Electrical Energy Storage Projects, Applications & Research Challenges for Grid Support

Daniel Borneo, P.E.

Presentation for
NM Energy, Minerals & Natural Resources Department

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AGENDA –

Presentation Outline

- Sandia’s Energy Storage Program
- Energy Storage Industry
  - Grid Problems Mitigated by Energy Storage
  - Projects and Applications
  - Summary – Challenges and Gaps
Innovation: Something to Consider

One of the first gasoline powered cars ~1891 by Henry Nadig of Allentown, Pa.

Innovation: Something to Consider

Quotes about the Nadig in 1891*

- Blasted as a “dangerous device” – backfiring caused FIRES!
- Car not allowed on the streets during the day as it “frightened” the horses
- Constable served notice; drivers/operators could be arrested, held liable for creating a “public nuisance”
- “Shouts of ‘Get a horse!’ were followed by the grand insult of the day - “Flying Cabbages” that were thrown at the hapless Nadig.”

* Whelan, Frank “Did Auto Age First Dawn in the Valley? Allentown Mechanic Built One of Country’s First Gas-powered Cars” Sept, 14, 1989 The Morning Call
DOE/Sandia’s Energy Storage Mission

DOE Office of Electricity (OE) drives electric grid modernization for the nation’s energy infrastructure, and Sandia National Laboratories (SNL) manages the majority of OE’s Stationary Energy Storage program. SNL accomplishes this mission through R&D, applied engineering, analysis, testing & demonstrations and partnering with Industry and academia.
Energy storage is an enabling technology that:
1. Improves grid efficiency
2. Improves grid reliability and resilience

DOE - Identified Key Challenges:
1. Lifetime return on investment (cost / performance)
2. Validated Reliability and Safety
3. Regulatory environment
4. Market acceptance
Five Sandia Thrust Areas to Meet Grid Challenges

- **Materials and Systems Development**
  - Leading the development of next-generation technologies
  - Improving current technology (flow batteries, flywheels, etc.)

- **Power Electronics**
  - Developing and testing new wide-bandgap power-electronic devices

- **ES Systems Demonstrations and Testing**
  - Laboratory testing and analysis from individual cells to 1MW systems
  - Field deployments
  - State-Initiated Demonstration Project Development

- **Grid Analytics and Policy**
  - Providing assessments of the impact of storage placement

- **Outreach** - Leading publications and meetings to help educate the Grid Energy community
Materials and Systems R&D

Improving the cost, performance and reliability of energy storage systems.

Near term – *Improvement* of existing energy storage technologies:

- Flow Batteries (separators, electrolytes, etc.)
- Flywheels (Carbon composites, new lift magnets)
- New Capacitor materials

Longer term – *Revolutionary* new energy storage systems:

- Nitrogen - air batteries (high energy density)
- Sodium-iodide batteries (low cost)
Power Electronics

Use of wide bandgap semiconductor devices, advanced topologies, and controls significantly reduce installed cost and footprint, improve control capability, and increase reliability of ES devices and equipment.

\[ P_{\text{dis}} = 200 \text{ W}, \quad \text{Max Temperature} = 166 ^\circ \text{ C} \]

Recent Recognition
- Four R&D100 Awards
- Three U.S. Patents
- Over 40 technical publications
- DR. Stan Atcitty received Presidential Early Career Award for Scientists and Engineers
Demonstrations and Testing

Assist the Industry in determining how to maximize return on investment (ROI). These projects help to ensure ROI and facilitate adoption via improving confidence in safety, reliability, system performance and cost-effectiveness.

Two Pronged Approach

**Energy Storage Test Pad (ESTP)** – 1MW test pad at SNL used to test and evaluate the safety, reliability and performance of ES systems.

**Battery Test Lab** – Battery Cell and module testing for safety and performance.

**Field Demonstrations** - Assist in the selection, installation, optimization and performance analysis of ES systems while providing verified technical and economic evaluations of technologies.

