EESDP 14

Electrical Energy Storage Demonstration Projects

Energy Storage Demos & Testing

Selected 2014 Projects

Market Assessment Guide Update

Coming Attractions for 2015

SAND2014-17245 O
Unlimited Release
Printed August 2014

Contributors

Editorial Staff

Senior Editor: Jacquelynne Hernández
Copy Editor: RedLine Editing
Proof Reader: Gail Kaplan

Design

Design Director: Roger Green
Production Manager: Bruce Shortz

Authors (in alphabetical order)

Donald Bender
Kevin Blackman
Daniel Borneo
Michelle Ellison
James Eyer
James Greenberger
Jacquelynne Hernández
Matthew Lazarewicz
Ali Nourai

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.

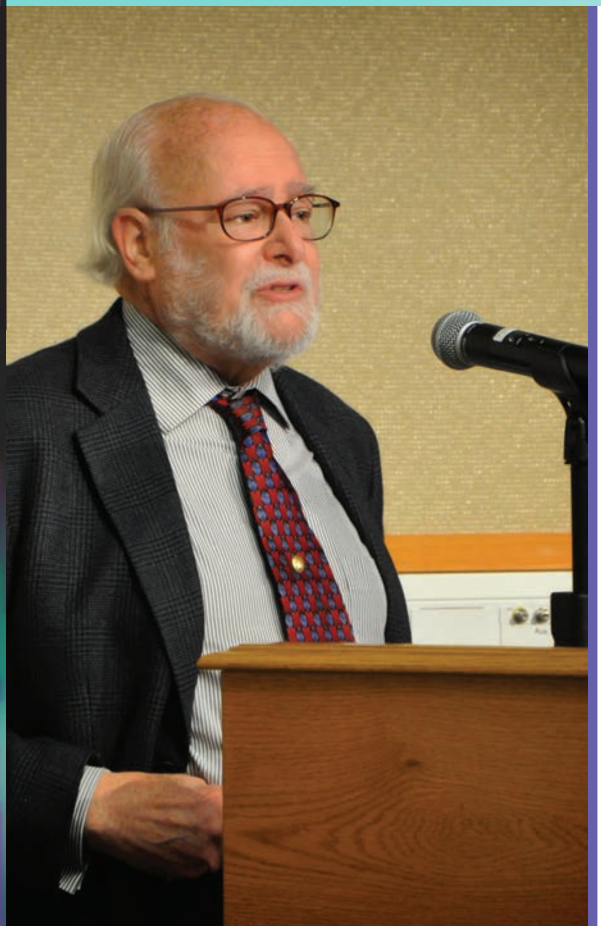
Look us up

http://www.sandia.gov/eesat/
http://www.sandia.gov/ess/

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Table of Contents

Acknowledgement



We gratefully acknowledge the support of Dr. Imre Gyuk, DOE Office of Electricity Delivery and Reliability - Energy Storage Program.

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: Hawaii, Vermont, Alaska and Washington. The SNL 2014 Energy Storage demonstration projects framework served as an incubator for emerging flywheel technology that has many different applications from providing ancillary services to electricity grid to transportation improvements. These DOE-sponsored projects were also instrumental in establishing a Roadmap for distributed energy resources at the substation level, supporting the dialogue on the development of critical needs projects for emerging technology and advanced applications of energy storage, and engaging municipal governments interested in improving local electrical power for grid resilience by use of electrical storage.

FY14 Accomplishments

- **Began response to California Energy Storage Targets**
- **Finalizing contract with Green Mountain Power in Vermont for a 2MW system**

FY 2015 SNL EESDP Plans

- **Clean Energy Initiatives**
  - **California • Hawaii • Oregon**
- **Emerging ES Technologies**
  - **Testing , Analysis**
  - **Control & Optimization**
  - **Incubator Projects**

Jacquelynne Hernández

Foreward

This journal features a variety of emerging energy storage technologies and innovative applications. Each technology contributes to the goals of achieving the core mission of grid modernization for a flexible, reliable, resilient electricity delivery system.

Sandia manages the Electrical Energy Storage Demonstration and Testing projects for the United States Department of Energy Office (DOE) of Electricity Delivery and Reliability (OE). Researchers, technologists, developers, economists and other analysts use the information and data collected to advance systems applications, devices, competitive marketing structures, etc., for energy storage.

The intent of the editor for this annual report is to plot a simple, yet interesting course: historical perspective, special articles, and an inventory. The historical perspective is an evolution of the ES Demonstration program that eventually grew comprehensively enough to include a testing program that ranges from individual cells to modules to systems. The special topics are selected from the current year's investigations and also vary broadly from the formal testing protocol to an incubator project that may be commercialized to a road map and market assessment. Finally, safety guidance in the form of commissioning of systems is the final special topic.

An inventory of projects closes out the discussion. A chart summary along with a map of the projects provides a pictorial overview. The brief summary of the EESDP projects includes the technology, milestones, and FY 14 status.

Energy Storage Evolution –The Next Tactic for Demonstration Projects – D. Borneo

Simply put, the purpose of electrical energy storage is to have access to a pool of energy for a later time. The history of energy storage is as old as human history. Technology has matured from small dams and reservoirs to large-scale pumped storage hydroelectricity; from electroplating for lighting to a variety of electrochemical batteries; from short-term thermal energy storage used in air conditioning to latent phase change materials for moderating indoor conditions through interior walls; and from electromechanical flywheels for localized commercial entities to grid-scale energy storage to match supply and demand. Much of this has happened within the last four decades.

Energy storage is not unlike other investment opportunities. There is a cycle where developers try to meet social and political expectations through technology. Energy storage has followed the natural disaster and green energy cycles as have other industries. Without exception, cost and return on investment remain important determinants in the matrix of delivering a product or service to end users.

It is my opinion that the next tactic for electrical energy storage will be to treat it more as a local resource – a movement from the concept of a microgrid to a localized, community grid. That approach also suggests that investors, developers, vendors, and users may easily migrate to a perspective where they consider energy storage and its benefits in the same manner as insurance.

In general terms, insurance is an exchange payment. It transfers the risk of a loss from one party to another. The two primary risks are financial risks (an economic metric is required) and risks particular to a certain area or demographic (localized, not widespread). In this scheme, vendors are the carriers, end users the insured, and investors are the agents who are most interested in controlling risks through reasonable contracts. When energy storage users can be protected from risks for a reasonable, long or short-term fee, based on frequency and severity of less favorable conditions like blackout, poor quality power, electricity interruptions, etc., and be compensated for delivery, then the complaint or observation that "energy storage is too expensive" will become a thing of the past. Providers will have the additional burden of meeting the customers' needs as a localized, commercial enterprise, thus helping users to save money against future loss.

