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# EESDP 15

## Electrical Energy Storage Demonstration Projects 2015

THE *Next Step* in ENERGY STORAGE

New Technology and Tactics for Tomorrow's Energy Demands

***Exclusive*** Energy Storage Demonstrations ***Update***

Sandia National Laboratories

Prepared by Sandia National Laboratories Albuquerque, New Mexico and Livermore, California 94550
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## About EESDP Journal

The EESDP Journal is a collection of technical reports of the current areas being explored by DOE National Laboratory scientists and technicians involved in the research and development and deployment (R&D and D) of electrical energy storage materials, devices, equipment, and facilities through purposed demonstration projects.

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Design Note: Cover design is inspired by a closed-loop spring system - doubling as a stair case - as the process unfolds in energy storage - always anticipating 'the next step'... and tripling in design as a simple lotus.

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We gratefully acknowledge the support of Dr. Imre Gyuk, DOE Office of Electricity Delivery and Reliability - Energy Storage Program Manager.
As a result of this support, the Electrical Energy Storage Demonstration Projects at Sandia National Laboratories (SNL) has become actively engaged in developing a strategy to meet historic energy storage targets. Partnering with the Clean Energy States Alliance (CESA) has allowed us to develop significant alternatives to traditional energy resources for several states: Hawai'i, Vermont and Alaska.
The FY14-FY15 DOE-sponsored energy storage demonstration projects at Sandia Labs:

- **Served as an incubator for emerging flywheel technology that has many different applications from providing ancillary services for the electricity grid to transportation improvements,**

- **Were helpful in establishing the next series of energy storage system protocols for evaluating performance metrics,**

- **Advanced technical applications, testing and analysis of cells, modules, and energy storage systems for industry partners, and**

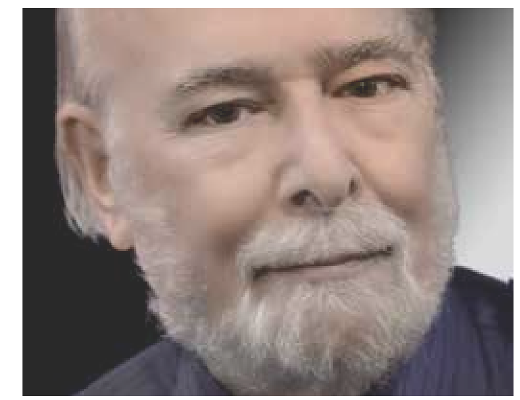
- **Encouraged local, rural, municipal, and state government entities interested in improving electrical power quality and grid resilience to use electrical energy storage technologies.**



## Statement of Dr. Imre Gyuk,

## Program Manager for Energy Storage Research, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy before the Committee on Science, Space and Technology Subcommittee on Energy U.S. House of Representatives May 1, 2015 [1]

Electricity is central to the well-being of the Nation. The United States has one of the world's most reliable, affordable, and increasingly clean electric systems, but it is currently at a strategic inflection point—a time of significant change for a system that has had relatively stable rules of the road for nearly a century.
Changes in technologies, markets, and public policies are transforming electricity delivery. Some key trends driving the evolution of the grid include a changing mix of electricity generation sources and characteristics, growing expectations for a resilient and responsive power grid, and growing customer participation in retail electricity markets.


Dr. Imre Gyuk

Grid Energy Storage Defined
Grid energy storage helps address the continuous 24/7 need to balance electricity generation and demand. That balance must be maintained on a narrow and precise basis and must address a set of legally enforceable reliability standards set by Congress in its Energy Policy Act of 2005. Storage provides a buffer between generation and customer demand, freeing the grid from the need for instantaneous response. Energy storage increases reliability and resiliency of the electric grid and can provide greater asset utilization of generation. Energy storage provides power when it is needed, just as transmission and distribution provide power where it is needed.

**The OE Program**
The Department of Energy's Office of Electricity Delivery and Energy Reliability's mission is to drive electric grid modernization and resiliency in energy infrastructure. OE accomplishes this mission through research, partnerships, facilitation, modeling and analytics, and emergency preparedness. OE's Energy Storage Program is an important component of the Department's strategy to support a more economically competitive, environmentally responsible, secure and resilient U.S. energy infrastructure by accelerating the development of emerging storage technologies.
The program's R&D activities focus on lowering cost while improving value, and advancing the performance, safety, and reliability of stationary energy storage technologies for utility-scale applications. Additionally, the program is designed to work with states, communities, industry, and other stakeholders to develop and demonstrate energy storage technologies, devices, and systems that can reduce power disturbances, improve system flexibility to better incorporate growing use of variable renewable resources, reduce peak demand, and provide resiliency to advance the modernization of the electrical utility grid.

**Recent Successful Projects**
The American Recovery and Reinvestment Act of 2009 (ARRA) provided a very considerable boost to the development of the program. OE received $185 million of funding for storage demonstration projects, but was able to boost this with $585 million of cost share from industry.

**Conclusion**
DOE has provided leadership in establishing energy storage as an effective tool for promoting grid reliability, resiliency, and better grid asset utilization of renewable energy. The program has developed new cost effective storage technologies that industry has commercialized and has contributed to the establishment of new regulatory structures and is developing codes and standards for safety. OE is providing input into major solicitations driven by state mandates and is pioneering storage projects. DOE's leadership in creating a storage industry is widely recognized in the U.S. as well as abroad.

DOE looks forward to continuing this important work. As our electric grid evolves, we expect that energy storage will be an integral component in assuring that electricity delivery for communities will be more flexible, secure, reliable, and environmentally responsive.

## Foreword

The energy storage demonstration program is broken up into four major components: Clean Energy States Alliance, testing and analysis, optimization and commissioning, and industry collaboration. The following illustration is a description of the FY14 and FY15 Energy Storage projects. There are two innovative projects that are planned for FY16 that will take place in Alaska and Hawai'i.

As part of industry collaboration, the electricity storage handbook has been updated to include thermal energy storage, cost methodology, flywheels, and ES safety codes and standards. Lastly, the optimization and commissioning task has been updated to include the latest performance protocol for microgrids. This annual journal concludes with the possible next steps from the policy and regulatory environment for energy storage.

### Energy Storage Demonstration Projects Summary Overview 2014-2015

| CLEAN ENERGY STATES ALLIANCE - CESA | OPTIMAZATION & COMMISSIONING | INDUSTRY COLLABORATION |
|---|---|---|
| Alaska | Safety & Standardization | Enervault |
| California | Metrics/ Standardization | Helix |
| Connecticut | Performance Protocols | Duke Energy |
| Hawai'i | | EMA/ Singapore Power |
| Massachusetts | **TESTING & ANALYSIS** | Bermuda Electric/Light |
| New Hampshire | Cells | |
| New Mexico | Modules | DOE/EPRI Electricity Storage Handbook |
| New York | Systems | |
| Oregon | DoD microgrid / FOB | |
| Pennsylvania | | |
| Vermont | | |



## SNL's FY14 and FY15 Energy Storage Demonstration Projects Inventory

Dan Borneo

### Aquion Energy

Project Description:

Aquion is taking their prototype designed and built under the ARRA program to the next step of building a 50-100kW/1hr aqueous battery and outfitting it with the newest version of the battery. This is a precursor to their eventual full-scale 1M/1hr ES demonstration of commercial installation. As part of this effort, DOE/SNL is supporting the building and testing of the 50-100kW unit through a contract that is funding specific tasks needed to engineer and build the commercial unit.

Key Project Events/Milestones:

- Revision to the voltage/current/temperature sensing PCB board was achieved and tested.

Project Status:

- Drivers and support of the A/C inverter were delivered.
- The racking structure was designed, ordered and put in place at the Aquion facility.

- Board design and build for the PCB were achieved.
- A prototype BMS was built with embedded software and demonstrated during site visits.
- Testing results of a 45V 35 Ah (1500 Wh) 'Silver' battery stack was carried out at Sandia.
- The Aquion system was retrofit with version two "Silver" battery units.

### Clean Energy State Alliance –ESTP Demonstrations:

Connecticut DEEP, Innovate MASS, Reading Mass, Others

Project Description:

As part of DOE's mission to proliferate energy storage adoption, a contract was put in place with CESA to develop and manage a program that would educate the states' energy offices regarding the benefits of energy storage and help to develop state-led ES demonstration projects.

