DOE Peer Review

Notrees Energy Storage Project

Utility-Scale Battery Energy Storage
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Duke Energy
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Project site

- Notrees wind farm, owned and operated by Duke Energy Renewables
- Located in west Texas – Ector and Winkler Counties
- 156MW total wind generation capacity
Project Objectives

• Integrate storage with intermittent renewable energy production
• Improve use of power-producing assets by storing energy during non-peak generation periods
• Demonstrate benefits of using fast response energy storage to provide ancillary services for grid management
• Confirm that the solution can dispatch according to market price signals or pre-determined schedules utilizing ramp control
• Verify that energy storage solutions can operate within the ERCOT market protocols
Phase 1: Economic and Industry Evaluation

• Evaluation of storage technologies and market applications

• Lessons learned in first phase of project:
  – Proposals showed installed cost higher than anticipated
  – Optimization showed far more bias to regulation market than anticipated
Phase 2: Demonstrate Integration of Energy Storage with Wind Generation

• Goal – Validation that energy storage:
  – Increases the value and practical application of wind generation
  – Alleviates intermittency issues, and
  – Is commercially viable at utility scale

• Description
  – Advanced technology Energy Storage System (ESS)
  – Locate ESS at wind farm substation
  – Operate ESS in various modes
  – Operational Q4 2012

• Participants
  – DOE Smart Grid Program
  – Duke Energy, Xtreme Power
  – EPRI
Energy Storage System (ESS)

- Technology: Advanced lead-acid battery
- OEM Partner – Xtreme Power (XP)
- 36 MW / 24 MWh output
- 24 Dynamic Power Modules (DPM™) with 1.5 MW / 1.0 MWh rating
- Modules housed in ~ 20,000 sq. ft. building
Project Activities to Date

- Site construction began, December 2011
- Construction substantially completed, October 2012
- Metrics & Benefits Plan, October 2012
- Commercial operation began, December 2012
- Two-year system performance testing & analysis: 2013-14
- ERCOT FRRS Program - February 2013 – March 2014
Performance

- Resources providing FRRS must provide full MW
  - Up response within 60 cycles after frequency hits 59.91 Hz trigger
  - Down response within 60 cycles after frequency hits 60.09 Hz trigger
- Resources providing FRRS (Up and Down) must be able to continuously remain deployed for up to 8 minutes with 95% or more of the requested MW for successful qualification

Pricing

- Day-Ahead Market clearing prices shall be used to price the FRRS awards
- Cost for MWs procured are paid for similar to other Ancillary Services
- Adjustments can be made depending on actual availability and performance
ERCOT FRRS

- FRRS Pilot ended in February 2014
- FRRS is now rolled into the normal Regulation Services as a subset of Reg Up and Reg Down
- Notrees BESS continues to offer into the ERCOT A/S Frequency Regulation market
- Revenue is based on Regulation market price
- Level of usage remains at pace
Purpose of FRRS Pilot

The pilot governing document states the purpose of the pilot project is to:

1. Determine whether FRRS can improve ERCOT’s ability to arrest frequency decay during unit trips

2. Determine the optimal means of deploying FRRS by testing various deployment methodologies

3. Determine whether FRRS can reduce the need for Regulation Service and thereby reduce total Ancillary Service costs

4. Assess the operational benefits and challenges of deploying FRRS

5. Provide data for ERCOT to determine the appropriate settlement treatment for Resources providing FRRS, including possible “pay-for-performance” methods such as those being developed in response to FERC Order 755.
Number of FRRS Deployments

FRRS Deployments

<table>
<thead>
<tr>
<th>Date</th>
<th>Total Number of Deployments</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-Feb-13</td>
<td>100</td>
</tr>
<tr>
<td>4-Mar-13</td>
<td>150</td>
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<td>11-Mar-13</td>
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<td>18-Mar-13</td>
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</tr>
<tr>
<td>13-May-13</td>
<td>650</td>
</tr>
<tr>
<td>20-May-13</td>
<td>700</td>
</tr>
</tbody>
</table>

59.97, 59.98, 59.975
ERCOT FRRS Example

Source: ERCOT
Notrees deployment event (11/1/2013)

Frequency drops to extreme underfrequency condition; Notrees instantly responds within 92 ms, before ERCOT has time to issue a command.