Special Selected Topics 2014

Advanced Energy Storage Testing

Duke Energy Substation

Flywheel Advancement

DER Roadmap

Assessment Guide

ESS Commissioning

Advanced Energy Storage Testing Projects

Sandia National Laboratories' Advanced Energy Storage Device Testing facilities include the Energy Storage Test Pad (ESTP) and the Energy Storage Analysis Laboratory (ESAL). Both represent integrated resources of the energy storage systems programs and advanced power sources research and development centers. The testing laboratories were established to provide independent third party performance and device system validation to support the U.S. Department of Energy's Office of Electricity Delivery and Reliability mission for the Energy Storage Program.

Proposals

The proposals to request testing at the ESTP or ESAL vary: DOE-sponsored projects, industry requests, and academia partnerships. DOE-sponsored projects are wholly funded through DOE funds, or they may be cost-shared with a technology developer. Results of these type projects are made public to encourage exchange of the information to be released in a case study format.

Industry-sponsored projects may be either wholly funded through private industry or some combination of government contracts external to the DOE OE. Results and data are typically proprietary in nature. Lastly, student projects are welcomed from academia. Joint research is an option; equipment and/or staff are subject to availability. An application is required to initiate all proposals. The current website is **www.sandia.gov/batterytesting/**

Safety

SNL engineers at the testing facilities perform a safety analysis as part of the commissioning of an on-site system. The safety protocol includes a Non-NRTL Inspection hazard analysis, safety system test, and thermal scanning during operation. Further, the ESTP and ESAL also partner with the Battery Abuse Testing Laboratory (BAT-Lab). Cells, modules, and system testing at one SNL electrical energy storage laboratory may also undergo concurrent safety testing at the BAT-Lab. Again, an application is required to request testing at ESTP or ESAL.

Testing capabilities at Sandia National Laboratories ES Facilities:

Battery and Cell Testers					
Name	**V max**	**I max**	**Channels**	**Aux V**	**Aux T**
Bitrode FTV	72V	1000A	2	32 Aux V (total)	32 Aux RTD (total)
Bitrode LCN	36V	100A	3	12 Aux V (per Ch)	2 Type K TC (per Ch)
Arbin	60V	500A	2	16 Aux V (total)	16 Type T (total)
Arbin BT2000	60V	200A	2 Testers 1 Channel	32 Aux V	32 Type K Tc
Bitrode LCN	36V	25A	5	18 Aux V (per Ch)	6 Type K TC (per Ch)
Arbin 16, 20A 10V with 8, 60A 10V	10V	20 or 60A	24	0	24 Type K
Arbin SCTS	10V	10A	48	24 Aux V (total)	48 Type K TC (total)
Maccor	5V	15A	8	0	16 Type T (total)
Arbin	5V	3A	48	8 Aux V (total)	8 Type T (total)

Temperature Chambers				
Name	**T Max**	**T Min**	**Size**	**# Steps**
T27s - 1.5A Tenny ('Big')	100 C	-20 C	D26" x W37.5" x H48" (0.66m x 0.95m x 1.22m)	24
T10C - 1.5 2 ea.	200 C	-73 C	D26" x W24" x H28"	256
BTC	200	-70	D19" x W20.5" x H22"	256

Chart of Capabilities

ESAL Testing

Analysis of cells to pack size modules are carried out in the ESAL.

- Cell level
- Module
- Pack level

ESTP Testing

- Scalable from 1 kW to 1 MW, 480 VAC, 3-phase
- Enables detailed independent analysis of system performance and safety
- Integrated with Distributed Energy Technologies Lab (DETL) to analyze advanced inverter functionality up to 200kW
- Grid simulation allows for precisely controlled changes in voltage, frequency, phase imbalance, and power quality
- Analysis duration is flexible to accommodate customizable testing scope

Offsite Testing

Flexible capabilities, contact us at:
www.sandia.gov/batterytesting/

Duke Rankin Energy Storage System—David Schoenwald

Project Scope

Duke Energy has installed a 402 kW/282 kWh, NaNiCl energy storage system (ESS) at their Rankin Avenue substation to mitigate photovoltaic (PV)-induced power swings. Duke has asked Sandia National Laboratories (SNL) on behalf of the Department of Energy (DOE) Energy Storage Program to collaborate with them to help further utilize their energy storage system. The goal is to optimize the use of energy storage in utility grid applications.

In this demonstration, SNL and Duke will develop control algorithms to increase the utilization of the ESS, thereby creating additional value. ESS functions that will be investigated include PV smoothing, 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.

Background Information

Duke Energy installed the Rankin Energy Storage System in February 2012 to test three technical applications: centralized solar-induced power swing mitigation, active VAR/Power Factor management, and combined Watt/VAR voltage control. The first task listed involves evaluating how a substation-scale battery that serves as a centralized energy storage system can assist with absorbing the high penetration of distributed solar on a 12.47 kV distribution circuit. The storage system is connected to the distribution circuit just outside the substation, and the 1.2 MW solar facility is approximately three miles from the substation. The installed energy storage

system is operational and uses a power-swing.

The storage system is connected to the distribution circuit just outside the substation,and the 1.2 MW solar facility is approximately three miles from the substation. The installed energy storage system is operational and uses a power-swing mitigation algorithm, developed by Duke Energy Corporation and its vendors. The chief software objective is to maintain and support distribution circuit power quality by absorbing the rapid increases and decreases of in-circuit loading caused by solar output intermittency.

The current algorithm provides charge and discharge commands to the battery based on changes in the real-power (kW) loading on the distribution circuit in an attempt to absorb any impact that the rapid solar-induced power swings may have on upstream circuit components. It is envisioned that an improved algorithm may enable the energy storage system to more efficiently mitigate the effects of solar-induced power swings on the distribution circuit. Potential improvements may include:

1. Implementing an algorithm that responds directly to voltage changes on the circuit (reactive rather than real-power);
2. Implementing an algorithm that utilizes the energy storage system's ability to absorb variable impacts to circuit loading; or
3. Implementing an algorithm that consumes reactive power in addition to maintaining its real-power capabilities.