Key Project Events/Milestones:

- Develop two state collaborations to support efforts to incorporate energy storage into their energy strategies and support placement of at least one energy storage contract for each:
- Connecticut – Provide technical review in Connecticut's $15M RFP for grid resiliency. Provide services to analyze project installation and data.
- Massachusetts – Provide technical review of proposals submitted for clean energy projects in Massachusetts. Provide services to analyze project installation and data.

**Alaska collaboration** - Kodiak Electric and Venitie

Project Description:

Kodiak Electric has added 4.5MW of wind power to an existing 4.5MW of wind, giving them a total of 9MW of wind. In order to manage this additional 4.5MW of wind, Kodiak installed a 3MW 15-minute Xtreme battery system. In this project DOE/SNL worked with Kodiak Electric Association (KEA), Alaska Center for Energy and Power (ACEP), Alaska Industrial Development and Export Authority (AIDEA), to gather performance data, and study the impacts of wind and energy storage in order to understand the benefits and how ES and renewables might apply and benefit other Alaska electrical grids and projects. DOE/SNL will also look at optimizing schemes to further the economics of the project.

Key Project Events/Milestones:

- 9.0MW wind in operation 12/12; and 3MW Xtreme Battery in operation Q1/FY14.

Project Status:

- ACEP and Sandia worked with Kodiak electric in data collection

Three of the six 1.5MW wind turbines on Pillar Mountain, Alaska

**Base Camp Integration Lab (BCIL) Energy Storage Demonstration**
Project Description:
DOE-OE/Sandia collaborated with Army Program Manger Force Sustainment Systems (PM FSS), to develop demonstrations at an experimental Forward Operating Base (FOB) to analyze energy storage's capability to increase the reliability of the electrical power microgrid at a FOB while decreasing the fuel consumption of the system. ES vendors conducted Demonstrations at Sandia National Labs and at BCIL's test forward operating base located at Ft. Devens, Ma. The vendors include:

- Milspray – 15kW/79kWh;
- Deka VRLA; to SNL 1/13;
- Princeton Power – 100kW/60kWh; Li-ion; to SNL 3/13;
- Earl Energy – 60kW/40kWh; Li-ion; to SNL TBD;
- Raytheon/K-tech – 30kW/120kWh;
- Red Flow Zinc Bromine; to SNL 3/13;
- GS Yuasa – 70KVA 100kWh VRLA; to SNL 6/13

Key Project Events/Milestones:
- Completed testing of five ES Systems at DETL to determine system reliability and operability. Issue report of findings by end of Q1/FY14. Issue individual reports to vendors.
- Created carbon copy of BCIL microgrid at Sandia ESTP to determine energy storage fuel savings.
- Completed testing and release the report by Q2/FY14.

Project Status: Final Report Completed [2]

**DUKE Energy RANKIN Site Evaluation**
Project Description:
Duke Energy has installed a 402 kW/282 kWh, NaNiCl energy storage system to mitigate PV-induced power swings. In this project, we will look to develop control algorithms that will increase the utilization of the ESS, thereby creating additional value. In addition to PV smoothing, ESS functions that will be investigated include active VAR/Power Factor management and combined Watt/VAR voltage control. The project will also investigate the ability of the ESS to mitigate the impact of PV-induced power swings on substation assets such as load tap changers, transformers, and relays.
Key Project Events/Milestones:
- System installed at the Rankin Substation, Mount Holly, NC – 12/2011
- System evaluation and algorithm development Q4 FY13 – Q1 FY14
- DOE ESS Peer Review presentation submitted & approved

Project Status: Final Report Due

**University of California San Diego Collaboration**
Project Description:
UCSD was awarded a $4.3M grant under the CPUC's Self Generation Incentive Program (SGIP) to purchase and install > 4MW/5MWh of Energy Storage. The goal of the project is to install three systems – 2.5MW/2hr, 500kW/2hr, and a ~650kW/2hr -- on the University's microgrid. DOE/SNL will provide technical consulting and support.
Key Project Events/Milestones:
- Issue RFP for 2.5 MW 2 hour Energy storage system(s) by Q4/FY13, and award contract(s) to purchase and install systems by end of Q1/FY14.

Project Status:
- RFP Issued Q3 FY13; University is awaiting official award.
- Sandia is meeting with UCSD engineer to discuss project role and additional collaboration possibilities.


University of California at San Diego

**Mesa Del Sol**
Project Description:
SNL has created a PV power-smoothing algorithm incorporating multiple distributed resources (e.g., batteries, fuel cells, natural gas engine-generator). Simulations to smooth the PV output have shown significant reduction in battery state of charge range and power conditioning system size when using a traditional power generator (gas engine-generator) in conjunction with a battery. To verify these benefits, the PV power at the PNM Prosperity Site was smoothed with the PNM Prosperity battery in conjunction with the Mesa del Sol gas engine-generator and fuel cell at the Aperture Center
Key Project Events/Milestones:
- Ran control system with real-time coordination while switching a portion of the PV system off. Repeated the test with the uncoordinated controller.
- Recorded a high variable day with the coordinated control.
- Preliminary results presented at the US-Japan Smart Grid Workshop.

Project Status: Final Report Completed [3]

**SunPower ES demonstration with PV**
Project Description:
Sunpower Corp under a grant from the California Public Utility Commission (CPUC) will demonstrate Electrical Energy Storage (EES) with PV and the benefits that EES might provide. The Project will install two EES systems, ICE Energy at KOHL's department store (Redding, Ca.) and a ZBB- 125kW/4hr flow battery at UCSD. The systems will be installed on existing PV systems. DOE/Sandia to provide technical consulting services, assist KEMA in the evaluation of the ZBB energy storage system.
Key Project Events/Milestones:
- Finalize Sun Power-UCSD lease agreement, designs and installation plans: 3/1/13
- Prepare data monitoring, testing and system evaluation plan: Q3/FY13
- Manufacture, ship, install and commission ZBB system; commence data collection: Q3
- Conduct 6-month system assessment, test and results validation; deliver report: Q1/FY14
- Conduct final, end-of-project, 12-month system assessment and issue report by end of Q1/FY15

Project Status:
- Installation of ES system complete. Waiting to install an additional 110V circuit for ZBB control, and the resolution of some punch list items. Planned startup in Q2 FY14

**NYSERDA**
Project Description:
In 2011, a memorandum of understanding (MOU) between DOE and NYSERDA established a collaboration to provide support from DOE (Sandia National Labs) to help NYSERDA demonstrate whether electric energy storage is technically viable, cost-effective and broadly applicable in increasing power system reliability. Sandia has and is assisting in: the project selection process, establishing a data acquisition system for each selected project, conducting performance and economic analyses, and providing technical and project management support.
Key Project Events/Milestones:
- Long Island MTA battery decommissioned.
- Premium Power Flow battery system at Niagara Falls State Park permanently removed from operation.
- LaGuardia Community College ES/PV system 60% design review completed.

Project Status:
- Long Island MTA: NaS Battery --Performance report completed by Enernex.
- Niagara Falls SP: Premium Power Flow System --Premium Power drafting performance report.
- LaGuardia CC: PV/ES System --Technical support provided by DOE/DUA during 60% design stage meeting.


SunPower Electrical Energy Storage, California

**Electrical Energy Storage Demonstration Program: Helix Flywheel**

Project Description:

Electric grid transmission operators depend on "reserves" to reliably operate their systems to deliver year round electricity to the end-user according to standards developed by the North American Electricity Reliability Council (NERC). This standard is in place regardless of the generating source (conventional fossil fuel vs. renewable). Some states require as much as 30% of generating inputs to come from renewable resources as part of their Energy Standards (RPS).

At the 30% level of renewable energy penetration degradation of the grid is predictable with unstable performance. Thus a 'spinning reserve' ancillary service feature becomes necessary as a standby for interruption of transmission operations. Flywheels represent the technology that allows for the deeper penetration of renewable energy resources into the grid as well as a means to provide services to advance support of the next generation, smarter grid regardless of the type generation available.