Notrees switches back to following ERCOT signal as ERCOT command catches up after 12 s, and frequency begins to recover.
Typical duty cycle profile – 1 hour snapshot

Deployment for bid 20MW and frequency
Typical Daily Battery Operation

Monday, April 22, 2013

- **RegUp**
- **RegDown**
- Not providing FRRS

---

**Graph Details**

- **Energy Received**: $-59.6$ MWh
- **Energy Delivered**: $47.8$ MWh
- **Net Energy**: $-11.8$ MWh
- **% Energy Delivered/Received**: $80.2\%$
- **Minimum Power**: $-10.5$ MW
- **Maximum Power**: $24.9$ MW
- **Time Charging**: $18.9$ hours
- **Time Discharging**: $5.1$ hours
- **% Time Charging**: $78.6\%$
- **% Time Discharging**: $21.4\%$
- **Mileage**: $5977.0$ MW
Typical Daily Battery Operation

Monday, November 18, 2013

RegUp

RegUp

Not providing FRRS

BESS stopped providing RegDown after 6/7/2013

- Energy Received: ~40.7 MWh
- Energy Delivered: 24.0 MWh
- Net Energy: ~16.7 MWh
- % Energy Delivered/Received: 58.9%
- Minimum Power: ~3.7 MW
- Maximum Power: 19.9 MW
- Time Charging: 21.7 hours
- Time Discharging: 2.3 hours
- % Time Charging: 90.6%
- % Time Discharging: 9.4%
- Mileage: 2517.1 MW
Typical Monthly Battery Operation

April 2013

<table>
<thead>
<tr>
<th>Sunday</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
<th>Saturday</th>
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Power, Megawatts

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<th>8AM</th>
<th>12PM</th>
<th>4PM</th>
<th>8PM</th>
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<td>8PM</td>
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</tbody>
</table>

Energy Received: ~1645.6 MWh
Energy Delivered: 1286.2 MWh
Net Energy: ~359.5 MWh
% Energy Delivered/Received: 78.2%
Minimum Power: ~10.5 MW
Maximum Power: 24.9 MW
Time Charging: 567.9 hours
Time Discharging: 152.1 hours
% Time Charging: 78.9%
% Time Discharging: 21.1%
Mileage: 159984.3 MW
November 2013

Energy Received: -1179.2 MWh
Energy Delivered: 791.9 MWh
Net Energy: -387.4 MWh

% Energy Delivered/Received: 67.2%
Minimum Power: -8.5 MW
Maximum Power: 20.5 MW
Time Charging: 641.8 hours
Time Discharging: 78.1 hours
% Time Charging: 89.1%
% Time Discharging: 10.8%
Mileage: 78826.8 MW
Summary of Findings

Based on the first three months of observations;

1. The introduction of FRRS improves ERCOT’s ability to arrest frequency decay during unit trips.
2. FRRS Pilot Resources generally followed ERCOT FRRS deployments and responded automatically using local frequency detecting techniques.
3. When deployed, FRRS reduces the rate of change of frequency and regulation deployed to conventional Resources.
4. Observed lower quantities offered for FRRS-down and an overall lower performance for FRRS-down.
Grid Operator observations

- After first 3-months of Notrees operating in FRRS, ERCOT’s observations:
  - “FRRS improves ERCOT’s ability to arrest frequency decay during unit trips”
  - “When deployed, FRRS reduces the rate of change of frequency and regulation deployed to conventional Resources”
  - “ERCOT believes that the pilot has already provided exceedingly valuable information about the degree to which the deployment of Regulation Service can be reduced by FRRS Resources”

- FRRS Permanent Protocol language approved by ERCOT Board on Feb 11th 2014
Appendix
Data Collection and Analysis

• This project requires a variety of data sets from several different sources:

  – Battery AC/DC measurements ➔ XP (Now Younicos)
  – Ancillary services prices/awards ➔ ERCOT
  – Settlement information ➔ Duke/Oncor
  – Wind farm, battery output ➔ Duke
Duke Notrees Substation Data

- The Notrees substation is metered at several different feeders:
Duke Notrees Substation Data

• Wind turbines are metered separately according to their manufacturer (GE or Vestas).

• BESS meter includes house loads.

• 1-minute interval data for power, frequency, and curtailment status
Summary Statistics Definitions

• Energy received = metered energy received by BESS (includes house load). Energy received is a negative quantity.

• Energy delivered = metered energy delivered by BESS (includes house load). Energy delivered is a positive quantity.

• Net energy = energy received + energy delivered
Summary Statistics Definitions

• % Energy Delivered/Received = Amount of energy delivered by the BESS divided by the amount of energy received, reported as a percentage.

• Time charging = Amount of time when the BESS power is less than zero.

• Time discharging = Amount of time when the BESS power is greater than zero.

• Mileage = Sum of absolute values of changes in power output per time step.
Response from FRRS Resource
Response from Conventional and FRRS

Graph showing the response from Conventional and FRRS resources over time.

