Pictures / Tables / Graphs:

Figure 1. Boost Converter

Main Test Fixture

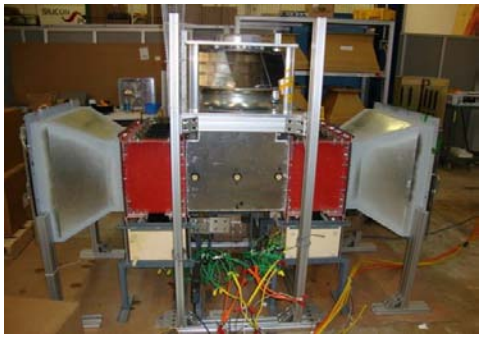


Figure 2. Mechanical Build of Thermal Management Test Setup

Power Electronics Reliability

Date Project Began:	FY2008
Dates for this Project Report:	January – March 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. These devices are key to future, high-efficiency power converters for both alternative power generation and energy storage. 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 further 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.

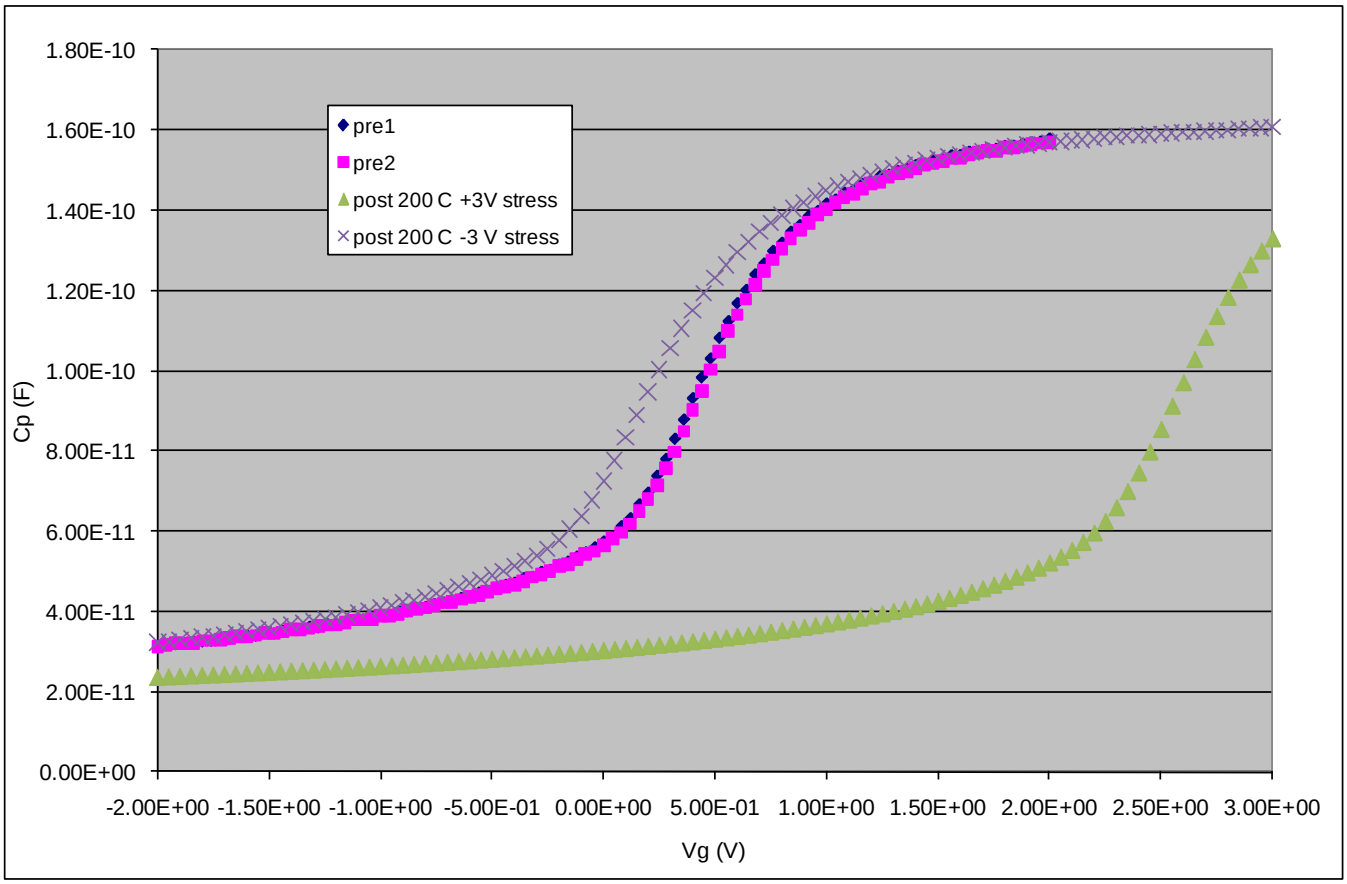
Key Project Events:

- April 2010 – Initial visits and teleconferences with SiC semiconductor industry and university contacts.
- May 2010 – Started drafting proprietary non-disclosure agreements (NDAs) with industry contacts. Obtained samples or placed initial orders for SiC products, including wafers of Metal Oxide Semiconductor (MOS) capacitors, discrete Schottky diodes, thyristors, and MOSFETs.
- May 2010 – Demonstrated the ability to trace down I-V curves of SiC Schottky diodes to high reverse voltages.
- June 2010 – Measured changes in electrical characteristics of a SiC MOS capacitor before and after applying voltage stresses at high temperature. Showed the expected hysteresis in the capacitance vs. voltage curve not present in ordinary silicon devices.