Key Project Events/Milestones:

- Complete HPSF Conceptual Design & Technical Peer Review with Panel Comments
- Identify Launch Customer for Pilot Installation
- Formal Technical Report of HPSF Flywheel Conceptual Design and Market Analysis Phase 1
- Formal Presentation to DOE/Peer Review

Project Status/Deliverables:

- Move to phase II toward commercialization

**Electrical Energy Storage Demonstration Program: Vermont**

Project Description:

The objective of this project is to design, install, commission, and test an energy storage system that supports renewable energy resource generation.

ESS will be 2MW with 1MWh Li-ion, and 2.4MWh Advanced Lead Acid.

Key Project Events/Milestones:

- Provide a list of states that are supporting and/or developing ES Demonstration projects
- Initiate contract with and provide cost share funding to selected project(s).
- Monitor project and deliverables and provide quarterly report to DOE/SNL.
- Attend and participate in CESA Webinar or other outreach on the status of operation at the completion of the project.

Project Status/Deliverables:

- Q4/FY15 Commissioning.

Rutland, Vermont




# SPECIAL DEMONSTRATION PROJECTS

ALASKA • HAWAII

# ALASKA

Background

The Cordova storage study is a two-phase collaboration between DOE/Sandia, University of Alaska, Fairbanks, and Cordova Electric to examine storage benefits and make technology-specific recommendations for integrating storage into the Cordova grid. The study will initially be technology agnostic, but, the final intent is to determine whether the requirements can be met with flywheels in the 500 kW range to displace diesel fuel presently used to supply spinning reserve. The flywheels could also contribute to conserving water for the hydro generators that is normally spilled during low-load periods.

Phase I will use an energy balance model to estimate the size, desired performance characteristics and location of the storage system in the Cordova grid.

Phase II will use stability models to refine the Phase I findings and provide more precise flywheel characteristics which could be used by Cordova as a framework to acquire and install a flywheel energy storage system.

Technology
The Cordova ES is comprised of:
Two hydro plants
- Pump Creek: 2 units, 3 MW each
- Humpback Creek: 2 units, 1.25 MW

Five diesel units at Orca Power plant.
- Unit 3 – 2.4 MW
- Unit 4 – 2.5 MW
- Units 5 and 6 – 1.2 MW each
- Unit 7 – 3.7 MW

The storage is needed for short duration system demands (15 minutes or less). Cordova's hydro units are run with a 500kW reserve diesel units provide reserve when the hydro capacity has reached its max.

Status
Schedule: Phase I completed May 2014; Phase II completed July 2014.

The storage is needed for short duration system needs of 15 minutes or less. Cordova's hydro units are run with a 500kW reserve, and diesel units provide reserve when the hydro capacity has reached its max.

Status
Schedule: Phase I completed May 2014; Phase II completed July 2014.

Diesel Units 3 and 4, Orca Power Plant


Units 4 and 5 at Power Creek, 3 MW each

## Hawaii Project Summaries

1. Title: **Ikehu Molokai Energy Storage Project**

Summary: Phase I will add 6 MW PV and 6MW/6MWh energy storage resources to achieve 40% renewables penetration on the Molokai island grid, allowing retirement of a portion of the island's diesel generation. Phase II seeks to achieve 100% renewable generation on Molokai.

Partners: The project will be developed by Princeton Energy Group in collaboration with HECO/MECO and the Hawai'i Energy Agency.

- Federal partners: US DOE-OE, SNL, PNNL. Sandia/PNNL contributions in Phase I include a cost/benefit analysis, system modeling, energy storage valuation, data monitoring and analysis
- State partner: Hawai'i Energy Office
- NGO partner: Clean Energy States Alliance
- Financing partner: Half Moon Ventures, a private equity firm

Timeframe: Completion of Phase 1 by the end of 2016. This deadline is important to allow the project to take advantage of the federal Investment Tax Credit for solar and associated storage resources, which is set to expire at the end of 2016.

2. Title: **Kaimuki Middle School Microgrid Project**

Summary: A demonstration microgrid at the Kaimuki Middle School in Honolulu. The project plans to make the school net zero by adding PV and 2 MW energy storage; provide resilient power to the school, which is an emergency shelter; demonstrate the first microgrid in the state; and allow HECO to test how a microgrid would work within the broader grid system for grid support services (voltage and frequency response etc.). This would also be a step toward exploration of alternative utility business models in HI.
Partners: The project will be developed by the state Dept. of Education, Opterra (PV installer), Spirae (subcontractor providing controls and logic), HECO, and the Hawai'i Energy Office.

- Federal partners: SNL, PNNL. Sandia/PNNL contributions in Phase I include a cost/benefit analysis, system modeling, energy storage valuation, data monitoring and analysis
- State partners: Hawai'i Energy Office, Hawai'i Dept. of Education
- NGO partners: Clean Energy States Alliance

Timeframe: Completion of Phase 1 by June 2016



# ESHB UPDATE

DOE/EPRI 2013 Electricity Storage Handbook* in Collaboration with NRECA Updates [4]

The purpose of the handbook is to serve as a resource for making decisions on technical devices, equipment, facilities, systems, and installations based on respective use cases, services, costs and benefits for the emerging technologies and application associated with electrical energy storage. Stakeholders who require this type of information include, but are not limited to, large electricity utility and rural cooperative engineers, investors, venture capitalists, resource planners, and end-users.

The 2013 version of the ESHB is composed of four chapters, with well over one hundred figures and twenty tables in the main body, seven comprehensive appendices, and an extensive glossary. The handbook engaged the talent of nine primary authors from four separate organizations, an advisory panel of ten subject matter experts, a construct of five different working groups, and a host of contributors.

*DOE/EPRI 2013 Electricity Storage Handbook is abbreviated as ESHB in this journal

## THERMAL ENERGY STORAGE

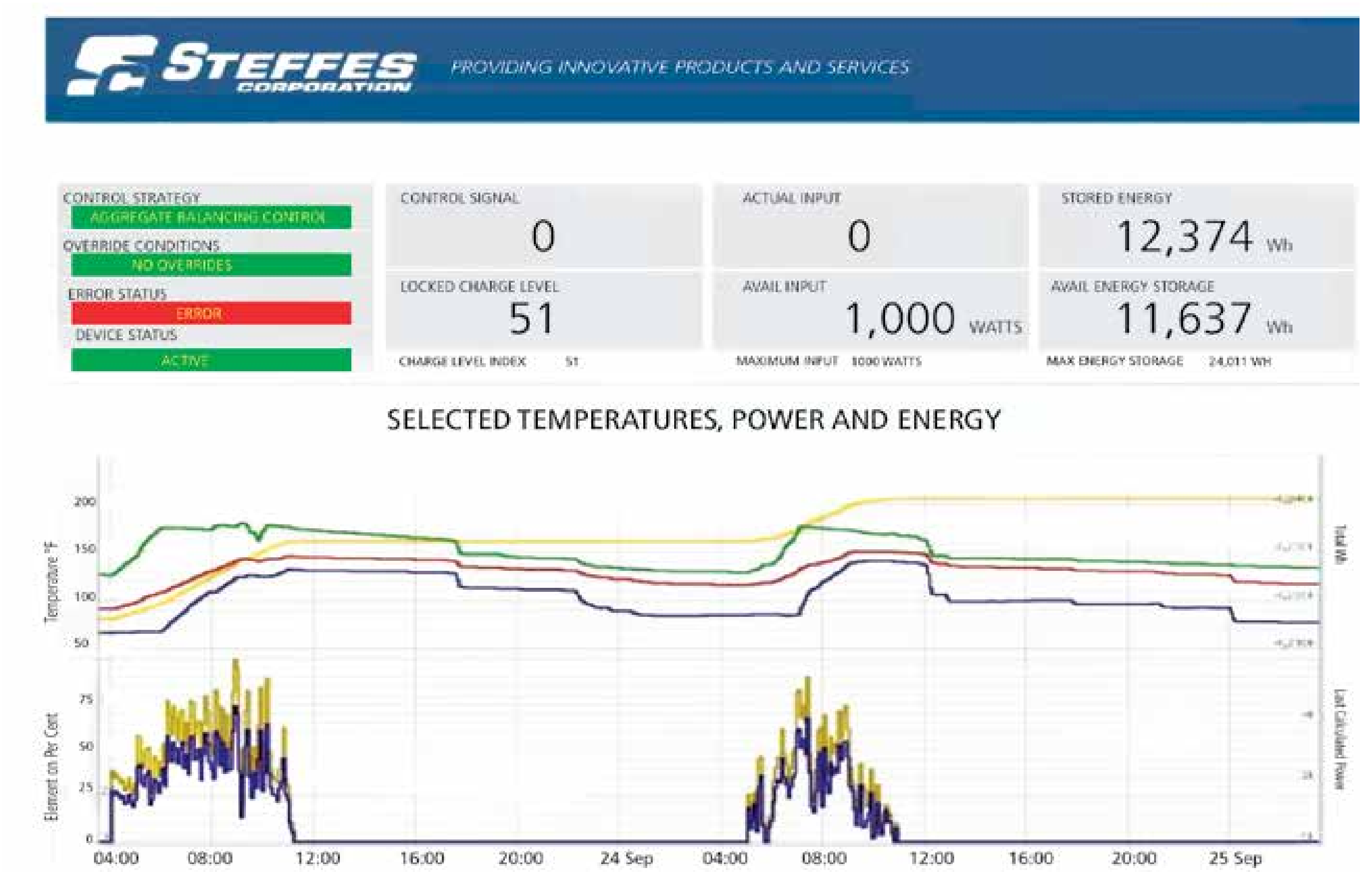
The following is a summary of Dale Bradshaw's Thermal Energy Storage: Insights and Results from the DOE and NRECA Smart Grid Demonstration Project.