- **Conventional Resources MW**
- **FRRS MW Output**

Legend:
- Blue dashed line: Conventional Unit Expected Generation
- Green line: Conv Unit Output
- Red dashed line: FRRS Deployment
- Purple line: FRRS Resource Output

Time intervals and values are indicated on the x-axis and y-axis.
FRRS Performance

<table>
<thead>
<tr>
<th></th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FRRS-UP</strong></td>
<td>76.83%</td>
<td>82.17%</td>
<td>88.15%</td>
<td>78.88%</td>
</tr>
<tr>
<td><strong>FRRS-DOWN</strong></td>
<td>76.83%</td>
<td>73.48%</td>
<td>82.39%</td>
<td>62.34%</td>
</tr>
</tbody>
</table>
RoCoF

Rate of change of Frequency (mHz/30 seconds)

30 seconds before FRRS deployment

without FRRS (1/1/2013~2/25/2013) with FRRS (2/26/2013~5/20/2013)

30 seconds after FRRS deployment

24.70 22.24 18.14 12.44 0.00 5.00 10.00 15.00 20.00 25.00 30.00

ERCOT
Rate of Change of Regulation Deployment (MW/30 seconds)

- 73.20 MW/30 seconds before FRRS deployment
- 74.27 MW/30 seconds before FRRS deployment
- 39.47 MW/30 seconds after FRRS deployment
- 22.47 MW/30 seconds after FRRS deployment

30 seconds before FRRS deployment:
- Without FRRS (1/1/2013~2/25/2013)
- With FRRS (2/26/2013~5/20/2013)
<table>
<thead>
<tr>
<th>Effective Date and Time</th>
<th>Operating Day 2-25-13 HE 11</th>
<th>Operating Day 3-30-13 HE 1</th>
<th>Operating Day 4-13-13 HE 1</th>
<th>Operating Day 6-3-13 HE 12</th>
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<tbody>
<tr>
<td>Band 1 High Trigger Frequency (Hz)</td>
<td>60.03</td>
<td>60.02</td>
<td>60.025</td>
<td>60.025</td>
</tr>
<tr>
<td>Band 2 High Trigger Frequency (Hz)</td>
<td>60.05</td>
<td>60.05</td>
<td>60.05</td>
<td>60.05</td>
</tr>
<tr>
<td>Band 3 High Trigger Frequency (Hz)</td>
<td>60.09</td>
<td>60.09</td>
<td>60.09</td>
<td>60.09</td>
</tr>
<tr>
<td>Band 1 Low Trigger Frequency (Hz)</td>
<td>59.97</td>
<td>59.98</td>
<td>59.975</td>
<td>59.975</td>
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<tr>
<td>Band 2 Low Trigger Frequency (Hz)</td>
<td>59.95</td>
<td>59.95</td>
<td>59.95</td>
<td>59.95</td>
</tr>
<tr>
<td>Band 3 Low Trigger Frequency (Hz)</td>
<td>59.91</td>
<td>59.91</td>
<td>59.91</td>
<td>59.91</td>
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<tr>
<td>Capacity Deployment in Band 1 (%)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Maximum Deployment Time per Band (sec)</td>
<td>120</td>
<td>60</td>
<td>60</td>
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<tr>
<td>Recall Interval (sec)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
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<tr>
<td>Single Event Reset High Trigger Frequency (Hz)</td>
<td>60.01</td>
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<tr>
<td>Single Event Reset Low Trigger Frequency (Hz)</td>
<td>59.99</td>
<td>59.99</td>
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</tbody>
</table>
Rate of change of Regulation Deployment
(MW/30 seconds)

30 seconds before FRRS deployment
- without FRRS (2/1/2013~2/25/2013)
- 77.15 MW/30 seconds

30 seconds after FRRS deployment
- with FRRS (2/25/2013~2/28/2013)
- 80.35 MW/30 seconds
- 42.03 MW/30 seconds
- 18.61 MW/30 seconds
## ERCOT FRRS Monthly Stats

<table>
<thead>
<tr>
<th>Month</th>
<th>Total FRRS Deployment Durations (Hour)</th>
<th>Total FRRS Deployment Durations (Hour)</th>
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<tbody>
<tr>
<td>February (start on 2/25)</td>
<td>11.42</td>
<td>11.17</td>
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<tr>
<td>March</td>
<td>106.53</td>
<td>120.76</td>
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<td>April</td>
<td>128.86</td>
<td>127.89</td>
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<td>May</td>
<td>90.74</td>
<td>92.87</td>
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<td>June</td>
<td>77.3</td>
<td>82.27</td>
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<td>July</td>
<td>74.66</td>
<td>79.06</td>
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<td>August</td>
<td>68.95</td>
<td>72.26</td>
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<td>September</td>
<td>77.11</td>
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<td>October</td>
<td>64.33</td>
<td>77.03</td>
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<td>November</td>
<td>61.04</td>
<td>74</td>
</tr>
<tr>
<td>December</td>
<td>42.38</td>
<td>59.7</td>
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</table>