Project Status:

Several SiC semiconductor companies have been engaged to obtain proprietary information and sample devices for reliability testing. In parallel, the open literature on SiC semiconductor device physics is being reviewed for effects and damage mechanisms that could be important for CM and PHM. The main effort is focusing on conducting accelerated failure testing by measuring changes in device characteristics over time under conditions of high stress, such as high voltage, electric fields, current density, and/or temperature. Experiments are also being set up for very high temperature measurements of bias temperature instabilities. Figure 1, containing recently measured data, shows stress-induced shifts in one device characteristic. Such shifts can lead to switching failures in power electronics equipment.

Pictures / Tables / Graphs:



Shifts in high-frequency capacitance as a function of bias due to combined temperature and voltage stress.

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
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 highly efficient 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 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:

The 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. The project is on track.

Project Status:

- Project work has begun ramping up; two technologists have been hired part-time to support the work
- Four auto-nucleation experiments have been conducted to produce GaN from Ga metal oxidation in the presence of Li3N; the products from the experiments that were successfully executed (two of the four) have been sent for analysis.
- Because of the chemical reactions that take place between the (inexpensive to use) quartz or alumina crucibles and the molten salt or molten lithium present during the experiments, a vendor for boron nitride crucibles and test tubes has been identified and a quote obtained for these materials. Boron nitride is more fragile and more expensive than the quartz or alumina, but does not react with the experiment. The project has reached a stage that warrants this level of purity for further investigation.

- Previous experiments conducted on the full ESG growth approach (i.e., seeded growth experiments with a rotating seed) have been performed using crude experimental apparatus. High quality, appropriately precisioned motor drives have been ordered to control both the rotation and the vertical positioning of the seed in the melt. These are expected to arrive in the lab this week. Once installed, the ESG experiments can proceed in parallel with auto-nucleation experiments.
- Equipment for analysis of residual gas species present in the reactor is being determined and is expected to be ordered soon. This will be useful in monitoring the process contamination by oxygen, nitrogen, and other gaseous impurities. It is also required for the final background nitrogen reduction experiments for the purposes of academic publications.
- A Photoluminescence (PL) apparatus has also been investigated and a quote received. The PL is a useful tool for monitoring the quality of crystals that are grown. It can also be adapted as an in-situ monitoring device. The cost is estimated to be between $7,000 and $10,000, depending on options.

Pictures / Tables / Graphs: None at present.

Mesa del Sol (MDS) Demonstration

Date Project Began:	FY09
Dates for this Project Report:	Apr – Jun 2010
Sandia Project Manager (PM):	Daniel R Borneo
Contractor:	GS Battery
Partner(s):	Forest City Ind (Mesa del Sol) GS Battery (USA)

Project Description:

GS Battery (GSB), a subsidiary of GS Yuasa International and GS Yuasa Power Supply, currently has an Energy Storage System consisting of 5 kW inverters and 8.92 kWh ECO R® Silicon Lead Acid (SLC) batteries with advanced nano-carbon technology that will be installed at Mesa Del Sol's (MDS) Towne (Aperture) Center in Albuquerque, New Mexico. MDS developed the Aperture Center in 2007 as an LEED Silver building and owned/operated by Forest City. This installation will demonstrate the use and advantages of an energy storage battery system connected to a Photovoltaic (PV) system in a commercial building. Aperture Center is equipped with an existing 17kW PV system. This project will install three (3) 5 KW inverters and two (2) 8.96 kWh battery strings on the existing 17 kW PV system inside the building. These new GS batteries have shown that the new technology produces up to 4,000 "deep-discharge cycles," as opposed to 1,000-1,500 cycles, from batteries currently available in the US. GSB will provide the storage system as a cost share with MSD.

Testing/monitoring will be performed under the supervision of Sandia National Laboratories (SNL). As part of the testing, SNL will set up a web site that will allow visitors to view the system operation.

Successful results will demonstrate with data and graphs that, by combining PV with an energy storage battery system in a commercial application, renewable energy output is smooth and dispatchable.

Key Project Events:

- Installation of new inverters and battery system,
- Interconnection with utility grid, and
- Monitoring of the system.

Project Status:

Because these inverters are from Japan and are not UL Listed, the local electric utility has not allowed the interconnection onto their grid. After meeting with the utility, the project team is exploring two options. One option is that one inverter, grid detection system, Schweitzer feeder, protection relay and shunt trip breaker would be tested by a third-party testing lab to certify that IEEE 1547 standards are met. The other option is to install Sunny Island devices between the new inverter and the utility.

The following list shows status of items:

- Installation of three GS inverters. – Completed 7/8/10
- Installation of two GS battery systems. – Completed 7/8/10
- Complete system test by third party or install Sunny Island devices. – Not Complete as of FY10Qu3
- Amended interconnection agreement approved by electrical utility (PNM). – Not Complete as of FY10Qu3
- Final system start up and testing. – Not Complete; estimated FY10Qu3
- Monitoring installation. – Not Complete; estimated FY10Qu3
- Monitoring phase. – Not Complete; estimated FY10Qu4 to FY11Qu4

- Final report – FY12Qu1

Pictures / Tables / Graphs:

New Inverters

New GS Batteries

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:	Apr - Jun 2010
Sandia Project Manager:	Georgianne Huff
Contractor:	EnerNex
Contractor Contact:	Jeff Lamoree
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 (developed jointly by NGK and Tokyo Elec. Power Co., of Japan) modules 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 1/17 Interconnection Agreement (IA) submission.
- The 1 MW, 7.2 MWh sodium-sulfur battery and PCS installation was completed on June 22, 2007.
- December 2007: NGK determines 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 have completed approximately 30 cycles.
- March 2009: 18-month operating test program began to monitor performance of the system.