**Scope**

Great River Energy (GRE), a Minnesota-based generation and transmission (G&T) electric cooperative, evaluated ten dynamically dispatched hot water heaters to determine the benefits of grid-interactive energy thermal storage (GETS). The overall goals were to validate and verify the GETS technology and determine their value in demand reduction and for providing such ancillary services to the Midcontinent Independent System Operator (MISO) electricity market.

The purpose of the GETS project was to evaluate the use of water heaters for storing thermal energy during off-peak hours and offset on-peak charging of hot water heaters, while providing frequency regulation to the MISO wholesale power market. The GETS project successfully deployed a new control technology for the water heaters. The controller for GETS has a fast, Internet Protocol (IP)-based connection back to the head-end system and the ability to vary the charge rate on the water heater between 0 and 100% of the appliances' maximum demand. Combining the fast connection with the ability to vary the charge rate technically provides a distributed resource capable of providing dynamic dispatch, spinning reserve, and fast frequency regulation during off-peak hours to a wholesale power market such as MISO.
These overall project goals were accomplished:

- Ten Steffes Water Heater Controls with remotely configurable charge rates were deployed in the service territories of the participating member distribution cooperatives;
- Two-way communication of the water heater controls was tested, evaluated, and proven to be effective;
- The use of power-line carrier, 700-MHz wireless, and Wi-Fi were tested as possible communication technologies;
- An economic model was developed for evaluating use of hot water heaters for frequency regulation.




Steffes Data on Temperature, Power, and Energy for an Individual Water Heater

**Background**

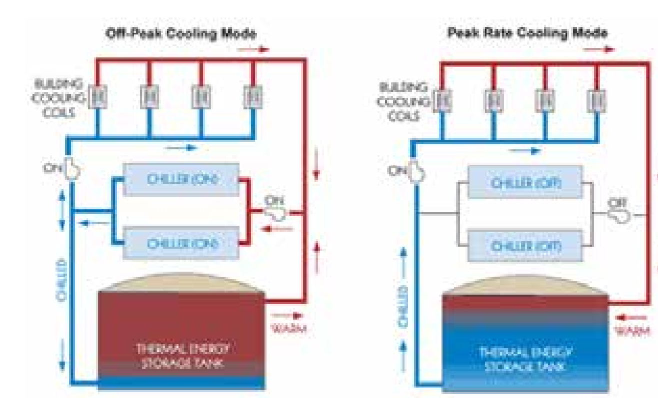
The GETS was an extension of thermal energy storage systems that have been in use for demand-side management (DSM) by GRE. GRE provides wholesale electric service to 28 distribution co-ops in Minnesota and Wisconsin that distribute electricity to more than 650,000 member-consumers—about 1.7 million people. GRE offers more than 3,500 MW of generation capability, consisting of a diverse mix of baseload and peaking power plants. As part of its DSM program, more than 70,000 hot water heaters have load management systems (LMSs) installed that will allow hot water heaters to be heated with low-cost off-peak energy. These hot water heaters generally are not allowed to contribute to the peak load that occurs during the day and early evening.

**Technology**

Thermal energy storage using hot water heaters is potentially an effective, low-cost method of providing peak shaving, spinning reserve, and balancing services for the electric grid, usually referred to as "frequency regulation service" or just "regulation service." This service can be provided by "charging up" a water heater in response either to an area control error (ACE) or automatic generator control (AGC) signal from a utility, independent system operator (ISO), or regional transmission operator (RTO). The utility, ISO, or RTO can request the hot water heater either to charge up (heat the water) from a mid-level charge of 1.5 kW to 3 kW, or stop the charge up by dropping the electric hot water heater to 0 kW. Thus, the hot water heater can respond to ACE or AGC signals for controlling frequency by providing frequency regulation up or frequency regulation down, providing the area balancing services. It can do this for hundreds of thousands of cycles.

Additionally, by combining controls and communications with water heaters, the technology can interface with standard load management through the GRE DSM program to provide not only responsive regulation but also spinning reserve and nearly instant "valley filling" building load during the off-peak hours. Effectively, hot water heaters can be "dynamically dispatched". This technology is being developed by the Steffes Corporation to provide regulation service during the off-peak hours of heating water, thus valley filling load exactly so as to minimize the cost of charging and remove the hot water heater load from the morning or early evening peak hours. Such a configuration could qualify for a capacity credit or demand charge reduction if enough hot water heaters are aggregated.

The system reliability within MISO and other ISOs/RTOs can be improved further by providing fast frequency response systems like GETS or energy storage. The PJM RTO has found that the implementation of performance-based compensation for regulation resources has been successful (PJM RTO report of October 14, 2013 to FERC on analysis of performance-based regulation for frequency regulation). To support this need, the dynamic dispatch of the hot water heaters can provide response as fast as 4 seconds (often obscured by the 20- to 90-second latency time for reporting). PJM noted that fast-responding resources (like thermal energy storage in hot water heaters) can participate in the PJM regulation market when aggregated to provide more than 100 kW of regulation. This will provide the PJM RTO market and other ISOs/RTOs in the future—with control over regulation that is the same or better, as measured by North American Electric Reliability Corporation (NERC) Control Performance Standards 1 (CPS1) and Balancing Authority ACE Limit (BAAL) reliability criteria. PJM concluded that paying for performance of fast-response/fast-moving frequency regulation can provide significant benefits and reduce overall frequency regulation costs, as well as meet synchronous reserve requirements, thus reducing the total cost for providing frequency regulation.