Source: ERCOT
### April and May 2013 Performance

<table>
<thead>
<tr>
<th>April, 2013</th>
<th>FRRS-UP</th>
<th>FRRS-DOWN</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRRS Resource A</td>
<td>98.51%</td>
<td>64.77%</td>
</tr>
<tr>
<td>FRRS Resource B</td>
<td>77.78%</td>
<td>100.00%</td>
</tr>
<tr>
<td>Total Average</td>
<td>88.15%</td>
<td>82.39%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>May 1 – May 20, 2013</th>
<th>FRRS-UP</th>
<th>FRRS-DOWN</th>
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</thead>
<tbody>
<tr>
<td>FRRS Resource A</td>
<td>97.61%</td>
<td>50.00%</td>
</tr>
<tr>
<td>FRRS Resource B</td>
<td>60.15%</td>
<td>74.69%</td>
</tr>
<tr>
<td>Total Average</td>
<td>78.88%</td>
<td>62.34%</td>
</tr>
</tbody>
</table>
Determination of max FRRS-pilot participation

Average Load (11/1/2011 through 5/1/2012) = 32,233 MW

General Rule of Thumb is, 1% change in load will change 0.1 Hz or 100 mHz of Frequency

That translates to System Bias of 322 MW/0.1 Hz

The pilot was intended to see whether FRRS can complement current regulation service and respond automatically to large frequency deviations

So, the pilot was constructed to observe maximum frequency impact of 0.02 Hz or 20 mHz

\[
20\% \text{ of } 0.1 \text{ Hz} = 20\% \text{ of } 100 \text{ mHz} = 20 \text{ mHz}
\]

Resonable FRRS – UP maximum capacity \[= \frac{322 \text{ MW}}{0.1 \text{ Hz}} \times 0.02 \text{ Hz} \]

\[= 64.4 \text{ MW} \sim 65 \text{ MW}\]

Maximum FRRS-Down designed to correct only 0.01 Hz or 10 MHz which resulted in 32.5 MW and was rounded to 35 MW.
Average Regulation-up usage
Regulation-up Procurement

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
FRRS-DN Award Amounts

Aggregate FRRS-DN Award Amounts First 13 Weeks

- Minimum
- Maximum
- Average

6/12/2013
FRRS-UP Award Amounts

Aggregate FRRS-UP Award Amounts First 13 Weeks

as of May 29 1100hrs
FRRS-DN Performance

Regulation Down Performance Feb 25 - May 20

- MWh Awarded
- Actual Performance

Int 1 to Int 24
FRRS-Up Performance

Regulation Up Performance Feb 25 - May 20

Mwh Awarded  Actual Performance

Int 1  Int 2  Int 3  Int 4  Int 5  Int 6  Int 7  Int 8  Int 9  Int 10  Int 11  Int 12  Int 13  Int 14  Int 15  Int 16  Int 17  Int 18  Int 19  Int 20  Int 21  Int 22  Int 23  Int 24
## Performance Rate for First 13 Weeks

### FRRS MwH Awards vs Actual Performance

<table>
<thead>
<tr>
<th>Date Range Feb 25 - May 20</th>
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<table>
<thead>
<tr>
<th>FRRS Service</th>
<th>MwH Awarded</th>
<th>Performance</th>
<th>Overall Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total RegDN</td>
<td>7,167</td>
<td>4,750</td>
<td>66%</td>
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<tr>
<td>Total RegUP</td>
<td>48,206</td>
<td>45,378</td>
<td>94%</td>
</tr>
</tbody>
</table>
Timeline

• **Project**
  – Selected for DOE SGDP Award Nov 2009
  – Site construction began Oct 2011
  – Battery delivery to site starting June 2012

• **System Testing**
  – Commenced September 2012
  – COD December 2012

• **FRRS operations**
  – Began February 25, 2013 under ERCOT FRRS Pilot program
  – Ongoing operational changes as ERCOT evaluated impact of different parameter

• **Performance**
  – Market Participation a function of **Site Availability & FRRS performance parameters**
Specific Actions:

✓ Project 39764 explored general storage issues
✓ Project 39657 was the rulemaking to implement SB 943
✓ Project 40150 was the rulemaking for ERCOT pilot project authority
✓ Project 39917 was the rulemaking for settlement issues
   ✓ Also exempted storage from retail load fees and 4CP cost allocation methods

✓ “We need to remove as many impediments to storage as we can.” - Texas PUC, September 2011