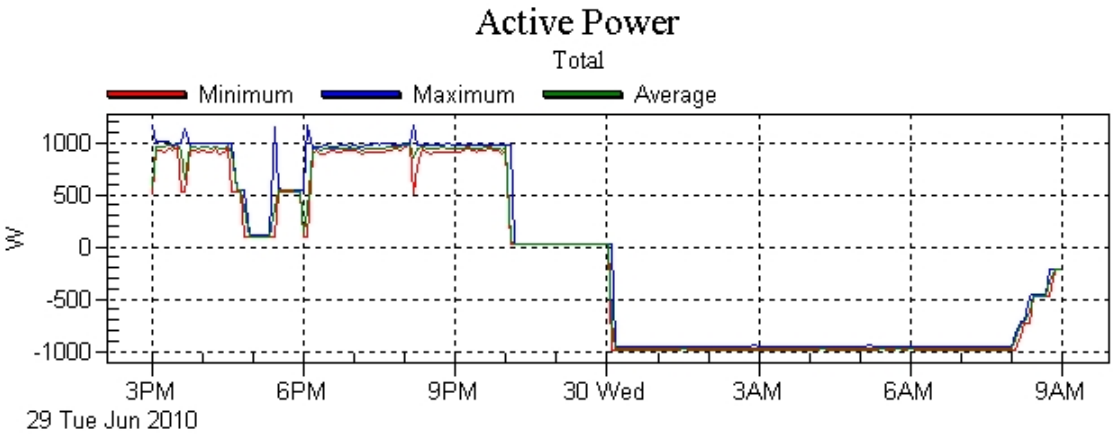
Project Status:

The repairs to the gas-powered compressor were completed. Problems with the air conditioners on the NaS battery were also corrected, which allowed the NAS BESS to be returned to service during this quarter.

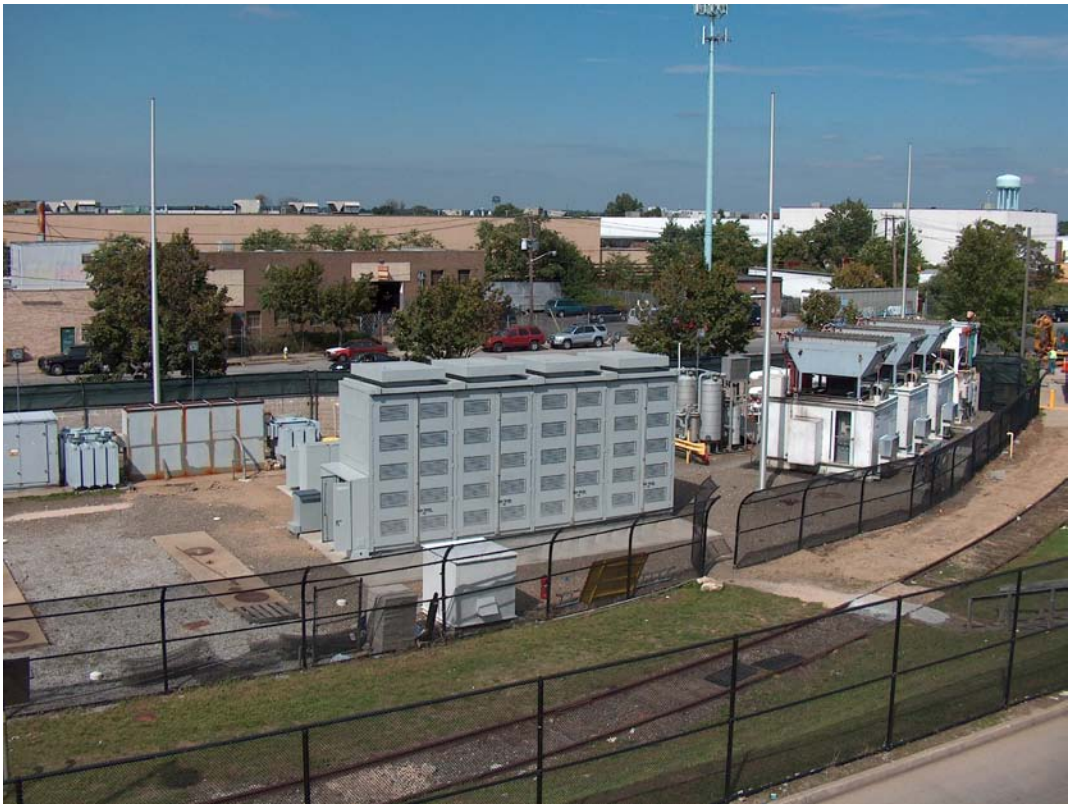
When the NAS BESS is on line, it operates as designed. The BESS transfers 1000 kW of power consumption from the daytime hours to the nighttime hours. Figure 1 shows the record of a single day of operation. The battery charges during the night, reaches full charge, and then goes into service as the bus fleet begins refueling.

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

Project Pictures / Graphs / Tables:



Daily active power of the battery system.