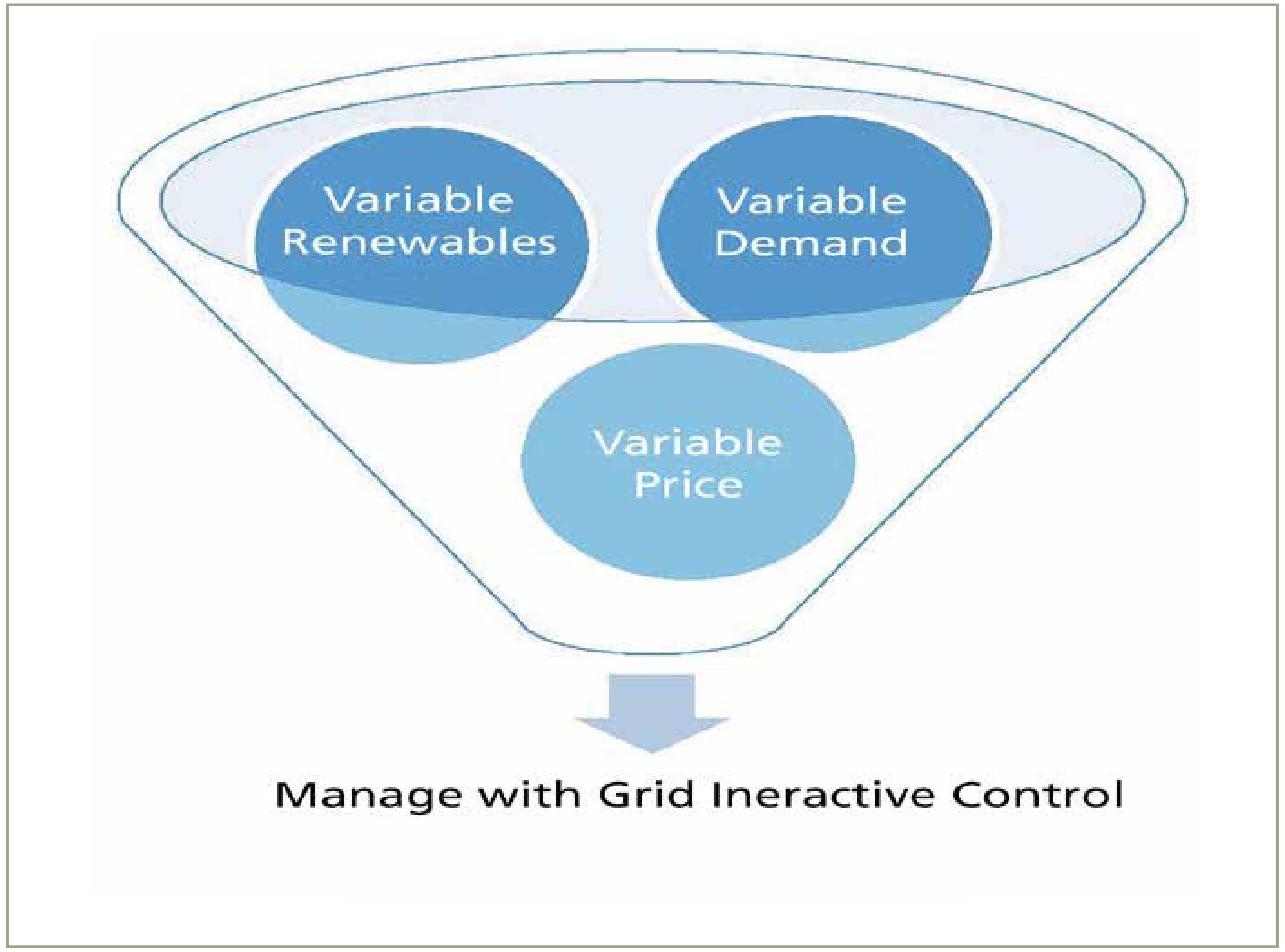



Example of Thermal Energy Storage

The GETS technology has a dynamic dispatch control system comprising a control panel with an embedded microprocessor connected to current transformers and thermocouples in the hot water heater; it also has a high-speed connection that for the demonstration was hard wired back to the internet modem and then back to the head-end computer monitoring and control system.

During the charging time period, for purposes of this demonstration, GRE communicates an Automatic Generator Control or AGC signal to simulate an Area Control error or ACE signal that GRE would receive in the future from MISO. In the future, the ACE signal would be more volatile than the AGC signal if the devices were enrolled in the MISO market to provide fast frequency regulation service but, as will be shown later, that will not be a problem for the Steffes GETS system. Currently, between 7 AM and 11 PM, the units are not allowed to charge or provide regulation service; but could be configured to allow manual over ride if the end user needs more hot water during the peak hours than was originally planned.

The advantages of using thermal storage include:
1. A balanced and stable electric grid, offering improved reliability,
2. More cost-effective, off-peak power load serving entity purchases of power load serving entities, avoiding high cost peak period buying,
3. Economic benefits from aggregating water heater controls responding to frequency regulation and obtaining payment for providing the service, and
4. Demand reduction during the daily peaks.

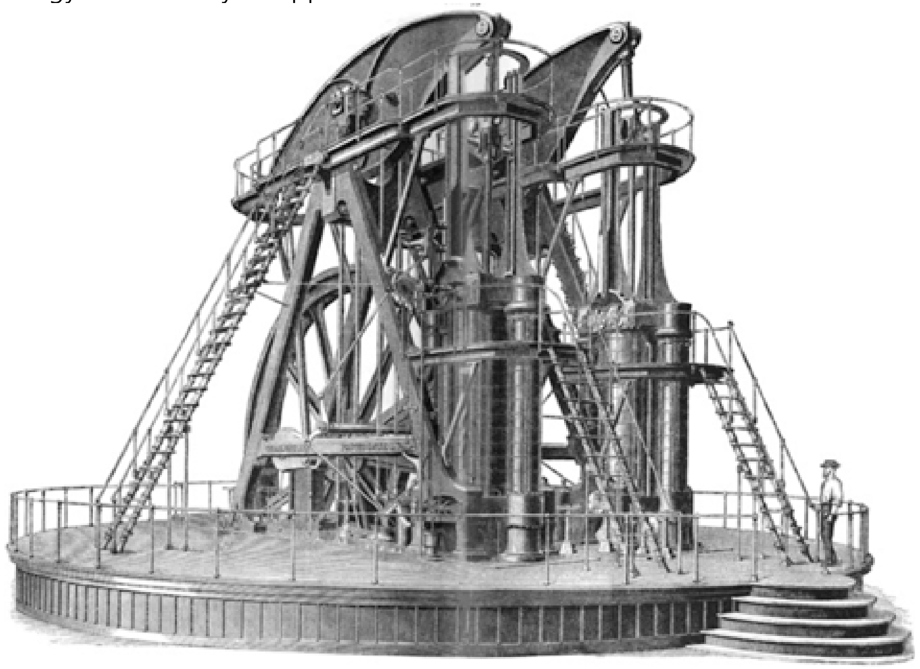





## Flywheels Basics

The following is a summary of Don Bender's white paper, Flywheels Fundamentals.

Since ancient times, the flywheel has been used to smooth the flow of energy in rotating machinery from small, hand held devices to the largest engines. Today, standalone flywheel systems are being developed to store electrical energy for a variety of applications.



Corliss Centennial Engine

Since the late 20th century, a new class of standalone flywheel systems has emerged. The modern flywheel, developed expressly for energy storage, is housed in an evacuated enclosure to reduce aerodynamic drag. The flywheel is charged and discharged electrically, using a dual-function motor/generator connected to the rotor. Flywheel cycle life and calendar life are high in comparison to other energy storage solutions.

20 MW Flywheel Frequency Regulation Plant (courtesy Beacon Power LLC)

Applications for flywheels are viable when two conditions are met. First, the flywheel must represent a more cost effective solution than competing forms of energy storage. Additionally, a market must exist so that the deployment of a flywheel system results in an economic return.

Flywheels are in use globally across various applications:

| | | |
|---|---|---|
| Grid-Connected Power Management | | |
| | Frequency Regulation | Flywheels are used to provide frequency regulation services at two 20 MW facilities |
| Industrial and Commercial Power Management | | |
| | Transit | Flywheels produced by Calnetix and URENCO have been demonstrated in a number of transit systems for trackside energy recovery |
| | Mining | The Usibili mine in Healy, Alaska uses a 40-ton flywheel to smooth the demand for electricity from a 6 MW dragline |
| Pulsed Power | | |
| | Electromagnetic Aircraft Launch | 80 MW flywheel alternators are being developed to launch aircraft from the next generation of aircraft carriers |
| Uninterruptible Power Supplies | | The global market for UPS systems is on the order of $10B per year. Rotary systems account for about 5% of the total UPS market. Among large systems (>2MW), rotary UPS account for 35% of the world market |
| Mobile | | |
| | Materials Handling | Flywheels recover energy and reduce emissions from raising and lowering loads with Rubber Tired Gantry Cranes at container terminals |
| | Motorsport | Flywheel hybrid powertrains were used successfully in the Audi R18 e-Tron LMP1s that won at Le Mans in 2012, 2013 and 2014 |
| | | |

Through the OE Energy Storage Safety program, Sandia is continuing to address flywheel system design, operation, and safety. These efforts include providing subject matter expert technical support to investigate industrial incidents involving flywheels and developing best practices for safe flywheel design and operation.



