ENERGY

Review of Testing on 1MW Lithium-Ion Battery at Reese Technology Center

Presentation to DOE/OE Program Peer Review

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DNV-GL Strategic Research & Innovation
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Project Scope and Team

- Shell International Exploration & Production (US) Inc.
- Group NIRE - TTU
- DNV-GL
- Sandia National Labs

Project Purpose

- Utilize the co-location of high power, utility scale wind and power energy storage devices to evaluate services
  - Review of previous testing and utilization
  - Wind integration
  - Dual Application
  - Battery Sizing
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Battery System & Presentation Overview

- Battery managed by Group-NIRE, operating on South Plains Electric Cooperative (SPEC)
- Testing program to be deployed Q4 2015
- This presentation to review analysis conducted on previous test data
  - Battery performance
  - Efficiency Assessments
  - Applications Analyses
    - Demand Response
    - Frequency Response
    - Wind Ramp Control
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Battery Performance Baseline Shows Consistent Performance in Demand Response Activity

- SOC calculation indicates a average total capacity of 1,088 kWh
- Maximum temperature is consistent 33°C (average 8° above ambient)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>#</th>
<th>Discharge Power (kW)</th>
<th>Initial SOC (%)</th>
<th>Final SOC (%)</th>
<th>Discharge Time (hrs)</th>
<th>Energy Out (kWh)</th>
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</thead>
<tbody>
<tr>
<td>July 16-18</td>
<td>1</td>
<td>478</td>
<td>100</td>
<td>9.0</td>
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<td>88</td>
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<td>823.18</td>
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<td>88</td>
<td>1.0</td>
<td>0.97</td>
<td>948.27</td>
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</table>
Efficiency of Demand Response Activity is Dependent on Power

- Round trip efficiency calculated as ratio of total discharge energy to total discharge energy
- Average AC efficiency (measure at feeder) **7.4%** less than DC efficiency
- Tests selected for minimal time between charge/discharge & constant power

<table>
<thead>
<tr>
<th>Date</th>
<th>Charge Power</th>
<th>Discharge Power</th>
<th>AC Efficiency (%, feeder)</th>
<th>DC Efficiency (%, battery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>August 12 2014</td>
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<td>1000</td>
<td>73.70</td>
<td>81.01</td>
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<tr>
<td>August 13 2014</td>
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<td>1000</td>
<td>65.68</td>
<td>72.72</td>
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<tr>
<td>August 19 2014</td>
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<td>1000</td>
<td>74.27</td>
<td>80.99</td>
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<tr>
<td>August 11 2015</td>
<td>250</td>
<td>1000</td>
<td>79.96</td>
<td>88.35</td>
</tr>
<tr>
<td>August 12 2015</td>
<td>200</td>
<td>1000</td>
<td>80.97</td>
<td>88.60</td>
</tr>
</tbody>
</table>
Efficiency of Demand Response Activity is Dependent on Power

- All discharged under same conditions (1,000 kW, full power, 1C)
  - Using round trip efficiency as metric with same discharge conditions
  - Efficiency of charging *increases* at lower power, which *lowers* total, round trip efficiency

- Evaluating round trip efficiency at same charge/discharge power hides these trends
Aggressive Frequency Response Activity Shows High Round Trip Efficiency

- ERCOT fast regulation market (FRRS)
- Lots of higher-power activity, large SOC movement
- Efficiencies very similar in scale to demand response activities

<table>
<thead>
<tr>
<th>Date</th>
<th>Function</th>
<th>AC Efficiency (feeder)</th>
<th>DC Efficiency (battery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept 4</td>
<td>FRRS</td>
<td>74.02</td>
<td>80.82</td>
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<tr>
<td>Sept 9</td>
<td>FRRS</td>
<td>73.97</td>
<td>81.16</td>
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<tr>
<td>Sept 10</td>
<td>FRRS</td>
<td>74.48</td>
<td>80.27</td>
</tr>
</tbody>
</table>
Local Wind Ramp Support and Frequency Response Efficiencies

- Inclusion of static load (20-40 kW) has significant impact dependent on time
- Operations much less active than FRRS, parasitic loads dominate efficiency
- Key concern for standby ‘spinning reserve’ applications as well as for guaranteed efficiency contract terms

<table>
<thead>
<tr>
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<th>Function</th>
<th>AC Efficiency (feeder)</th>
<th>DC Efficiency (battery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept 30</td>
<td>Wind+Freq</td>
<td>27.46</td>
<td>33.20</td>
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<tr>
<td>Oct 10</td>
<td>Wind+Freq</td>
<td>21.71</td>
<td>32.43</td>
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<tr>
<td>Oct 11</td>
<td>Wind+Freq</td>
<td>11.24</td>
<td>22.78</td>
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</table>
Wind Ramp Support Tests Also Characterized by Low Energy Throughput

- Small power correction followed by large energy compensation
- DC efficiency: 28.7%, AC efficiency: 21.8%
Additional Profile Characteristics for High Interval Applications

- Quantifying differences in battery application profiles
- Equivalent cycles per day calculated as the number of full 100% DOD cycles that would have resulted based on total energy throughput

<table>
<thead>
<tr>
<th>Date</th>
<th>Function</th>
<th>ΔSOC (%)</th>
<th>Cycles Per Day</th>
<th>Equivalent Cycles Per Day</th>
</tr>
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<tbody>
<tr>
<td>August 26</td>
<td>Wind Ramp Support</td>
<td>0.71</td>
<td>158.4</td>
<td>1.12</td>
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<tr>
<td>Sept 4</td>
<td>FRRS</td>
<td>1.71</td>
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<td>Sept 9</td>
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<td>2.66</td>
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<tr>
<td>Sept 10</td>
<td>FRRS</td>
<td>1.60</td>
<td>152.9</td>
<td>2.44</td>
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<tr>
<td>Sept 30</td>
<td>Wind+Freq</td>
<td>0.44</td>
<td>267.5</td>
<td>1.18</td>
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<tr>
<td>Oct 10</td>
<td>Wind+Freq</td>
<td>0.34</td>
<td>204.0</td>
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<tr>
<td>Oct 11</td>
<td>Wind+Freq</td>
<td>0.63</td>
<td>135.0</td>
<td>0.85</td>
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</table>
Compare histograms of demand response, FRRS, low interval frequency, wind activity

- Wind

<table>
<thead>
<tr>
<th>Occurrence</th>
<th>Delta SOC (%)</th>
<th>Charge Power (kW)</th>
<th>Discharge Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>1000</td>
<td>1000</td>
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</table>

- FRRS

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<tr>
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<th>Discharge Power (kW)</th>
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</thead>
<tbody>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>10</td>
<td>5</td>
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<tr>
<td>10</td>
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<td>1000</td>
<td>1000</td>
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</tbody>
</table>

- Wind+Freq

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<thead>
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<tr>
<td>200</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>5</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

\[x \times 10^4\]
Observations, Insights & Next Steps

Data to date provides significant insights into operational efficiency

- Full system efficiency (AC measured at the feeder) trails DC by 7-8%
- Imbalance of charge / discharge power level can result in at least 15% variation in system efficiency
  - Points to importance of methods for quantifying efficiency
- Low use factors or low energy throughput can result in very low effective system round trip efficiency
  - Points to importance of calculating operational efficiency in contracting
  - Parasitic loads play a dominant role
    - Test procedures for properly measuring standby loads \(\rightarrow\) DOE working group

Next steps – Begin new testing

- Test plan builds on data analysis to further focus on wind integration concepts and efficiency testing and evaluation
Thank You

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