Completed installation – 2008

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

Date Project Began: FY 2008

Date of This Project Report: Apr - Jun 2010

Sandia Project Manager: Georgianne Huff

Contractor: EnerNex

Partner(s): NYSERDA, CUNY, 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 LaGuardia Community College (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.

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.

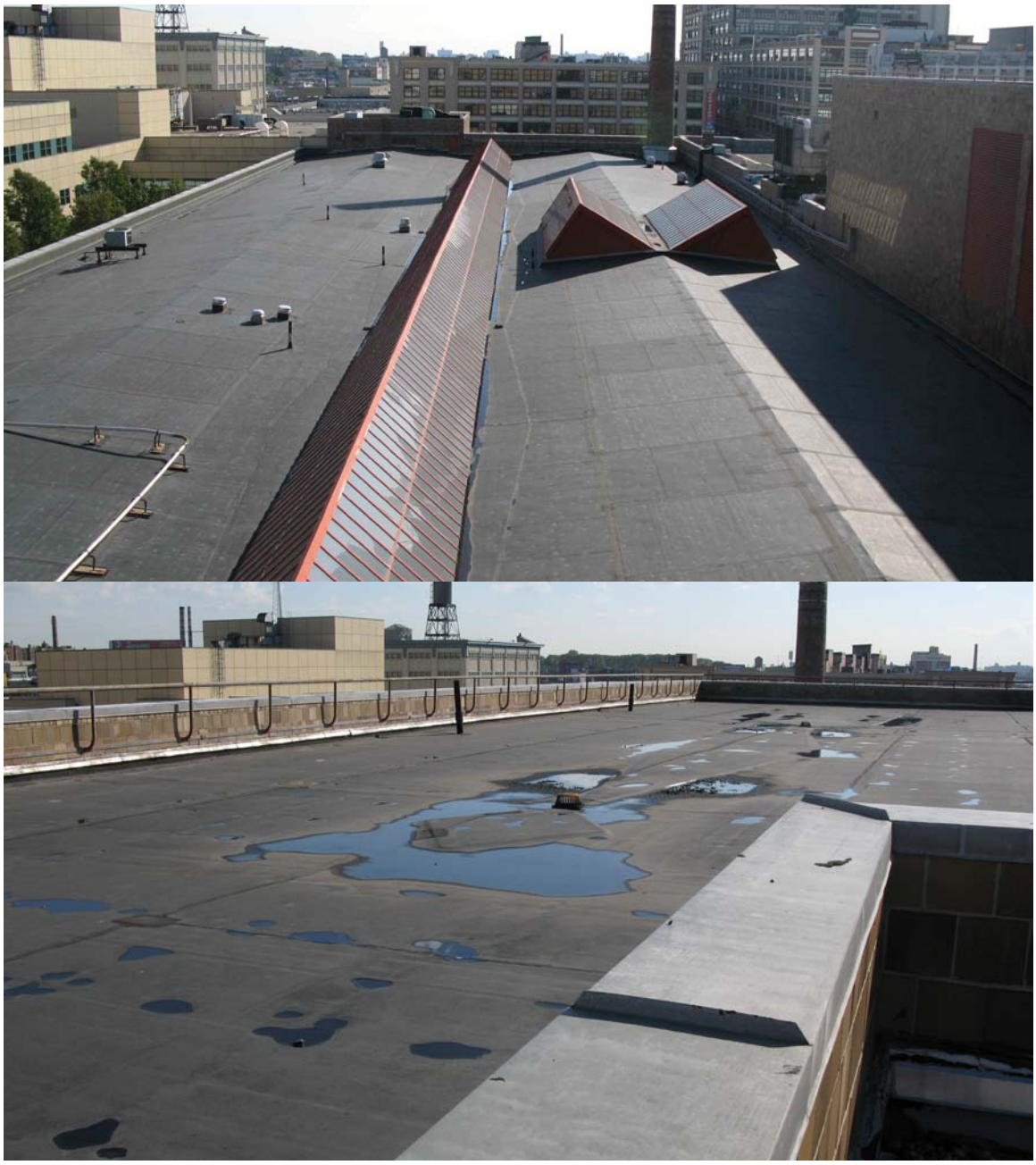
Key Project Events:

- Oct. 2, 2008 Project Kick-off Meeting

Project Status:

NYERSDA renegotiated their contract with CUNY/LGCC. This was due to the fact that the manufacturer of the BESS filed bankruptcy. A kick-off meeting to restart the project is expected in August.

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:	Apr - Jun 2010
Sandia Project Manager:	Georgianne Huff
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 in 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:

