Energy Storage Systems Analysis Laboratory – ESTP Operations and Results

9/24/2015    David Rosewater, Summer Ferreira, Roy Lopez, Jacquelynne Hernandez, Lana Kimmel
Project Overview: Purpose

- **Industry Acceptance:** There is significant uncertainty about how storage technology will be used in practice and how new storage technologies will perform over time in applications. Currently, systems operators have limited experience using deployed storage resources; stakeholder input suggests that development of algorithms to employ storage technology effectively and profitably could encourage investments.

“Industry adoption requires that they have confidence storage will deploy as expected, perform and deliver as predicted and promised.” - Energy Storage Strategic Goal

Project Overview: Infrastructure
The Energy Storage Systems Analysis Laboratory (ESSAL)

Providing reliable, independent, third party analysis and verification of advanced energy technologies for cell to MW systems

Cells and Modules

72V 1000A Bitrode (2 Channels)
Cell, Battery and Module Analysis
• 14 channels from 36 V, 25 A to 72 V, 1000 A for battery to module performance analysis
• Over 125 channels; 0 V to 10 V, 3 A to 100+ A for cell performance analysis
• Potentiostat/galvanostats for spectral impedance
• Multimeters, shunts and power supply for high precision testing
• Temperature chambers

Energy Storage Test Pad (ESTP)
• Scalable from 5 KW to 1 MW, 480 VAC, 3 phase
• 1 MW/1 MVAR load bank for either parallel microgrid, or series UPS operations
• Subcycle metering in feeder breakers for system identification and transient analysis
• Thermal imaging

System Safety Analysis (new)

Fully Integrated Systems

Lab Analysis

Field Analysis (new)

Remote Data Acquisition System (RDAS)
• Portable, Modular, Remotely Reconfigurable, and outdoor-ready
• Subcycle metering
• Tractable calibration
• Command Signal Ready for Grid Operator Simulation
• No control over grid conditions
Project Overview: Scope (Jet Analogy)

Activity

Cells and Module Analysis
- Adjustable Environmental Conditions
- Control Signals and
- Components need to perform reliably

System Laboratory Analysis
- Adjustable Grid Conditions
- Simulated Control Signals
- Components need to perform reliably

Demonstration and Field Analysis
- Real World Grid and Environmental Conditions
- Real World Control Signals
- Interconnection Requirements
- Maintenance

Spectrum of Sandia Stationary Storage Activities

- Advance Materials Laboratory research
- Laboratory/bench-scale research in materials, chemical physics, and electrochemistry
- Systems testing at DETL and ESTP
- Demonstration projects:
  - Clean Energy States Alliance: ES technology advancement project
  - U.S. Army: Ft. Devens Support for 10 nationwide ARRA projects
- Regulatory policy analysis
- CINT nanoscale energetic material research
- Modeling/simulation of ES materials at the molecular level
- Storage component development, fabrication, and testing
- Power electronics development and testing
- Grid modeling and simulation
- Market structure analysis

Range of the ESSAL

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By Robert Nyman, Miami airport - Bogotá, Colombia, May 2013
FY15 Accomplishments

Publications


FY15 Accomplishments

Projects

Installation of the Raytheon RK10 at ESSAL

UET system in Washington (rendering)

Installation of TransPower Grid Saver at ESSAL

Installation of TransPower Grid Saver at ESSAL

String E (top) and D (bottom) in GridSaver

String F in GridSaver
Results: Review of the DOE Protocol for Frequency Regulation

- 24 hour duty-cycle
- 12, two-hour sections
- 10, representative “average”
- 2, representative “aggressive”
Results: Review of the DOE Protocol for Frequency Regulation

- Comment 1: 24 hour profile is very difficult to apply to a prototype system for all the reasons discussed in the best practices for safe operations
- Comment 2: 2 hour profile generates half the data in 1/12 the time and so can be very useful
Results: Review of the DOE Protocol for Frequency Regulation

Metrics
- Sum of squared error
  \[ \sum (P_{signal} - P_{ess})^2 \]
- Sum of absolute error
  \[ \sum |P_{signal} - P_{ess}| \]
- Sum of energy error
  \[ \sum |E_{signal} - E_{ess}| \]
- % of time signal is tracked
  \[ \% \text{ of time of which } (P_{signal} - P_{ess})/P_{signal} < 0.02 \]

Comment 3: Non-normalized metrics produce meaningless performance values

Transpower System

<table>
<thead>
<tr>
<th>Metric</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Sum of squared error</td>
<td>3,646,416 kW^2</td>
</tr>
<tr>
<td>*Sum of absolute error</td>
<td>103,820 kW</td>
</tr>
<tr>
<td>*Sum of energy error</td>
<td>439,614,224 kWh</td>
</tr>
<tr>
<td>*% of time signal is tracked</td>
<td>24.5%</td>
</tr>
</tbody>
</table>

* From DOE Protocol
Results: Review of the DOE Protocol for Frequency Regulation

Comment 4: Even highly accurate systems can have poor tracking accuracy because measurement becomes less accurate (as a %) at low power.

* From DOE Protocol

<table>
<thead>
<tr>
<th>Power</th>
<th>Measurement Accuracy (%)</th>
<th>±kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 kW</td>
<td>0.5 %</td>
<td>5 kW</td>
</tr>
<tr>
<td>500 kW</td>
<td>1.0 %</td>
<td>5 kW</td>
</tr>
<tr>
<td>250 kW</td>
<td>2.0 %</td>
<td>5 kW</td>
</tr>
<tr>
<td>100 kW</td>
<td>5.0 %</td>
<td>5 kW</td>
</tr>
</tbody>
</table>

Duty Cycle spends most of its time in the region within ±250kW, where measurement is less accurate than the protocol’s requirement for tracking.
Results: Review of the DOE Protocol for Frequency Regulation

Alternative Metrics

- Tracking Error RMS
  \[ \Sigma (P_{signal} - P_{ess})^2/N \]
- Tracking Error RMS %
  \[ \Sigma (P_{signal} - P_{ess})^2/N \]
- Alternate % of time signal is tracked
  \[ \% \text{ of time of which } (P_{signal} - P_{ess})/\text{RatedPower} < 0.02 \]

<table>
<thead>
<tr>
<th>Metric</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking Error RMS</td>
<td>22.5 kW</td>
</tr>
<tr>
<td>Tracking Error RMS %</td>
<td>2.3 %</td>
</tr>
<tr>
<td>Alt. % of time signal is tracked</td>
<td>73.5%</td>
</tr>
</tbody>
</table>

Comment 5: There are better metrics to use when expressing performance.
- Tracking Error RMS and Tracking Error RMS % provide an intuitive measure of accuracy
- Alternate % of time signal is tracked accounts for measurement error at low power
“There are three principal means of acquiring knowledge... observation of nature, reflection, and experimentation. Observation collects facts; reflection combines them; experimentation verifies the result of that combination.” – Denis Diderot
Conclusion

Impacts
- Infrastructure and experience leveraged into publications
- Data collected to form the technical foundations for R&D, Standards, and Outreach
- Improved methods for industry acceptance

FY 16
- Continue to work with industry to collect valuable data, perform analysis, and conduct demonstration experiments which drive industry acceptance.
- Publish revised testing protocols based on lessons learned
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Questions?

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