Audience

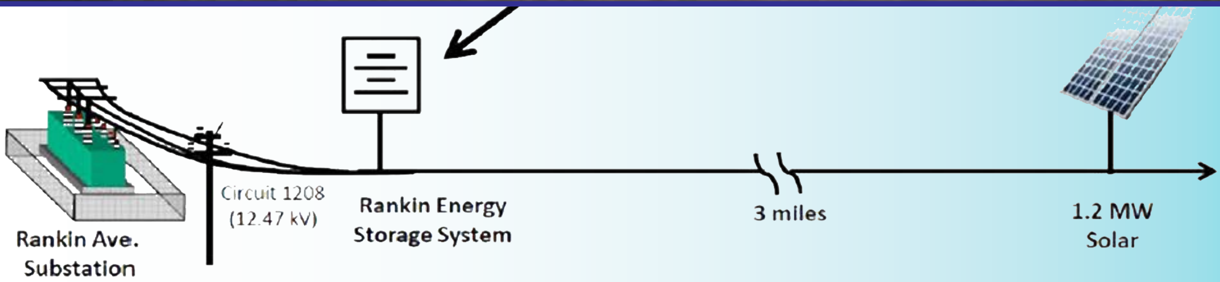
DOE/SNL in collaboration with Duke Energy Corporation will issue a technical report on the findings of this electric energy storage demonstration. DOE/SNL and Duke will also make recommendations to the electric utility industry in this report regarding lessons learned from implementation of ESS to this application. Finally, the report will also assess the costs and benefits of ESS deployment in a distribution circuit to protect assets at the substation level.

Deliverables

- Dynamic system analysis of detailed Rankin distribution circuit, including PV, ESS, and upstream load tap changers (LTC) using Cyme© distribution modeling software.
- Reduced order model of distribution circuit and substation using Matlab/Simulink and Duke provided load data to assess impact of PV on LTCs.
- ESS control algorithms to implement the improvements stated in (1)-(3) above.
- Final report on technical findings, lessons learned from implementation efforts, and cost/benefits of ESS in pursuit of the above goals.

Next Steps

Successful completion of the above deliverables could lead to additional R&D efforts to increase the value of energy storage at the distribution level. First, the formal optimization of ESS control algorithms for various applications including smoothing, voltage flicker, and reactive power/voltage control can be conducted using the modeling approaches outlined above. The Cyme model can serve as a "truth" model for evaluating the improvements in any optimization features. The Matlab/Simulink reduced order equivalent circuit provides a more tractable model for designing such optimization algorithms. Second, other ESS-based demonstrations in which the ESS is deployed differently from the Rankin ESS could benefit from the above approach. This may lead to further utilization of ESS at the distribution level.



Helix Power: *Electric Grid Ancillary Service through Advanced Flywheels*

Project Scope

Helix Power is a developer of next generation power management hardware for utility scale applications. Helix recently completed a conceptual design program with Sandia National Laboratories for a power management solution that can store or deliver 1MW of power for 90 seconds utilizing a cutting edge flywheel energy storage system capable of 1,000,000+ cycles in a lifetime. This system is ideal for applications that require 150 full charge and discharge cycles a day such as mining, train power management, grid scale UPS systems, microgrids, and renewable energy grid connection power management. Helix Power's hardware design may be used as a stand-alone system or in a hybrid system with either generation or longer duration energy storage assets

The objective of the project was to advance the conceptual design of the Helix Power system by reducing technical and programmatic risk. During the project, Helix Power focused on design improvement, strategic supplier relationships, customer relationships, and in-depth analytic approaches to the value proposition for launch applications.

Background

Helix Power is focused on a class of power management problems that are not cost effectively addressed by existing solutions. According to the president of Helix Power, Matthew Lazarewicz, "existing solutions inherently involve a tradeoff of performance with efficiency, product life, and/or O&M expenses." The Helix Power system is technically a flywheel energy storage system, but it is best described as a power management device that can significantly improve power quality. The system is designed to inject or absorb 1MW+ of rated power for 90 seconds to control power ramps for grid connected systems or isolated systems while simultaneously improving power quality. A single module will be sized to source or sink 1MW for 90 seconds and modules may be installed individually or in sets. Response time will be on the order of milliseconds and cycle life will be at least two orders of magnitude greater than batteries. Flywheels can cycle at 100% rated power, do not lose performance with time and do not need to be oversized to improve expected system life.

Energy storage is analogous to memory storage used in computers. Computer manufacturers use multiple types of memory storage including RAM (short-term), hard drives (long term/internal), thumb drives (portable), and bulk external storage (long-term/external). Most of those technologies are not economically interchangeable and users choose the optimal mix of economics and performance for their requirements. In this analogy, Helix Power provides the RAM equivalent for short-term storage that can be paired with other assets to optimize both economics and performance.

Prime applications for the Helix system require high power, short duration, and frequently cycling variations in power. These characteristics are prominent where there is a cyclic load and in isolated systems where a significant portion of the power is produced by intermittent resources. Currently, existing power infrastructure is ill-suited to such sudden, cyclic, high power demands because most generators respond too slowly to efficiently meet these load requirements and these requirements far exceed the cycle life of batteries. This type of power demand profile is both common and growing due to increasing variability of both generation and load.

On the generation side, increasing short duration variability is the inevitable result of increasing wind generation, increasing solar generation and decreasing coal generation. On the load side, increasing variability stems, in part, from an on ongoing industrial shift from induction to synchronous electric motors. Both of these trends are continuing worldwide. Helix Power hardware will provide a solution to the resulting ramping issues that can tax the efficient operating limits of existing solutions.

Technology

Modern, advanced flywheels store energy using a built-in motor/generator to spin a rotor up to very high speeds. Energy is retrieved by electronically switching the motor to operate as a generator that produces electricity as the rotor is decelerated. Currently, flywheel systems are available from a number of manufacturers but tend to cost more than competing energy storage solutions. Therefore, they are usually used in niche applications. In addition, available systems have fairly low power ratings and cannot be used cost effectively to serve high power applications. To date, flywheel power ratings have been limited, in part, as a consequence of the challenge of developing a high power motor that operates in vacuum.

The Helix module is designed to offer high power, short duration, and fast response ("HPSF").

The Helix HPSF will be able to source or sink 1MW for 90 seconds with greater than 80% round trip energy storage efficiency and steady state power losses <1% of rated power. For applications with events of this duration, the Helix module will provide the most cost effective solution. This capability gives Helix a strong competitive advantage for sudden, cyclic, high power demands.