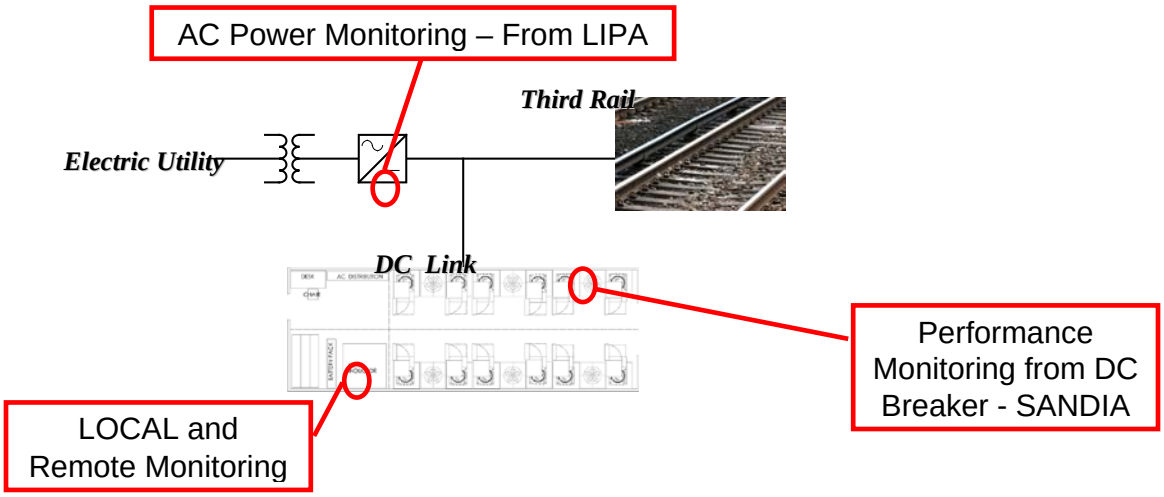
- Project kick-off meeting January 8, 2008
- Turn-key FESS re-bid due July 11, 2008
- FESS contract awarded to Pentadyne July 2009
- Kick-off meeting with FESS contractor Aug. 2009

Project Status:

Pentadyne completed the design phase and kicked off the construction phase of the project. Soil boring tests were completed and they were prepared to put down the concrete pad at the site. Meanwhile, several sub-assemblies of the flywheel were delivered to Pentadyne for assembly and factory acceptance testing of the first flywheel, which was scheduled for later this summer.

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: Apr –Jun 2010

Sandia Project Manager: Georgianne Huff

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), connected 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), 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, which can be deployed in emergencies, for backup power or to relieve congestion at critical "load pockets" in NYS; and
- 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 that have limited cycling capability and life.

Key Project Events:

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

Project Status:

While the PB 150 unit was being exercised and tested, problems with the cooling system were discovered. The PB150 unit was returned to Premium Power (PPC) to allow a problem with the system chiller to be assessed and corrected. They determined that there was a problem in the fan/fan motor assembly.

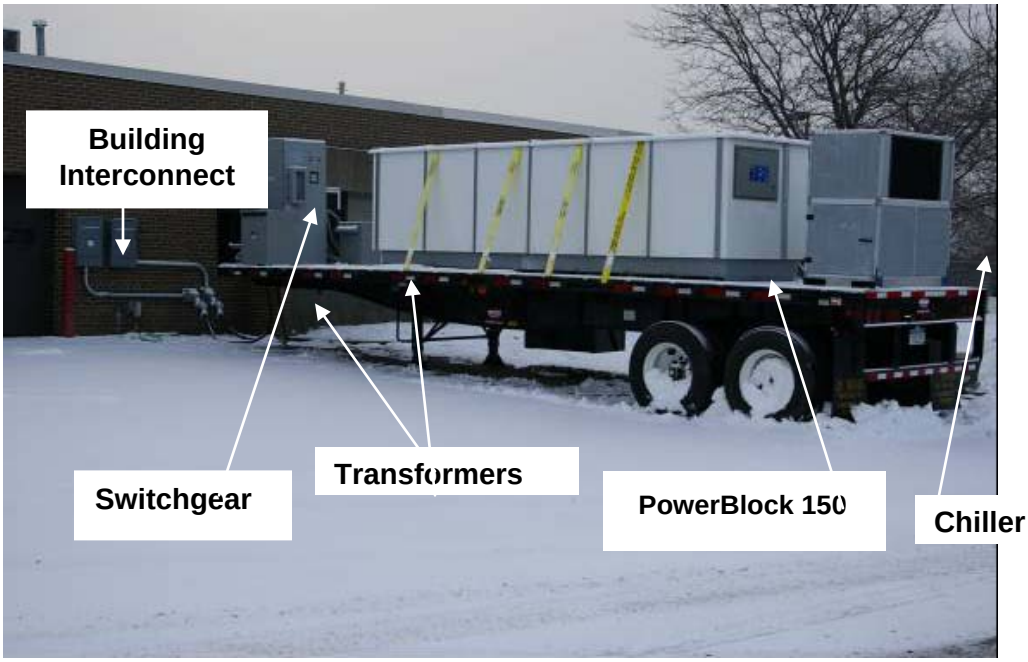
In order to independently assess the situation, PPC hired an independent service firm that was familiar with the Edwards Engineering chillers.They confirmed that the fan motors were damaged during operation on the PB150 system because they were being operated at 480V +/- 10% , while they were only rated at 440V.

The service firm replaced the fan motors with suitably-rated motors and replaced some components that had been damaged as a result of the fan issue. They also verified all settings, voltages, and currents.

Charge/discharge cycles and software check-outs were performed to ensure the system and chiller were operating to specifications. PPC shipped the unit back to NYSERDA on May 25th.

PPC contacted EnerNex to discuss the data collection task for DOE prior to the unit being returned.

Project Pictures / Graphs / Tables:



NYSERDA / DOE: Stephentown Flywheel Frequency Regulation Demonstration

Date Project Began:	FY 2010
Date of This Project Report:	Apr - Jun 2010
Sandia Project Manager:	Georgianne Huff
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 20 MW plant might be deployed such that all or part of the plant capacity would be interconnected to 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 June 2010

Project Status:

Beacon Power signed contract with NYSERDA and site work has begun. The foundations and auxiliary systems are being installed. The flywheels are expected to start arriving on site by the end of July. A portion of the plant might be operational by October, 2010.