**CESA-ESTAP Program** — Work with State Energy Offices to advance the use of Energy Storage though state led initiatives.
<table>
<thead>
<tr>
<th>SNL Industry Collaborations</th>
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<tr>
<td><strong>Beacon Power</strong></td>
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<td><strong>SunEdison</strong></td>
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<td><strong>Arkansas Power Electronics International</strong></td>
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<td><strong>Southern Company</strong></td>
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<td><strong>Green Mountain Power, Vermont Dept. Of Energy</strong></td>
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<td><strong>Connecticut, Massachusetts, New York, New Jersey, Maryland, Vermont</strong></td>
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<td><strong>Aquion Energy, SustainX, SEE0, EnerVault, Primus Power.</strong></td>
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<td><strong>Kodiak Electric Association (KEA)</strong></td>
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<td><strong>DoD</strong></td>
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<td><strong>Duke Energy, Fiamm</strong></td>
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<td><strong>PNM, NEDO, MDS, East Penn</strong></td>
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<td><strong>CPUC, SunPower/DNV-KEMA/UCSD, ICE</strong></td>
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<td>University</td>
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<td>Colorado School of Mines University of Maryland</td>
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<td>Oregon State University</td>
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<td>Iowa State University</td>
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<td>University of California San Diego</td>
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<td>The State University of New York</td>
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<td>Arizona State University Iowa State University</td>
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<td>University of California/Los Angeles; Drexel University</td>
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<td>Texas Tech University</td>
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Grid Analytics and Policy

Motivation

• Determine where and how to implement storage with the greatest benefits to the utilities, regulators and consumers, e.g. grid resilience, frequency regulation, peak shifting
• Explore grid-level storage cost effectiveness in actual markets:
  • Evaluate impact to the delivered cost of electricity, especially with projected increases in renewable deployment;
  • Study pumped-storage hydro, flywheels, and batteries as well as combinations of these options.

Recent Accomplishments

• Published 5 reports – two on a new wholesale market design, and three storage valuation studies (on Maui, NV Energy, and Southern Company).
  • Maui study provided additional evidence that storage ameliorates wind curtailment and is an economic option
  • NV Energy study showed that new storage deployments can be cost effective when pay-for-performance is enacted.
Outreach

- **Electrical Energy Storage Applications and Technology Conference (EESAT)**
  - The international conference disseminates the latest advances in storage technology, analytic and economic methods and demonstrations

- **DOE Online Energy Storage Database**
  - Disseminates project information on active energy storage projects worldwide. energystorageexchange.org

- **Handbook**
What Problems Can ES Help Alleviate?
Electrical Energy Storage

Overview

- Electrical Energy storage decouples generation from demand:
  - Adds **reliability** to the nation’s electricity power grid
    - The lights are on when you flip the switch, even in an emergency
  - Electrical energy storage makes **renewable energy resources more dispatchable**
  - Electrical energy storage can support an **aging** or **overloaded** grid
  - Energy storage faces unique **technical and market challenges**:  
    - Nascent industry
    - Reliability of systems
    - Cost of systems
    - Regulatory polices
## Energy Storage Applications

<table>
<thead>
<tr>
<th>POWER</th>
<th>ENERGY</th>
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<tbody>
<tr>
<td><strong>LOAD</strong></td>
<td><strong>ENERGY</strong></td>
</tr>
<tr>
<td>PQ, Digital Reliability, UPS</td>
<td>Peak Shaving, Load Shifting</td>
</tr>
<tr>
<td>Spinning Reserve/Load Following, UPS</td>
<td>Time of Use Arbitrage, Upgrade Deferral</td>
</tr>
<tr>
<td>Voltage Support, Transients, Regulation</td>
<td>T&amp;D Congestion Mitigation, Time of Use Arbitrage, Upgrade Deferral</td>
</tr>
<tr>
<td>seconds</td>
<td>minutes</td>
</tr>
<tr>
<td>minutes</td>
<td>hours</td>
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</tbody>
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**POWER (<15min)**
- PQ, Digital Reliability, UPS
- Spinning Reserve/Load Following, UPS

**ENERGY (>1hr)**
- Peak Shaving, Load Shifting
- Time of Use Arbitrage, Upgrade Deferral
Role Electrical Energy Storage On the Electricity Grid

Bulk Storage

Ancillary Services

Distributed Storage

Residential Storage

Industrial Storage

Commercial Storage

ESA Basics of Energy Storage Workshop
2011/ SNL-EPRI
BPA Generation and Load Profile

Based on 5-min readings from the BPA SCADA system for points 45583, 79687, 79682, and 79685
Balancing Authority Load in Red, Wind Gen. in Green, Hydro Gen. in Blue, and Thermal Gen. in Brown
Click chart for installed capacity info
BPA Technical Operations (TOT-OpInfo@bpa.gov)
Variable Energy Resources Create More Demand for Balancing

Wind

Solar

Bonneville Power: Wind data for one month
- Power range >1200 MW
- Fluctuations for 5 minute and 6 hour time frames

Typical daily solar power output pattern
- Fluctuations can be >80% rated power in 5 minutes
- Can continuously fluctuate on partially cloudy days

Renewables need all three time scales of storage
Fast Response: Speed Matters

Significance of ES Contribution
Generators are slower than load changes

ES Attributes
- Storage has a near instantaneous response
- Only need enough for gen to catch up
- Works with slower, more efficient generators
- Helps firm variable generation like wind & solar

Storage for Load/Power balancing is new state of the art
Storage Applications – Load Leveling

Ameren: Taum Sauk, Missouri
440MW re-commissioned May, 2010

Arbitrage has difficult economics today
Microgrid Applications – i.e. Disconnected Distribution Line

Microgrid Network

Utility Power Grid

Switch

Power Electronics

Wind Turbines

Industrial User

Power Electronics

Micro turbines

Power Electronics

Commercial User

Power Electronics

Energy Storage

Gen sets

Residential User

Power Electronics

PV Array
Major outages can last for 5-7 days in some disasters; but backup systems are not commonly designed for that type of duration.
Is Storage Expensive?
(The Ugly Truth)

$/kW?  What is in the “kW”?
Total System Cost?
Life Cycle Cost?
Balance of Plant Cost?
Installation Cost?
Replacement Cost?
Disposal Cost?

$/kWh?  What is in the “kWh”?
Environmental conditions?
System losses?
KWh Stored?
KWh Delivered?
Number of cycles?
Cost of operations?
Maintenance Cost?

Cost metric must include a variety of important elements.
Several Available Storage Varieties/Options

<table>
<thead>
<tr>
<th>Type</th>
<th>Storage Mechanism</th>
<th>Common Duration</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitor</td>
<td>Electrical charge</td>
<td>Seconds (minutes)</td>
<td>100,000’s</td>
</tr>
<tr>
<td>Flywheel</td>
<td>Kinetic energy</td>
<td>Seconds / Minutes</td>
<td>1000’s - 100,000’s</td>
</tr>
<tr>
<td>Battery</td>
<td>Electro-chemical</td>
<td>Minutes (hours)</td>
<td>100’s-1000’s</td>
</tr>
<tr>
<td>Pumped Hydro</td>
<td>Potential energy</td>
<td>Hours</td>
<td>1000’s</td>
</tr>
<tr>
<td>Thermal</td>
<td>Ice, Molten Salts</td>
<td>Hours</td>
<td>1000’s</td>
</tr>
</tbody>
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World-Wide Energy Storage Projects
What’s happening in the Industry -
(www.energystorageexchange.org)
Mesa del Sol PV Output Smoothing Demonstration Project

- Goal: Smooth 500 kW PV output with distributed resources (i.e., natural gas gen set, battery, and fuel cell)
  - Sandia has optimized a PV smoothing control algorithm to minimize power output variability and battery use.
  - Field demonstration began in the summer of 2013.
PNM Prosperity Project

Evening Peak Shaving & Simultaneous Smoothing

Blue: PV Output
Yellow: Battery Output
Red: Primary Meter
New Energy and Industrial Technology Development Organization (NEDO) has commissioned a Demonstration Project in Los Alamos County, New Mexico (USA):

- 800 kW/1-hr Lead Acid Battery (VRLA)
- 500-kVA PCS for storage batteries.
  - two circuits of DC/DC converters that can be connected to storage batteries and photovoltaic cells.

Demonstration of suppressing short-term output fluctuations in photovoltaic power generation through the charging and discharging of lead-acid batteries. More information at:

http://www.hitachi.com/New/cnews/1209...
1.2-MW photovoltaic (PV) power plant in Lanai, Hawaii

- Operating since December 2009 on a 5 MW grid
- An interconnection study concluded that PV output ramps had the potential to negatively impact system frequency.
- System output curtailed to 50%

- In 2011, a 1.5MW 40 min energy storage system was installed and allowed the PV system to operate at rated output.
Kodiak - System Modeling & Simulation

**BACKGROUND**

Kodiak Electric Association, Inc. (KEA) is a rural electric cooperative located in Kodiak, Alaska. Generation comes from a mix of hydroelectric turbines, diesel generators and wind turbines. An XP 3MW 0.25h LA ESS was installed to mitigate the variability of the 9MW wind system.

Enhance system frequency and voltage stability.
Laurel Mountain Energy Storage Project

- The 32 MW 0.25hr Li-ion ES system is a fully-integrated portion of the Laurel Mountain Wind Farm developed by AES Wind.
- Provides frequency regulation in the PJM market and ramp rate control for wind variability.
- Operational Q3 of 2011.

Location
Belington, West Virginia (PJM)

With 150 MW of resources online, AES Energy Storage operates the largest fleet of battery-based storage assets in commercial operation today.
Sacramento Municipal Utility District (SMUD) piloted both residential energy storage (RES) units and community energy storage (CES) systems in Anatolia. Thus far, the research team has installed 15 RES units in the garages of volunteers.

In February 2012, the team planned to set up three additional CES systems in the neighborhood with each CES connected to the pad-mounted transformers on distribution feeders – all sized to work with the group of homes serviced by each transformer. These are about three times larger than the residential units, but can be shared between five to ten homes.

SMUD pioneered this technology as part of the Photovoltaic (PV) and Smart Grid Pilot project, which was funded by the SunShot Initiative of the U.S. Department of Energy (DOE), the American Recovery and Reinvestment Act of 2009 (ARRA), and industry partners. The utility company also planned to develop two-way communication capabilities and analyzing production characteristics of distributed PV systems (with a $5.96 million award; $4.3 million from DOE and $1.66 million from SMUD and partners).
Grid-Connected, Long Duration Energy Storage

EnerVault - Fe-Cr Redox Flow Battery 1 MW-hr$_{AC}$

- DOE ARRA Storage and CEC funding
- Began commissioning January 2014
- Co-located with a PV solar system driving water pumping at an almond farm in Turlock, CA

Largest Iron-Chromium Redox Flow Battery Installed Globally

- EnerVault - 250 kW$_{AC}$, 4-hour Iron Chrome
- Inherently safe system design based on NASA science
- Grid-scale EnerVault systems advertised to meet DOE cost targets and deliver 4-12 hrs of energy
EaglePicher Demonstration
Joplin, Missouri

- EPT’s PowerPyramid™ hybrid energy storage
  - 1 MW/2 hr ES
  - Consists of three systems:
    - Li-ion, tubular Pb-Acid and AGM Pb-Acid
    - Peak Shaving and UPS

View real-time operational statistics and monitoring at: www.eptpowerpyramid.com

- Multiple energy inputs and storage tiers housed in 4 - 40 foot containers
  - Tier #1 provides rapid response to short duration load changes and high cycle count
  - Tier #2 can provide medium-duration load support for longer duration load fluctuation and Medium cycle count
  - Tier #3 can provide long-duration load support for extended load fluctuations and low cycle count
Closing Technical & Economic Gaps

Key ES Challenging Questions

• How do we **design** and **correctly** size Energy Storage Systems?

• How do we **utilize and control** ES so the system performs multiple functions to get the most value for the least cost?

• ES is like a life insurance policy: **term life** - no value until a disaster hits; or **whole life** – you can utilize the assets (for a price). What capability can be built into an ESS to access the service during normal operation and in emergency? **How do you monetize that capability?**
Thank You and a mention of SNL Sponsor – DOE/OE - Grid Energy Storage program managed by Dr. Gyuk

Questions?

Contact Information:
Dan Borneo - drborne@sandia.gov
2014 Call:

The database will be open for FAST-Track Proposals. These should be limited in scope and have strong justification for expedited processing.

Contact: Summer Ferreira srferre@sandia.gov or David Rose dmrose@sandia.gov
Resources

- www.cleanenergystates.org/projects/energy-storage-technology-advancement-partnership/

- www.electricitystorage.org

- http://energy.gov/oe/services/electricity-advisory-committee-eac