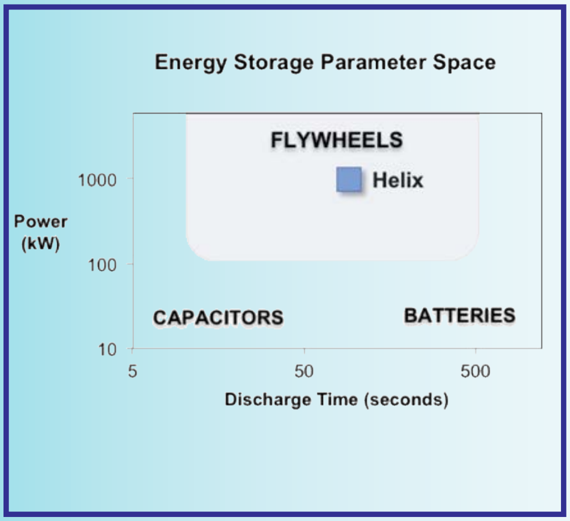
Competitive Position

Helix Power addresses power management applications that are underserved by competing technologies such as electrochemical capacitors and batteries. Electrochemical capacitors are most cost effective for applications requiring power for a few seconds or less. Batteries are most cost effective when power is required for 10 minutes or more, provided that a cycle life of a few thousand cycles or less is acceptable for the application. The discharge times of batteries are inherent in the chemistry of the device and are difficult to change. Significantly, a flywheel is an engineered system that can be designed or operated for any discharge time to meet customer specifications. Helix Power is focused on applications where batteries, electrochemical capacitors, and existing flywheels cannot provide an effective solution. Namely, high power, cyclic loads with a 90 second discharge time.

Helix Power

Helix Power: *Electric Grid Ancillary Service through Advanced Flywheels*

The shaded area in *Fig. 1* below indicates the parameter space where flywheels compete favorably with other energy storage technologies. Specifically, discharge times from several seconds to several hundred and power levels greater than 100kW.



Path to Commercialization

Helix Power is focused on developing strong customer relationships by utilizing an in-depth analytic approach for launch applications. In an effort to reduce programmatic risk, Helix Power is focused on markets that can be realized within the next five years. Helix has identified its markets with either behind the meter applications or applications collocated with an existing grid connected asset. Helix's focus on behind the meter or collocated assets reduces risk by obviating the need for new interconnection requests and involvement in ISO and RTO processes. In turn, this approach enables productive conversations with potential customers, as there are fewer hurdles to a successful installation. According to Lazarewicz, "many potential customers are currently using one piece of storage equipment where two would be more efficient and lower cost. Helix is proud of its place as a developer of high power, short term energy storage systems that deliver very high cyclic life." Helix has identified near term markets of up to $31 billion in behind the meter applications worldwide.

Stakeholder Engagement

Helix Power is actively seeking feedback from industry participants including end use customers, utilities, system integrators, transit systems, hardware manufacturers, and industry groups. The company is active in the energy storage community and has presented its plans at industry forums.

Helix Power believes that customer discovery is an iterative process requiring close communication. To that end, where possible, Helix seeks to thoroughly understand customer issues and then model the Helix Power solution for the customer. Helix is speaking directly with potential customers and providing model analysis of the impact of adding a Helix Power system. In addition, Helix is in discussions with experts within industry organizations in order to better understand the needs of their member base and facilitate new customer discussions. According to Lazarewicz, "potential customers are very pleased with Helix's analytic approach that allows them to quantify multiple value streams from the installation of Helix hardware."

Deliverables to Sandia National Laboratories

Helix Power delivered a series of reports to Sandia National Laboratories over the course of the contract and participated in a peer review. The final report delivered to Sandia National Laboratories included substantial technical, market, safety, and cost information.

Projections (future work)

Helix plans to build, test, and deploy its HPSF Flywheel over the next 18 months. Helix is currently in the process of qualifying potential suppliers and finalizing initial customer requirements.

Purpose

The purpose of this project was to design a master list of DES demonstration projects that addresses industry and market challenges for grid-scale electrical energy storage delivery systems with a focus on the distribution aspect of the electricity grid and to subsequently recommend potential demonstration projects that will advance the maturation of DES systems deployment.

Scope

DNV GL conducted a survey of representatives from EPRI, 18 utilities, 11 energy storage vendors, 8 consultants or analysts, and 2 other types of stakeholders. The results from this survey were instrumental in identifying the most valuable applications and benefits of DES, creating a Master List of DES demonstration projects addressing industry and market challenges, generating a list of highly feasible and useful DES Projects from the Master DES Projects List, identifying the technical basis for conducting the project and defining risks and solutions, then designing a method and checklist for utilities to share deployment information and practical experiences to overcome technical challenges and improve the cost-effectiveness of grid-scale DES systems.

The survey respondents consisted of representatives from EPRI, various electric utilities, Energy Storage (ES) vendors and manufacturers, consultants, analysts, the Underwriter Lab and a Public Service Commission. The survey effort was conducted in two phases; there were 45 respondents to the first survey, and 14 to the follow-up survey. In addition to the responses to the storage questions, the survey recipients were prompted to provide a list of innovative DES projects that they completed in the past three years or are planning to perform within the next three years.

It is exceedingly clear that government-funded DES projects should focus on demonstrating command and control technologies that will permit the owners and operators of DES systems to optimize the value of the multiple applications that those systems can provide to the grid. Demonstrating the maximization of the economic value of DES storage systems is the most important function that future, government-funded DES demonstration projects can serve.

More demonstration projects of existing storage technology are necessary to transition DES technology from planning and theory to reality on the grid. Future demonstration projects should focus on optimizing the economic benefits of DES systems. Enabling utilities to see specific examples of how DES systems can maximize benefits and generate an acceptable return on investment will vastly increase the potential for incenting additional voluntary utility investments in DES systems.

Special Selected Topics 2014

DES Applications

The results in this section were weighed with respect to the number of respondents from each stakeholder type. The applications labeled with an asterisk (*) were gathered from the follow-up survey, and consist of responses from six utilities, five energy storage vendors, and two consultants. The applications considered were evaluated for primary usage, where the application is the DES device dispatch priority and secondary usage, and where the application is bundled with another primary application to provide additional benefits. The primary applications ranking is presented in *Fig.7* and the secondary applications ranking is presented in *Fig. 8.*

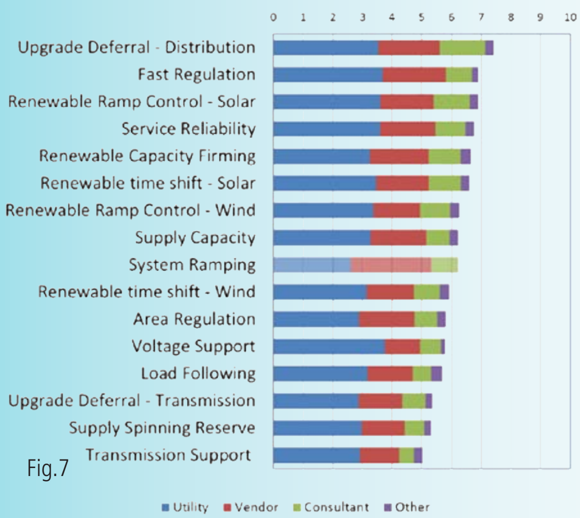


Fig.7

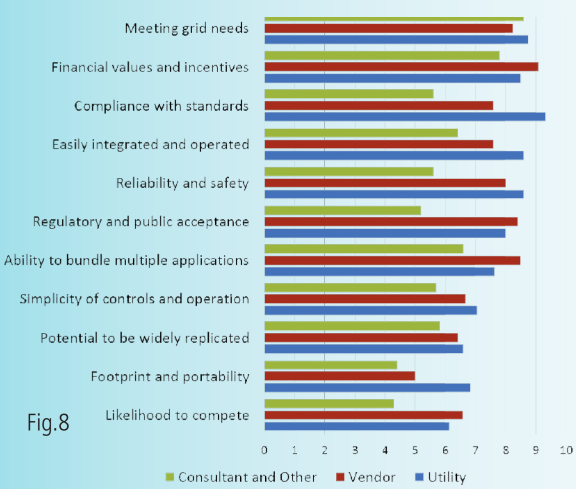


Fig.8

Drivers

Survey results suggest that meeting the grid needs and financial values and incentives of DES deployment are important drivers as seen by all stakeholders. Additionally, utilities care about DES systems compliance with standards due to the limitations a non-compliant system would pose. Ease of integration and operation, and reliability and safety are also considered important drivers. The likelihood of DES systems to compete with other technologies seemed of relatively little importance to survey respondents. Also, the potential to be widely replicated, the footprint and portability, and the simplicity of controls and operation appeared to be secondary concerns for utilities.

Analysis of Survey Results

Considering that the purpose of this study focuses on distributed energy storage systems to be deployed by utilities, the responses from the utilities, storage vendors, and other contributors were analyzed independently, and compared. Energy storage vendors' opinion could be biased towards the specific capabilities of their products. Consultants, analysts, and governmental agencies are likely unbiased in their responses. The order of importance for each item populating the charts in this section was kept the same as the aggregated results.

NAATBatt

DNV·GL

Energy Storage for the Electricity Grid & Market Place–*J. Eyer & M. Ellison*

Project Scope

The report *Energy Storage for the Electrical Grid of the 21st Century: Benefits and Market Potential – An Assessment Guide* (The Guide), is being developed by E&I Consulting for the U.S. Department of Energy (DOE) and Sandia National Laboratories (SNL). The Guide is a detailed, semi-technical reference covering a broad array of topics related to energy storage for the evolving electrical grid and future electricity marketplace.

The Guide provides an introduction to the intricacies and multifaceted nature of the electricity storage story for existing stakeholders and a growing array of new stakeholders. Primary themes addressed include 1) characterization of the storage market opportunity and business case, including market segmentation, 2) storage uses (*i.e.,* services), 3) benefits associated with storage uses, 4) storage technology characteristics, 5) a top-down market framework and estimation and 6) numerous cross-cutting themes affecting prospects and value for storage, such as Smart Grid and localized voltage and reactance management.

Genesis and Background

The Guide builds on the work from two previous reports funded by DOE/SNL which were developed before the potential for electricity storage for the grid was widely acknowledged.

The original version – the first of its kind – was published in 2003 as a resource for energy storage vendors seeking co-funding from the California Energy Commission's Public Interest Energy Research (PIER) program. The intent of that report was to enable storage technology demonstration project proposers to establish a value proposition for storage.

In 2010, an expanded and updated version of The Guide was published in response to the growing need for information regarding storage uses, benefits and potential. The report, entitled *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*, has been widely read, often cited, and it has contributed significantly to the familiarity with and understanding of opportunities for storage for the electrical grid.

During the four years since the 2010 Guide was published, interest in and focus on storage has burgeoned – driven by numerous factors, such as: 1) increased focus on renewable fuels generation whose output varies, 2) managing peak demand, 3) proliferation of modular and distributed energy resources (DERs), 4) an increasingly "smart" grid, 5) growing recognition by utility executives, engineers and regulators of the critical role storage can play in the grid and 6) accelerating storage and power electronics technology development.

As an example, California recently adopted a historic energy storage procurement target of 1.325 GW for its major utilities to be in place by the year 2020. The Guide is a timely and essential resource to facilitate development of the business case for this type of storage opportunity.

Audience

The Guide is targeted at a broad audience of storage veterans and newcomers who seek detailed introduction to the many ways that electricity storage may be used, the benefits it provides and a general indication of the market potential. Users include a rapidly expanding array of business, technical, legal, regulatory and policy stakeholders. Of particular note is the need for such information for prospective investors in storage technology and/or project development, most of whom a) are not familiar with the storage value propositions and business case and b) prefer unbiased information.

Phase I–Deliverables

Phase one of The Guide update was completed in April 2014. Deliverables provided included:

- Formed an advisory team representing the Electric Power Research Institute (EPRI), the Energy Storage Association (ESA), standards committees, electric utilities, developers of the *DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA* and other storage industry leaders.
- Updated, high-level coverage of the storage business opportunity, including drivers, trends and detailed market segmentation.
- Updated listing and characterization of individual storage uses (a.k.a. "services").
- Framework for high-level market potential estimates for individual uses.
- Enhanced characterizations of numerous storage value propositions (*i.e.*, use/benefit combinations or "use cases").
- Appendices that provide enhanced coverage of cross-cutting themes affecting or underlying the storage opportunity: voltage management, storage and Smart Grid, distributed resources, etc.

Phase II–Products Expected

The second and final phase in development of The Guide–to be completed by early 2015–is expected to include:

- An overview of storage technologies with an emphasis on storage characteristics required for specific uses, storage systems and storage cost metrics.
- Updated benefit characterizations for individual storage uses.
- Refinement of market potential estimate frame work.
- Characterizations of ten *incidental and other benefits*–listed in the table below–such as increased operational flexibility and improved generation fleet fuel efficiency and environmental performance.
- Coverage of additional important cross-cutting themes and topics (via appendices).
- Draft Report and Review
- Final Report.

Incidental and Other Benefits	
1.	Increased (GT&D) Asset Utilization
2.	Generation Dynamic Operating Benefits
3.	Reduced Generation Fossil Fuel Use
4.	Reduced Generation Air Emissions
5.	Reduced T&D I^2R Energy Losses (net)
6.	Avoided Transmission Access Charges
7.	Reduced T&D Investment Risk
8.	Power Factor Correction
9.	Flexibility (especially modular & transportable)
10.	"Real Options"

	Service	Location: Central	Location: Distributed
Electric Supply			
1.	Electric Energy Time Shift	○	**○**
2.	Electric Supply Capacity	○	**○**
Grid Operations (a.k.a. Ancillary Services)			
3.	Frequency Regulation - Conventional and Fast	○	○
4.	Frequency Response	○	○
5.	Balancing	**○**	**○**
6.	Load Following	○	**○**
7.	Ramping	○	**○**
8.	Electric Supply Reserve Capacity (3 types)	○	○
9.	Voltage Support	**○**[1]	●[1]
10.	Black Start	**○**	**○**
11.	Synthetic Inertia	○	○
Grid Infrastructure (T&D)			
12.	Transmission Support	●[3]	●[3]
13.	Power Factor Correction	--	●
14.	Volt/VAR Optimization and Control (VVOC)	--	●[1,3]
15.	Avoid Current Backflow	--	●[2,3]
16.	Transmission and Distribution Capacity	●[2,3]	●[2,3]
17.	Transmission and Distribution Upgrade Deferral	--	●[2,3]
18.	Transmission and Distribution Life Extension	--	●[2,3]
19.	Transmission Congestion Management	●[2,3]	●[2,3]
End User			
20.	Time of Use Energy Cost Management	--	●
21.	Demand Charge Management	--	●
22.	Electric Service Reliability	--	●[3]
23.	Electric Service Power Quality	--	●[3]

Location limited or no importance	○
Location *may* be important	**○**
Location somewhat or very important	●

Notes
1. Best if located near the most troublesome loads during voltage emergencies
2. Must be located at or (electrically) downstream from "hot spots"
3. Value is especially situation specific.

ES Commissioning– *Jacquelynne Hernández and Daniel R. Borneo*

Abstract

Sandia National Laboratories offers this document on start-up and commissioning to serve as guidance through the use of tools like checklists, flow diagrams, non-compliance protocols, and gated certificates. The value of the start-up process relates to failure mode avoidance for interruptions, outages, or unscheduled downtime. Commissioning electromechanical installations is important because it supports quality engineering activities designed to achieve, verify, and document that the performance of a device, equipment, facility or system, and all associated assemblies meet defined criteria and objectives. Not all energy storage systems are the same, so the broad process presented along with some implements suggested will require modifications to fit the design intent and purchase specifications of any particular system such that an installed electrical energy storage system (ESS) can operate as part of an efficient, fully integrated system for the end users.

Understanding the equipment or facility owner's overall decision priority for a project design is the critical element in commissioning any system. The priority can be any of several considerations like cost, reliability, return on investment, customer use, impact on industry, etc. The priorities tend to help focus commissioning activities into areas that meet the owner's needs. More importantly, though, understanding the owner's priorities both defines acceptance criteria for evaluating compliance with design intent and helps to determine which verification checks and functional tests need to be performed.

Coordinating a versatile team is an early indicator of a successful commissioning process. For it is that team that is responsible for understanding design specifications, evaluating manufacturer cut sheets, for field work, verifying installation instructions, assessing adherence to standards and codes, conducting tests according to project-specific test procedures, and determining acceptance criteria to assure that the device, equipment, or facility operates in an integrated manner according to design. For an Electrical Energy Storage System (ESS), the primary start-up and commissioning goal is to verify that the system has been installed and is working as specified by protocols.

Protocols for commissioning an ESS should minimally include functional tests and verification of the ESS interface with installed equipment, subsystems and systems. Historically, other important commissioning elements involve operational control panels, hardware and software monitoring, and equipment controls that specify time of day, voltage, amperage, current, state of charge, cycling behavior, temperature, heat dissipation, etc. The type, size and complexity of the system matters when verification procedures are drafted for both start-up and commissioning.

A final report is the instrument used to document in detail the complete start-up and commissioning process for the ESS. It should include a project summary, all findings and recommendations, and copies of all completed verification checks and tests performed. Before formal turnover, signature forms are usually required along with the final set of commissioning sequences of operations.

Current EESDP Projects & Status Report

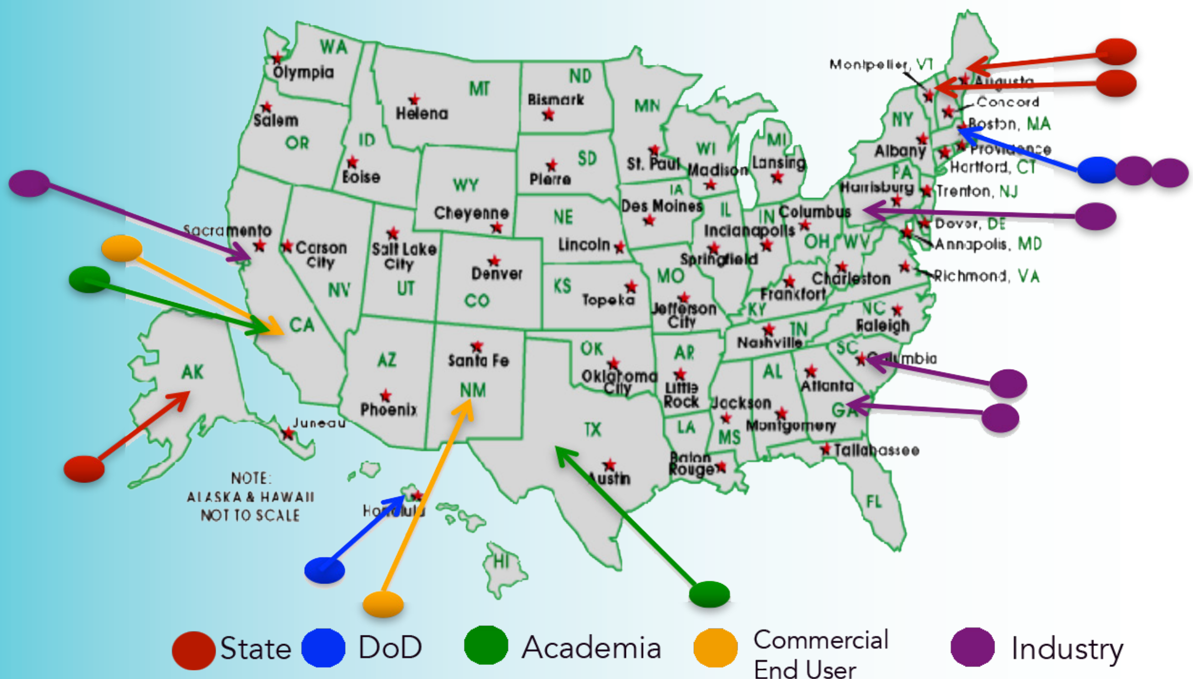
CESA

Military Collaborations

Demos & Installations

Critical Needs Projects

Current EESDP Projects



States are rapidly discovering the value of energy storage and are acting accordingly through updated policy and regulations. SNL's projects with states increase awareness of value and return on investment (ROI) of energy storage installations. These projects illustrate the successful deployment of energy storage systems in varying settings, with the goal to improve confidence in safety, reliability, performance and cost effectiveness.

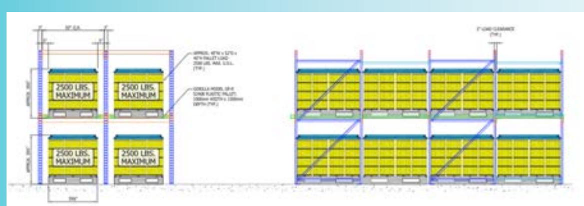
Partner	ES Vendor	System	Size	Location	Milestone	Application
PM-FSS	Milspray, Princeton, Ktech, GS Yuasa, Earl,	Milspray 15kW 2hr LA PP – 100kW 40min Li-ion; Ktech – 10kW 4hr RedFlow zinc GS – 70KVA 1hr VRLA; Earl – 100kW 40min Li-ion;		BCIL	To ESTP: Mil – 1/13 PP – 3/13 Ktech – 3/13 GS – 7/13	Military Forward Operating Base Microgrid Generator fuel reduction
UCSD	TBD	3-5 systems will be selected	3.6MW 2hr	UCSD Campus	TBD	Campus Microgrid (with PV) support
SunPower/DNV-KEMA/UCSD	ZBB	ZnBr	125kW 4hr	UCSD	Startup 6/13	PV W/ES performance and economic value
Kodiak Electric/Alaska Energy Auth/Alaska energy	Xtreme power	XP lead acid	3MW 15 min	Kodiak, AL	Operational 12/12	9 MW wind support
ERDC-CERL/SPIDERS	ZBB	ZnBr	125kW 4hr	Pearl Harbor Hickam	12/12	Microgrid support
DUKE	Fiamm	NaNiCL Zebra	400kW 40min	Rankin site	Operational	PV smoothing
Texas Tech/SNL	Xtreme Power	Samsung Li-ion	1MW 1MWh	Reese Wind Site (SNL Wind Facility)	6/13	Wind support
Aquion/Pennsylvania Dept. of Energy	Aquion	Aqueous Sodium	50-100kW 1hr	Pittsburgh Facility	9/13	Grid connection
Mesa del Sol/NEDO/PNM	East Penn	Lead Acid	500kW 40 min 250kW 2hr	Mesa del Sol	9/2011	PV smoothing and energy shift
Connecticut Dept. of Energy	TBD	TBD	TBD	Connecticut	TBD	Energy Storage on Emergency Microgrid
Vermont Energy/GMP	TBD	Lead Acid/Li-ion	2MW 1MWh – Li-ion; 2.4MWh LA	Vermont	FY2014	Energy Storage w/ I microgrid

Current EESDP Projects

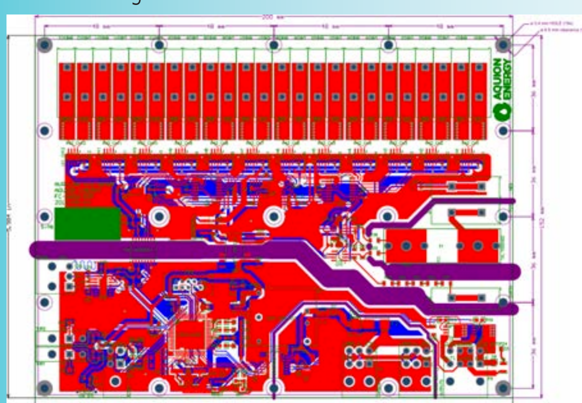
Aquion Energy
Project Description:
Aquion is taking their prototype designed and built under the ARRA program to the next step of building a 50-100kW/1hr aqueous battery and outfitting it with the newest version of the battery. This is a precursor to their eventual full-scale 1M/1hr ES demonstration 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.

FY14 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 in February 2014.

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 adaption, 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.

Project Status:
- Connecticut Department of Energy is in the process of issuing the second RFP for energy projects. Sandia is working with them to include language soliciting for energy storage.
- Both Oregon and New Mexico are interested in having a meeting similar to the Vermont Meeting during which we will be able to explain energy storage.

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 will work 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 are working with Kodiak Electric in data collection.

Base Camp Integration Lab (BCIL) Energy Storage Demonstration
Project Description:
DOE-OE/Sandia is collaborating with Army Program Manager 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. Five ES vendors will conduct Demonstrations at first Sandia National Labs and second, if meritorious, at BCIL's test forward operating base located at Ft. Devens, Ma. The five vendors include: *Milspray – 15kW/79kWh; Deeka 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; and GS Yuasa – 70KkVA 100kWh VRLA; to SNL 6/13*

Key Project Events / Milestones:

- Complete 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.
- Create carbon copy of BCIL microgrid at Sandia ESTP to determine energy storage fuel savings.
- Complete testing and release the report by Q2/FY14.

Project Status:

- SAND report in Review and Approval for predicted fuel savings using the energy storage systems Sandia is testing if incorporated into the BCIL electrical system.
- Milspray, Princeton Power, Raytheon and GS/YUASA energy storage systems have completed functional test and report finished and publicly available.
- BCIL does not have the controls in place that would optimize the ES. Sandia ESTP has received 3 60kW TQG generators from PM FSS that will be controlled by Sandia PLC to control the energy storage in a way that maximizes fuel savings. This will be completed by the GS/YUASA energy storage system, which will then be shipped to the BCIL for a final testing phase.

Pearl Harbor/ Hickam (SPIDERS)

Project Description:

The first SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability and Security) microgrid was implemented at Joint Base Pearl Harbor Hickam in Honolulu; it takes advantage of several existing generation assets, including a 146-kW photovoltaic solar power system and up to 50 kW of wind power. This project will support Concurrent Technologies Corporation (CTC) in conducting an analysis of the system and issuing a report of findings concerning the operation of the ES system in a microgrid application.

Key Project Events / Milestones:

- ZBB system operational – 12/2012.
- Provide technical and project management support to define, develop, and implement solution to solve system's control problem. Implement fix and commission system by end of Q1/FY14.

Project Status:

- While the ZBB system is operational, it is not being utilized on the microgrid due to a problem in the control between the ZBB unit and the microgrid. ESS will run in normal mode until we can prove the reliability of the ESS.