Project Pictures / Graphs / Tables:

Characterization and Assessment of Bulk Energy Storage

Date Project Began: FY 2010

Date of This Project Report: Apr. – Jun 2010

Sandia Project Manager: Georgianne Huff

Contractor: Sentech

Project Description:

This project will focus on the identification and evaluation of novel concepts in compressed air energy storage (CAES) and pumped storage hydropower (PSH)l; and serve as an initial scoping study for novel, energy storage facilities, with emphasis on 100's of MW output and 100's of MWh capacity. The study will identify relevant applications, define the associated technical requirements, characterize and assess the feasibility of the novel concepts, identify gaps and barriers and recommend R&D needed. The study will also address locational considerations, permitting issues, siting requirements, and timelines required to develop, test, and commission new multi-megawatt facilities.

Key Project Events:

- Project Kickoff Conference Call held May 13, 2010

Project Status:

During this quarter

- Developed novel technology table,
- Developed requirements matrix,
- Created outline to include technology types and details of requirements matrix, and
- Planned assessment of confirmed technology types.

Report outline and draft requirements matrix expected in early 4th quarter.

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

Analysis and Modeling to Support CAES Development

Date Project Began: FY 2010

Date of This Project Report: April – June 2010

Sandia Project Manager: Georgianne Huff

Contractor: Internal Sandia

Project Description:

This project comprises modeling and analysis studies that begin to address the following potential underground risks to compressed air energy storage (CAES): (1) experimental deformation of salt in cyclic loading, (2) assessment of biologic growth potential in an aquifer, resulting from air cycling, and (3) assessment of ignition/explosion potential in a depleted reservoir, from air cycling associated with CAES. Additionally, modeling and analyses of reservoir formation (porosity, permeability, degree of saturation) and borehole parameters (diameter, length and spacing) will be evaluated to determine appropriate ranges for CAES installations.

Key Project Events:

- April 2010 - Paper presented at Solution Mining Research Institute Technical Conference on initial results of deformation of salt in cyclic loading

Project Status:

This quarter, some work was directed toward gaining an understanding of the potential biological impacts of CAES in porous bedrock aquifers. A compilation of USGS groundwater chemistry data for the Mt. Simon sandstone and adjacent formations, near the planned site of the Iowa Stored Energy Park, show that it is under reducing conditions. Calculation of Gibb's free energy for potential oxidation reactions using the above data and locations determined that microbial oxidation of iron, manganese, and ammonium will become favorable as the oxygen content of groundwater in the formations increases due to CAES-induced air cycling. Additionally, a reaction-path model was developed; which showed that, if pyrite is present and exposed to oxygenated groundwater in the area under study, microbial oxidation of the pyrite will cause the groundwater pH to become acidic, unless sufficient carbonate minerals are present to buffer acid production.

To evaluate the experimental deformation of salt in cyclic loading, rock salt specimens (a Gulf Coast domal salt, 99% halite) were confined at room temperature and cyclically stressed. Test results indicated that Young's Modulus (determined from unloading cycles) decreased with increasing axial strain, load cycle, and time after an initial period of small change; wherein the modulus remained the same or increased (see Figures 1 and 2). This was a limited study, but the measurements imply that the samples were cracking at low cyclically-applied differential stresses below the dilation criterion curve. Acoustic emission recordings taken during testing and the presence of microfractures (shown by impregnating the deformed samples with rhodemine-dyed epoxy) confirmed the source of the dilatant behavior.

Work to determine borehole and reservoir formation focused on the availability and development of accurate and comprehensive modeling tools. Computational tools (*e.g.*, TOUGH2) are readily available for flow in porous

media, but a tool that couples the flow in the porous media (formation) with flow in a borehole does not currently exist. This coupling is essential to properly evaluate the flow rate and the pressure drop in the total system.

A beta version of TOUGH2 that includes a borehole model for CO_2 applications has been developed and an air-water applications module (as is needed for this study) is currently being added to that beta. An evaluation of the current TOUGH2 beta by project staff uncovered a number of problems with the model implementation. Consequently, project staff are actively collaborating with Lawrence Berkeley National Laboratory (LBNL) to ensure the correct implementation of the two-phase flow drift flux model. Additionally, TOUGH2 does not (is not currently planned to) include turbulent flow in the formation, which is important for borehole analysis in the vicinity of the borehole. A turbulent flow modification for TOUGH2 done by another researcher was identified and will be implemented for this study once the once the borehole modification to the TOUGH2 beta is complete.

Additionally, a thorough review of existing CAES reservoir papers and reports was conducted to understand the range of typical CAES operating parameters (*i.e.*, reservoir conditions, such as the size of the air bubble, formation compressibility, two-phase characteristic curves, pressure ranges, *etc.*). The appropriate values of these parameters for this study were determined and the proposed simulations will begin when the modeling software is ready.