## Platform for Rethinking the Cost of Energy Storage

The cost of energy storage expressed in the DOE/EPRI Electricity Storage Handbook published in 2013 used hypothetical scenarios and best guesses from vendors. The body of wok took place before real-world grid-integrated storage installations and demonstrations were in place. In a 2011 report[5] , Susan Schoenung offered the following analysis.

Costs of energy storage systems depend not only on the type of technology, but also on the planned operation and the hours of storage needed. Calculating the present worth of life-cycle costs makes it possible to compare benefit values estimated on the same basis.

The most important factors influencing total life-cycle cost are the capital cost of the equipment, followed by replacement costs, and, finally, the cost of energy for recharging. Replacement costs are affected by the system's expected service life and the life-cycle costs of energy. Benefits, in large part, depend on the functions required by the user and, again, the expected service life of the system. When calculating the benefits or costs of a storage system over the entire life of the system, proprietary information and algorithms are sometimes used to calculate a value that is then multiplied by the present worth factor to determine the present worth of the cost or benefit. Service life, discount rate, and inflation rate are three factors used to calculate the 'present worth' factor, which provides a simple, consistent way to represent the value of a regular stream of revenues or payments for a given number of years.

The 'present worth' concept is used so that the cost numbers provided here are directly comparable to the quantified benefits published elsewhere by the Energy Storage Systems Program. In general, present worth is based on ownership of the device over 10 years for a given application and includes the following factors:

- Efficiency
- Cycle Life
- Initial Capital Costs
- Operations and Maintenance
- Storage-device Replacement

| Technology / Use | Advanced Lead-acid Battery | Na/S (7.2 hr) | Zn/BR | V-redox | Lead-Acid Battery w/Carbon-enhanced Electrodes | Li-ion | CAES (8 hrs) | Pumped Hydro (8 hrs) | High-speed Flywheel (15 min) | Supercap (1 min) |
|---|---|---|---|---|---|---|---|---|---|---|
| Long-duration storage, frequent discharge | 2839.26 | 2527.97 | 2510.03 | 3279.34 | 2017.87 | 2899.41 | 1470.10 | 2399.90 | | |
| Long-duration, infrequent discharge | 1620.37 | 2438.82 | 1817.82 | 2701.41 | 1559.57 | 2442.79 | | | | |
| Short-duration storage, frequentdischarge | 1299.70 | | 905.53 | 1459.85 | 669.85 | 1409.99 | | | 965.73 | 834.62 |
| Short-duration storage, Infrequent discharge | 704.18 | | 697.78 | 999.78 | 625.57 | 960.48 | | | 922.87 | 793.02 |

Table. Present worth cost of 10-year operation in year 1 ($/kW)

Analysis reveals that present worth is highly variable. The most apparent cost difference lies between long-duration and short-duration uses. Long-duration simply requires more storage capacity. The differences between frequent and infrequent operation are also substantial for some technologies. Frequent use is more expensive because more electricity is purchased for charging, and some technologies will outlive their cycle life during the 10-year time frame and requiring expensive replacements. Technologies with good cycle life are attractive for applications requiring frequent charge and discharge.

Electric utilities across the country are motivated to advance the work of grid modernization and to manage peak demand. Some are also required to meet renewable generation mandates. With these key stakeholders keenly involved in demonstration activities, we are in a position to collect, test, and analyze data and to evaluate an interesting mix of energy storage applications and technologies. We can now rethink how to share an update on energy storage costs by utilizing real data to define an approach or methodology for systems rather than per-unit costs.

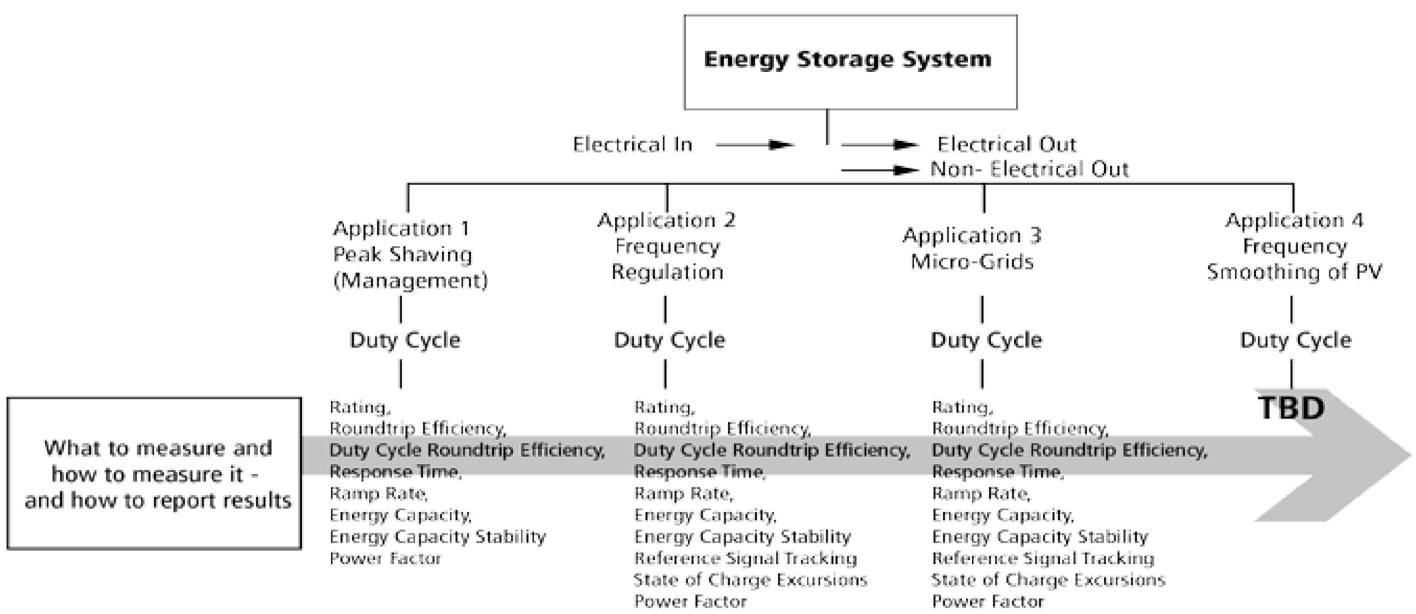
## Energy Storage System Protocol Update

The Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems[6] was first issued in 2012 as a first step toward providing a foundational basis for developing an initial standard for the uniform measurement and expression of energy storage system performance. Its subsequent use in the field and review by the protocol working group and most importantly the users' subgroup and the thermal subgroup has led to the fundamental modifications reflected in updates and revisions of the 2012 Protocol. Protocol development and enhancement is intended to be a dynamic process that will occur over time through a phased approach to address enhancement and consideration of all applications and relevant performance metrics.

## 2012 Protocol -- Measuring Performance

The Department of Energy launched this protocol development activity officially on February 3, 2012, with a sense of urgency to establish and empower a working group of industry leaders in the grid-connected energy storage field to craft a written document that addresses the most urgent needs in the industry related to measuring and reporting performance characteristics for ESSs in various applications. The protocol development process has been open and widely representative of ESS industry leaders, developers, users, government, research, and other interested stakeholders

Protocal Overview




The original 2012 Protocol covered peak-shaving applications, but initially focused on all electric systems, so enhancements were needed to address thermal storage systems.

**2013 Protocol -- Metrics and Testing[7]**

While completing this protocol, it became clear that the level of detail and specificity provided might need additional refinement in the future. During the development of the protocol, the following items were among those identified as potential enhancements to the protocol through future work on the protocol and for any standards development organizations that develop standards associated with ESS performance or others that use the protocol as a basis for specifications or other documents covering the purpose and scope addressed by the protocol.

- Structuring of the protocol.
- System life.
- Where and how to do testing of ESSs?
- Duty cycle.
- Inclusion of ESS other than batteries.
- Minimum system size.
- Common reporting format.
- Additional metrics.



The 2013 update resulted from the protocol users' subgroup, whose members agreed to "test drive" the 2012 Protocol and provide feedback about their experiences to help refine the performance measurement and expression criteria to make them easier or less time consuming to apply, enhance the accuracy of the results, and/or ensure that the metrics are equally applicable to all systems.

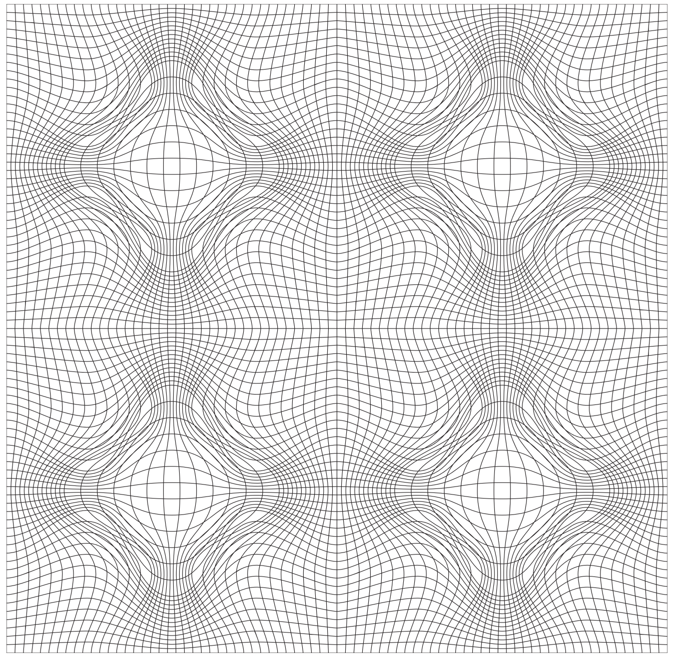
**2014 Protocol -- Microgrids**

In 2014, Provisions were added to cover an islanded microgrid application for an ESS. For the islanded microgrid, each use case involves storing some excess energy and providing it when necessary. All of the use cases include serving critical loads, VAR support, power quality, frequency response and black start. The working group discussed addressing some other use cases such as modeling, life and safety. Three different use cases for islanded microgrids were considered, and a corresponding duty cycle for each was developed:

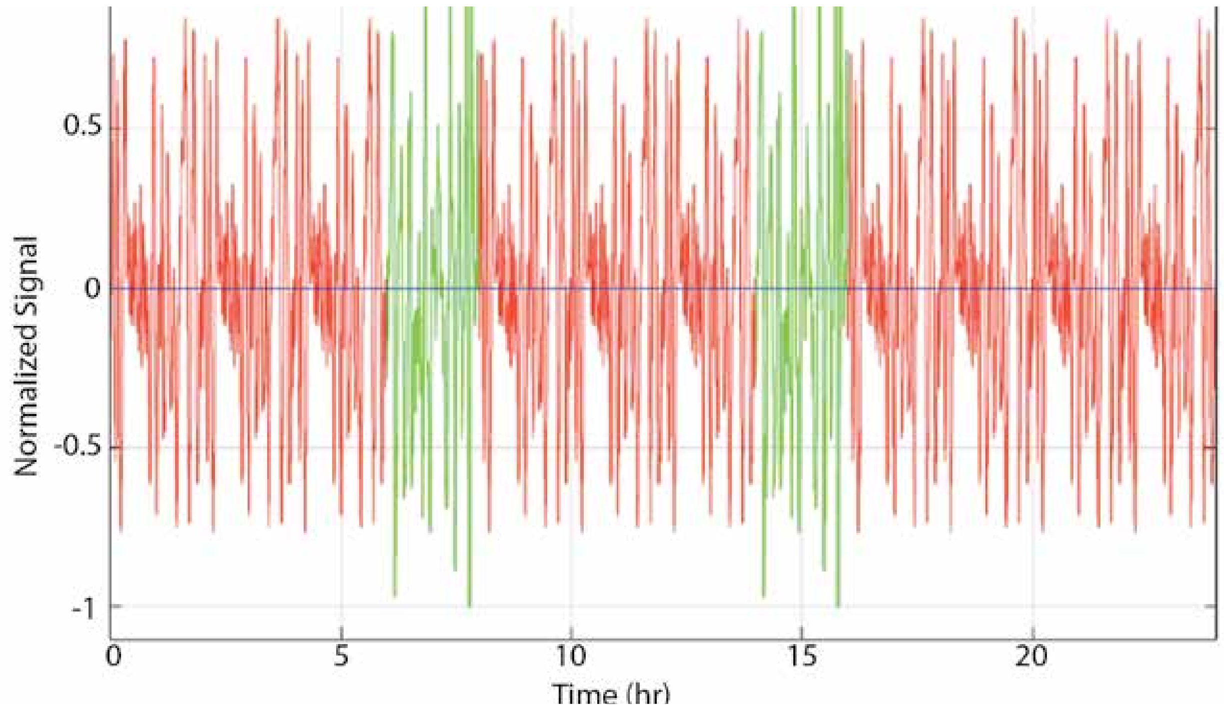
- Microgrid with renewables included in the generation assets and frequency regulation
- Microgrid with renewables but with no frequency regulation
- Microgrid with no renewables and no frequency regulation

Summary

The protocol is intended to assist the energy storage industry more effectively communicate to all interested parties and ESS customers and users about energy-storage applications in terms of the technical performance associated with providing a service or services that employ ESSs. This in turn will foster the ability of the ESS industry to showcase applicable options for increasing the reliability and energy management capabilities of the electricity delivery system, whether it is connected to the grid or through onsite stand-alone systems.



Communities around the world are increasingly deploying smart microgrids to achieve 21st century energy goals, such as improved reliability, reduction of carbon emissions, cost reductions, and diversification of electric generation sources.




Example Frequency Regulation Duty Cycle

## Afterword

J. Hernández

This annual review features energy storage demonstration projects that define technical advances and new processes that help the researcher, the technologist, and the device or system owner understand the state of art of storage – operations, performance metrics and new products and services. This journal is intended to encourage an appreciation of the emerging and enabling technology of energy storage and its many applications and techniques. It has become clear over the last fifteen years that maximizing the value of energy storage continues to be a policy and regulatory challenge.

Consumers want cleaner, more efficient and cost-effective electricity. Providers, who are becoming increasingly more responsible, want to satisfy their customer and ensure investors of reliable return on investment. Energy storage clearly represents an integral bridge for potential gaps in supply and demand (i.e., predictable peak conditions) that the new, smarter electricity grid will experience.
Through the technologies associated with batteries, electrochemical capacitors, flywheels, etc. energy storage can move energy where it needs to go, when it needs to be there. However, the multiple personality of energy storage has resulted in several policies from the Federal Energy Regulatory Commission (FERC) to address the uniqueness of ES in a market environment. FERC's Orders 755, 784, 890, and 1000 were intended as starting points to help investors and providers benefit from energy storage's value by:

- Redefining and/or altering traditional structures based on function only
- Creation of market structures to provide proper compensation
- Altering market structures to establish predictable cost recovery
- Requiring states to cooperate in resource planning

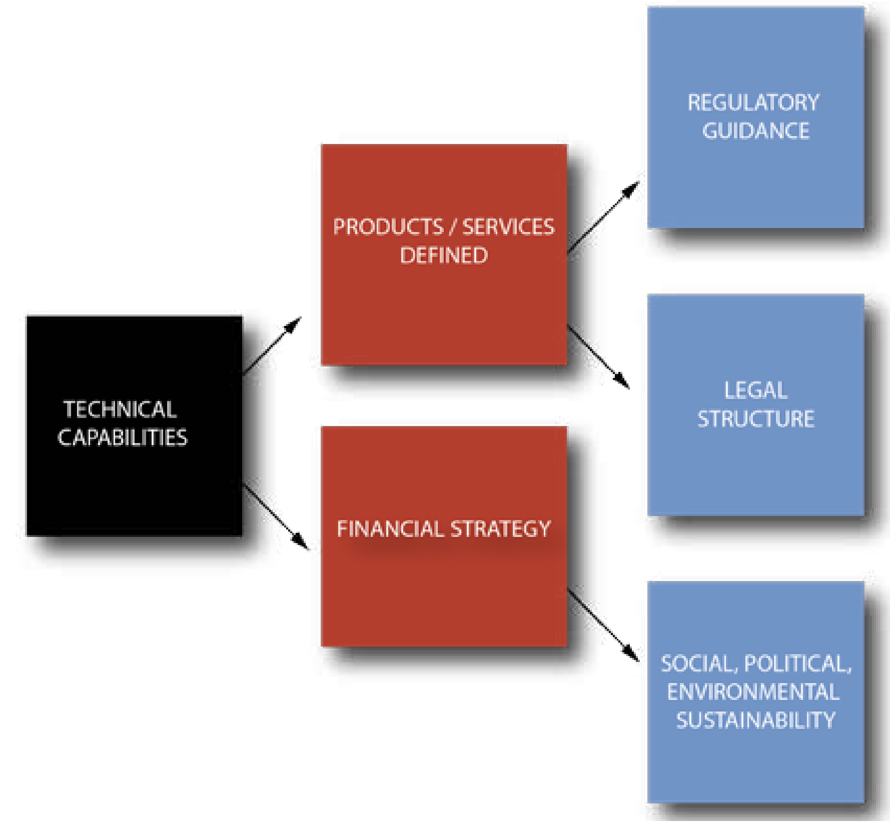
Even with the regulatory guidance, it is still a challenge for all parties to know how costs and benefits should be allocated. The nature of storage is not uniformly consistent in market structures once based on the vertical integration electricity delivery elements: generation, transmission, and distribution. So, from a policy and regulatory vantage point, what is an important next step for energy storage to encourage market participation and stakeholder investment? Indeed a basic question asked quite often in workshop and conference settings is "do you make money from energy storage". This query is followed by the observation that there is no one consistent business model for energy storage.

Too often those in the energy storage industry are very willing to make the business case for energy storage for the modern grid. With respect to energy storage, it is easier to state what a business model is NOT. An energy storage model is NOT a value proposition, a business case, a revenue model, a financial model, nor a strategy. After working with states, vendors, utilities, strategists, for the last four years, it is clear a next step for energy storage is go design a blueprint, a construct that identifies systems, technology assets that are connected to business processes with goals and the external environment of customers, suppliers, and competitors with agreed-upon standards and policies. Rather than present an all-encompassing 'business model' for energy storage, it is more intellectually honest to develop a business construct.

Business Constructs Problem Statement
The business case for energy storage is well documented. However, given the recent regulatory and policy challenges in FERC Orders (i.e., 755, 784, 1000, etc.) and some state mandates, it is now fitting to develop a well-defined business model for electrical energy storage for U.S. market designers, legal entities, investors, utilities, and end users.



The following illustration is proposed as an introduction in the dialogue about the elements of an electrical energy storage business construct:




Energy storage has an impressive mix of technical capabilities, and all sorts of stakeholders have weighed in on their desire for environmental stewardship and sustainability. Therefore, a facilitated discussion to establish a meaningful energy storage business construct begins with fundamental questions:

**Questions to ask of regulatory entities:**
- **What are the commonalities across the products/services?**
- **Can you create a narrow focus for this complex element?**

**Questions for legal structure:**
- **What is an exchange?**
- **What are the legal instruments to advance an exchange?**
- **How do you share decision-making liabilities?**

**Questions for social, political, and environmental sustainability:**
- **What changes are needed in the (existing) revenue stream?**
- **What party can best manage the consequences of failure?**
- **Who has the most to gain and/or lose?**

## 2015 Annual EESDP Journal Biographical Notes of Contributors

**Dr. Imre Gyuk**: Dr Gyuk has a BS from Fordham University, and he completed his graduate work at Brown University where he was a research assistant to Nobel Laureate, Leon Cooper. After obtaining his PhD in Theoretical Physics from Purdue University, he became a research associate. Dr. Gyuk has taught Physics, Civil Engineering, and Architecture at the University of Wisconsin and Kuwait University. He directs the energy storage research program at the U.S. Department of Energy, which funds a wide variety of technologies such as advanced batteries, flywheels, super-capacitors, and compressed air energy storage.

**Daniel Borneo**: An electrical engineer and Principal Member of Staff at Sandia National Laboratories. He holds both a BSEE and MSEE from the University of New Mexico. In 2012 he became a scholar in residence at the University of California at San Diego (UCSD) where he now serves as a consultant. At Sandia, he serves as the principal investigator and project leader for the Department of Energy/Office of Energy (DOE/OE) Electrical Energy Storage Demonstration Program. His primary focus is collaborating with representatives of the energy storage industry, academia, and state energy groups to facilitate moving innovative electrical energy storage technologies and systems to commercialization products and services.

**Jacquelynne Hernández**: Educational Background: AB History/Physics, Vassar College; BSEET - DeVry Institute of Technology; MS: New Mexico State University Electric Utility Management Program; MSEE – (Power Engineering) New Mexico State University; Areas of Expertise: Asynchronous Machine Modeling & Validation, Electricity Utility Management, and Energy Policy (Oil & Gas Pipelines, Energy Cyber Standards, RTO/ISO Market Compliance). Currently she is the Sandia Energy Storage Demonstration special project lead for the Clean Energy States Alliance; she serves as the primary resource to the team for local, state, and national policy and regulatory guidance for (energy) market consideration.

**Benjamin Schenkman:** BSEE and MSEE from New Mexico State University; Areas of Expertise: Power Systems Analysis, Microgrid Design and Control, Energy Storage Optimization and Control (software).
Ben started his career at Sandia as a PEM cell technician, working on commissioning plug power fuel cells. He then worked in the facilities group, where he revised codes and standards for the corporation's Master Electrical Design Manual. Schenkman's current projects in energy storage technologies require him to develop dynamic models for electrical stability analysis- serving industrial and commercial customers. Other ES demonstration data analysis, performance evaluation and (controls) optimization of energy storage systems.

**David M. Rosewater**: BSEE and MSEE Montana Technology of the University of Montana; Areas of Expertise: Energy Storage Testing, Experimental Design, Data Collection and Analysis, Energy Systems (Conventional and Renewable), Power Engineering Theory, Modeling and Application; Energy Storage Safety Standards (Working Group).
Rosewater is an Energy Storage Test Engineer at Sandia National Laboratories and serves as a key member of the Sandia Energy Storage Safety Validation team where he uses the US Department of Energy's Energy Storage Test Pad (ESTP) located at Sandia National Laboratories to characterize AC integrated energy storage systems up to 1MW in size. Mr. Rosewater holds a Professional Engineering license in the state of New Mexico with a specialty in electrical power engineering. Prior to moving to the stationary energy storage sector at Sandia National Laboratories in 2011, Mr. Rosewater spent three years working with the Idaho National Laboratory developing advanced spectral impedance measurement techniques for hybrid vehicle batteries.

**Donald Bender:** A Mechanical Engineer and Principal Member of the Technical Staff at Sandia National Laboratories. He holds BSME and MSME degrees from the Massachusetts Institute of Technology. Mr. Bender is a subject matter expert in the area of flywheel energy storage with more than 20 years of industrial and research experience in the field. At Sandia he supports System Surety Engineering and special projects pertaining to energy storage.

**Summer R. Ferreira**: B.S., New Mexico Institute of Mining and Technology; Ph.D., University of Illinois Urbana-Champaign: Topic Structure, Dynamics and Flow Behavior of Model Biphasic Colloidal Mixtures.

**David Schoenwald**: B.S.E.E., University of Iowa; M.S.E.E., University of Illinois at Urbana-Champaign; Ph.D., The Ohio State University: Electrical Engineering. Areas of expertise: Control theory, Robotics, and Electrical Energy Storage.

**Dale Bradshaw**: BS (Engineering Physics), M.S.M.E., University of Oklahoma. Finance MBA, University of Tennessee. He retired after 29 years as a senior manager of R&D for generation and transmission projects and also worked in central planning and nuclear. In addition to his current role as a Technical liaison and with 35 years of experience in all aspects of the electric utility business, Dale is the CTO for Advanced Coal Technologies LLC, developing a low cost coal refining technology.



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David Conover, Alasdair Crawford, Vilayanur Viswanathan (PNNL) Summer Ferreira, David Schoenwald (SNL); PNNL/SNL Protocol for Uniformly Measuring and Expressing Performance of Energy Storage Systems, PNNL-22010 Rev.1, June 2014.


# What to Expect From Electric Energy Storage Demonstration Projects in 2016

Energy Storage Systems Demonstration Projects Global Engagement

Singapore at Night. Photography by J. Hernandez