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 (Rpt #: SAND2013-8848C) – 10/2013.

Project Status:

- Modeling of feeder circuit with PV underway using Cyme© distribution modeling software.
- Metrics for evaluation of ESS performance in mitigating PV fluctuations developed.

Texas Tech Reese Wind Site

Project Description:

Sandia, as part of its ongoing R&D efforts with Texas Tech University, is installing approximately 900kW of wind power at the Reese test site located on the campus. As part of this program, DOE, under the ARRA award, has provided ~$1.7M to TTU to install an Energy storage system. The system will not only be tied to the SNL site but to additional substations and wind turbines. DOE/SNL will utilize this test facility to conduct R&D in the operation and control of ES in Wind power applications.

Key Project Events / Milestones:

- Installation of three ea. 300kW wind turbine is in process. Est. completion date - 3/2013.
- RFP issued and awarded to Xtreme Power who will provide a 1MW/1hour Li-ion system.

Project Status:

- System installed and being commissioned
- Met with Group NIRE (Project developer) and Sandia Wind group to determine what services we can provide that will further the DOE/SNL mission. Sandia will collaborate on this work with DNV-GL (KEMA), as they have funding from the state to support this project.

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 project is looking 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 in the following areas.

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.

Current EESDP Projects

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 will be 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:

- PNM needs to verify SNL visual basic code for replaying PV and genset data into the battery energy storage system.
- SNL and PNM will run coordinated/uncoordinated control for moderate and high PV variability days once VB code is functional.

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/Fy13.
- 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:

Starting from FY2011, a memorandum of understanding (MOU) between DOE and NYSERDA established a collaboration to provide support from DOE (Sandia National Labs) to help NYSERDA demonstrate electric energy storage to be 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. There are four demonstration sites that this work covers.

Key Project Events / Milestones:

- Long Island MTA battery decommissioned.
- Beacon Flywheel system in operation in Stephentown, NY.
- 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.
- Stephentown, NY: Beacon Flywheel System --Data collection underway.
- 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.

Electrical Energy Storage System (ESS): NATTBAT RoadMap

Project Description:

The National Alliance for Advanced Technology Batteries (NAATBatt) is a trade organization for advanced battery manufacturers, vendors, and related supply-chain partners that is uniquely situated to conduct a series of purposed meetings that will serve as a catalyst in the development of a roadmap to advance Distributed Energy Storage (DES) technology for practical, cost-effective applications to the distribution segment of the electricity grid.

Key Project Events / Milestones:

- Identify applications and benefits of DES systems that are likely to provide the greatest value;
- Survey Electric Power Research Institute (EPRI), at least 9 progressive utilities and leading storage system manufacturers and systems integrators to develop a master list of demonstration projects that address stated industry and market challenges with a focus on the distribution aspect of the electricity grid;
- Establish from the master list a subset of viable projects that will serve to advance knowledge and utility experience in deploying and operating electrical energy storage systems (ESS);
- Design a method and format for utilities to share deployment information and experiences.

Project Status/Deliverables:

- Summary Focus and Methodology for Distributed Energy Storage (DES) systems Roadmap for local electric utilities.
- Final DES Roadmap with all seven (7) elements of the project tasks completed 2014.

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:

- Comprehensive Scope of Work.
- HPSF Flywheel Market Analysis.

Electrical Energy Storage Demonstration Program / 2014 Benefits & Market Report

Project Status:

The report entitled "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide–SAND2010-0815" (The Guide) published by the U.S. Department of Energy (DOE) and Sandia National Laboratories (Sandia) has been a seminal document for the electrical energy storage industry. The Guide is often cited by professionals and industry subject matter experts and provides important bases for technology and energy storage project developers establishing and evaluating numerous electricity storage value propositions.

Since publication, a number of well-informed stakeholders have identified important updates and additions that are required in order to ensure that the document reflects current knowledge and remains consistent with other important, storage-related resources and evaluation frameworks. The updated Guide is the subject of this contract and represents the first revision of the original report issued in 2003.

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:

- Contract with CESA completed.

The Upcoming 2015 Energy Storage Demonstration Projects Include:

2015 Updates

- **Vermont/ Green Mountain Power**
- **Duke Energy Substation Analytics**
- **Texas Tech & Wind Energy Project**
- **ZBB & Manufacturability Report**
- **FY15-16 Plans**

Work with state and municipal governments to improve grid resilience with energy storage, e.g. NJ, NY, MA

Optimize and increase safe energy storage deployments and resulting ROI in varying application spaces

Alaska, Hawaii, California Critical Energy Storage Needs Initiatives

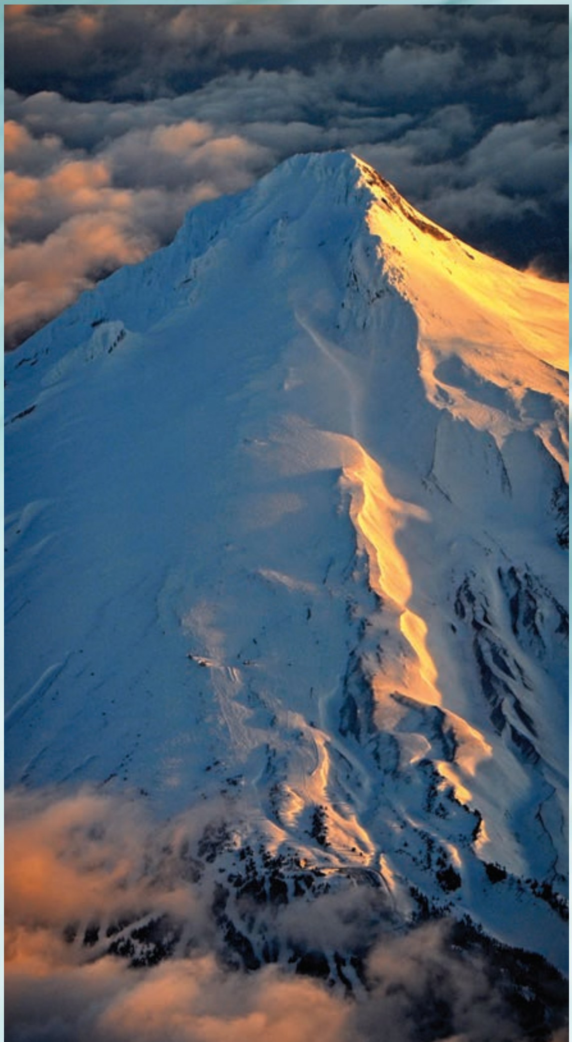


Photo by Jacquelynne Hernández

Sandia National Laboratories