Project Pictures/Graphs/Tables

Figure 1. Testing system used to conduct cyclic load triaxial comp ano-composites for Flywheel Applications

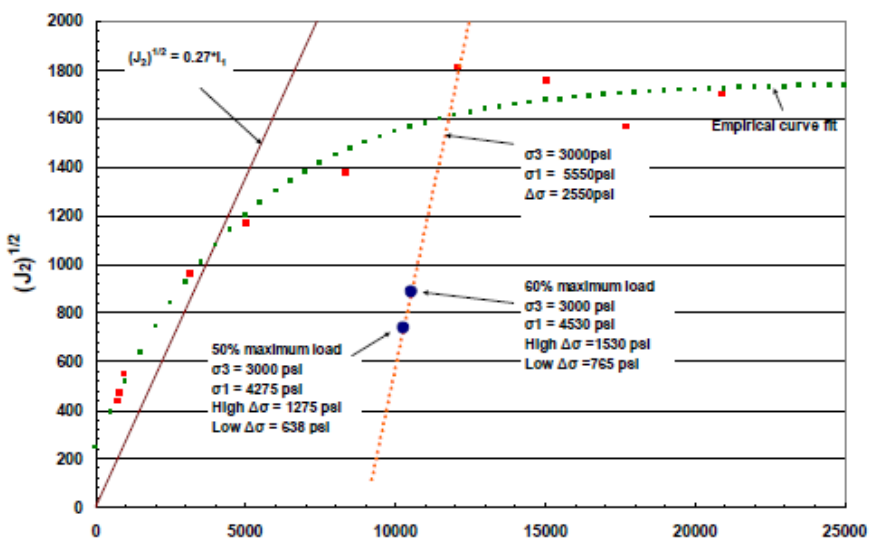


Figure 2. Dilatant behavior of salt determined from quasi-static tests and test stress states.

Improved Properties of Nano-composites for Flywheel Applications

Date Project Began: FY 2010

Date of This Project Report: Apr – Jun, 2010

Sandia Project Manager: Georgianne Huff

Contractor: Internal Sandia

Partner(s): Beacon Power

Project Description:

This project will develop nano-composite materials for tailored mechanical behavior and operational performance optimization in flywheel energy storage systems. Current composite flywheels have significant obstacles in the existing materials, including transverse strain behavior, long-term mechanical creep and micro-fracture propagation, composite processing/manufacturing, plus 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. This project is a collaboration between Sandia and Beacon Power, Inc.

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:

- Project kick-off meeting on Jan. 30, 2010

Project Status:

During this quarter, the Sandia project team of Tim Boyle, Mat Celina, John Bell, and Ben Anderson began work on improving the properties of Nano-composites for Flywheel Applications. Results include:

- Regarding nanoparticles, TiO2 was measured and testing on commercial baseline materials is underway.
- ZnO nano-rods and nano-wires were set up for zeta-potential measurements.
- Testing on MnO and FeO is underway.
- De-bonding testing was begun and micro-droplets were successfully applied to fiber.

It appears that degassing the sample has mostly solved an initial problem of the presence of micro-bubbles. Figure 1 shows the influence of BYK525 and BYK525 with degassing. The formation of single micro-droplets without the production of multiple droplets is the goal. Initial de-bonding tests have resulted in fiber breakage, rather than droplet de-bonding. This is believed to be a result of the fiber-imbedded length being too long. We plan to control the amount of material applied to the fiber and the fiber-imbedded length with the assistance of an optical microscope.

Tests are planned for next quarter to measure hoop strength and transverse strength.

Project Pictures / Graphs / Tables:

w/o BYK525 w/ BYK525 w/ degassing

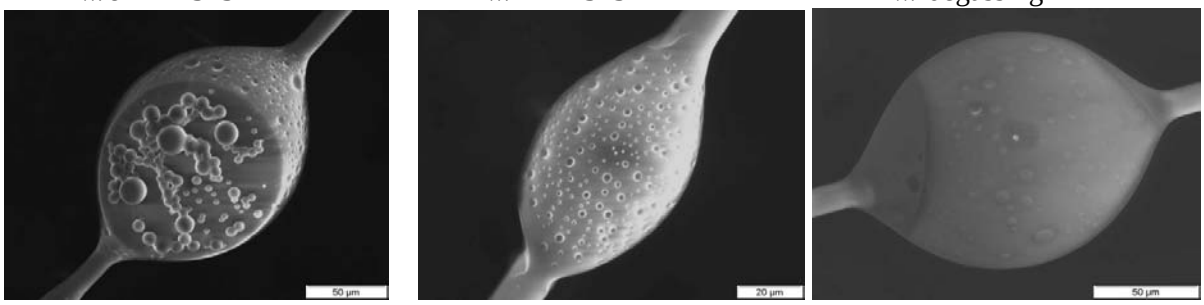


Figure 1. SEM images of EPON862/LS-81K microdroplets applied to 1062 Roving E-glass.

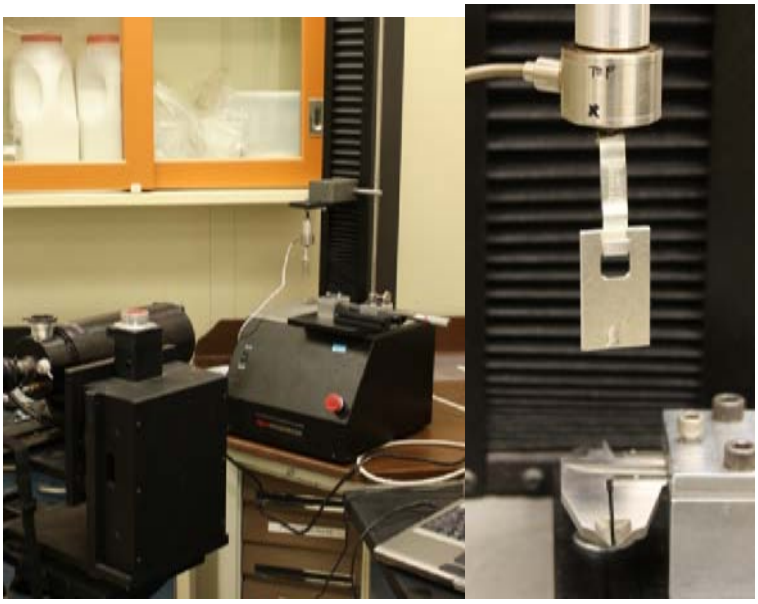


Figure 2. Picture of test setup for measuring the single fiber microdroplet debonding force.

Iowa Stored Energy Park

Date Project Began:	FY05
Dates for this Project Report:	Apr – Jun, 2010
Sandia Project Manager (PM):	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
  Began search for geological sites
- 2005 – Conducted seismic surveys; Completed feasibility analysis
- 2006 – Found suitable geologic formation
- 2007 – Public announcement of site; 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 started

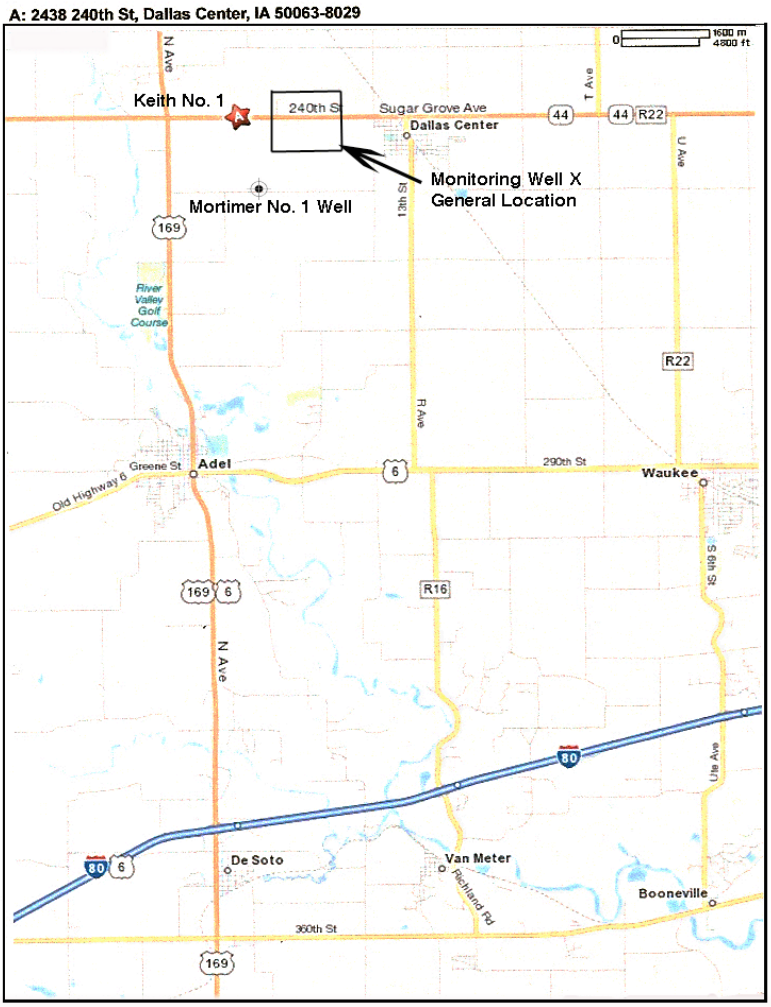
Project Status: Preliminary analysis of the first exploratory test hole (Keith No. 1) was completed. It was found that the Keith No. 1 Well provided key formation top data on the Dallas Center Mt. Simon structure. Based on this data, the revised structure map indicates a saucer shaped structure with approximately 50 feet of closure over a 1½-mile area. The Keith No. 1 Well is located near the crest of the structure. The average thickness of Mt. Simon is 85 feet at the crest of the structure. Although the Keith No. 1 Well provided important structural control data, approximately two-to-three additional Mt. Simon exploratory monitoring wells will be necessary to further confirm the structural configuration of the Dallas Center Mt. Simon structure to be at the confidence level required to recommend further development of this structure for CAES service.

The test cores from the exploratory test hole were transported to Sandia National Laboratories Geophysics lab for analysis. In addition, water samples were collected from the pump tests for chemical analyses at Sandia. The results of the Sandia core permeability test, expected in the 4th Quarter, will be critical to evaluating the CAES

feasibility of this Mt. Simon air storage vessel. The water chemistry of the Mt. Simon aquifer indicates a relative high concentration of sulfate that will need to be evaluated for impact on air oxygen content.

The continued evaluation and eventual development of a Dallas Center CAES facility hinges on the two key factors of 1) feasibility of an aquifer air storage system, and 2) the integrity of the Dallas Center structure. The overall work plan is designed to resolve these two key issues and will include confirmatory air injection testing and air bubble development, plus preliminary air storage system design.

Pictures/Graphs/Tables:



Keith No. 1 Well Locations

Carbon-Enhanced Lead-Acid Battery and EC Testing

Date Project Began: December 2005

Date of This Project Report: April – June 2010

Sandia Project Manager: Tom Hund

Contractor: (SNL In-house Project)

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 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) test for solar and utility applications.

Project Status:

Testing for FY10Qu3 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. Test results using the PV hybrid power system test procedure are showing very positive results with the capacity at 89 and 97% for the East Penn Ultrabattery and Furukawa Ultrabattery, after more than 200 days of cycling. This contrasts with a conventional East Penn Unigy II VRLA battery, in which capacity dropped about 20% after the first 42 days.

Project Pictures / Graphs / Tables: