DOE Peer Review

Notrees Energy Storage Project

Utility-Scale Battery Energy Storage
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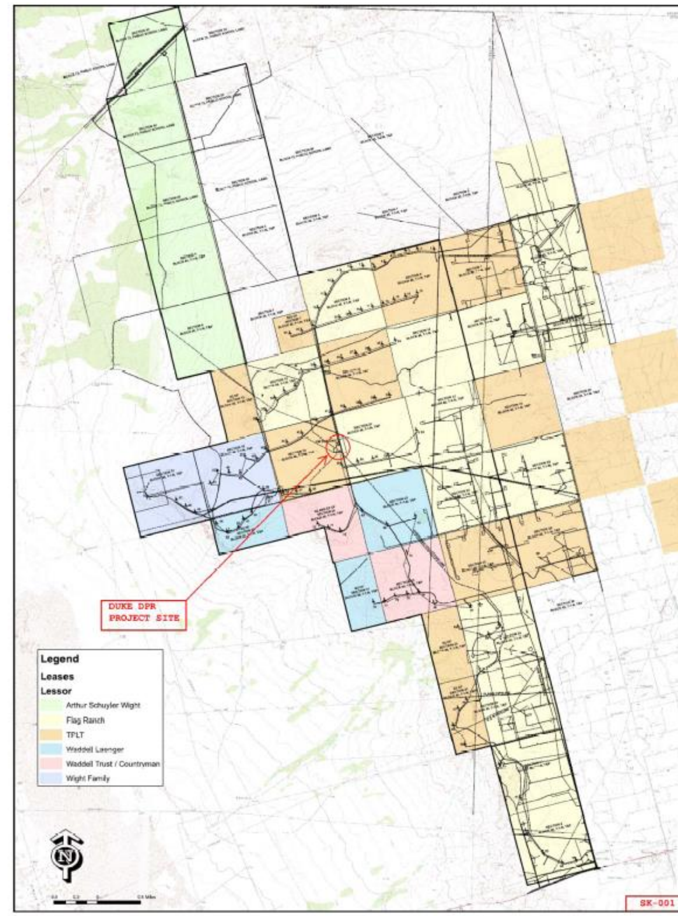
Duke Energy

March 20, 2014

- Acknowledgment: "This material is based upon work supported by the Department of Energy under Award Number(s) DE-OE0000195."

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

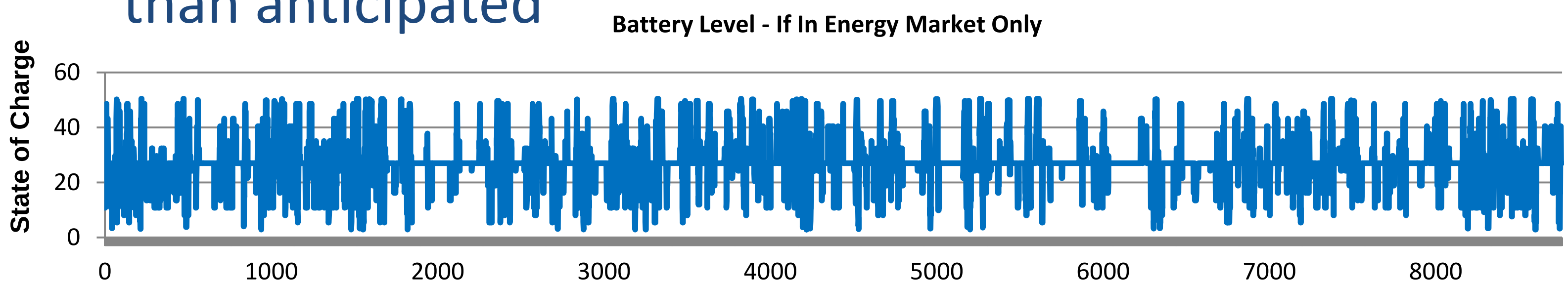


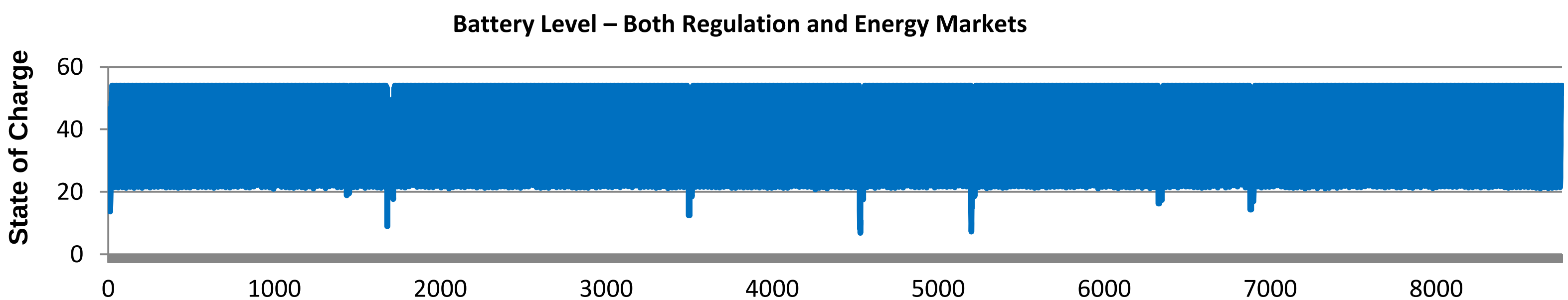
Project Objectives

- 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



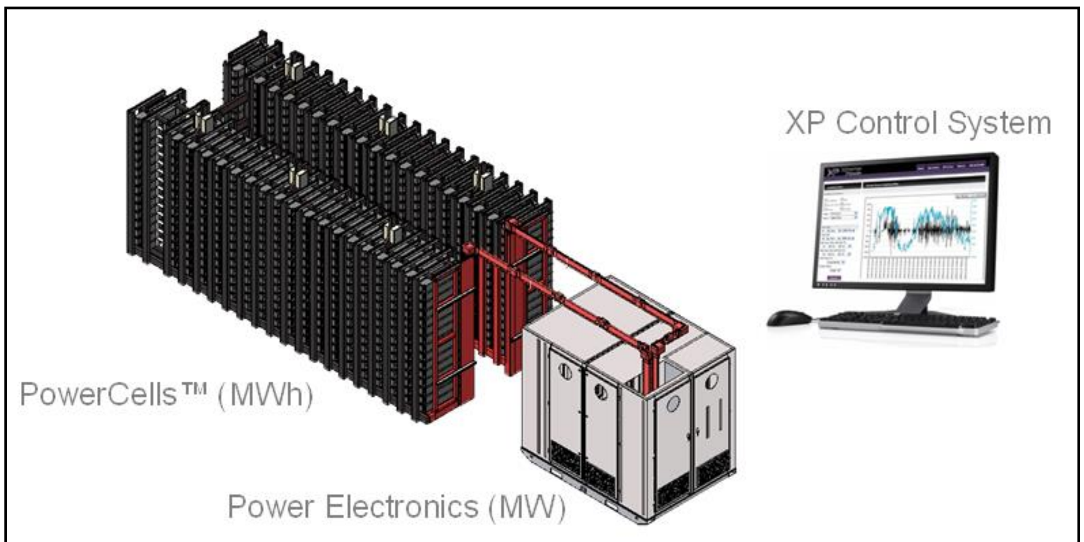


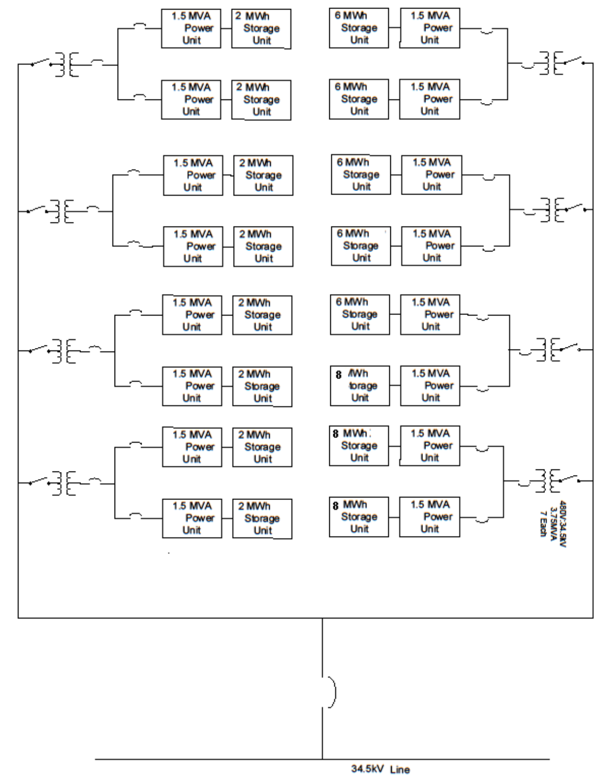
Phase 2: Demonstrate Integration of Energy Storage with Wind Generation

- 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





Representative Layout

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

ERCOT FRRS
Overview

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

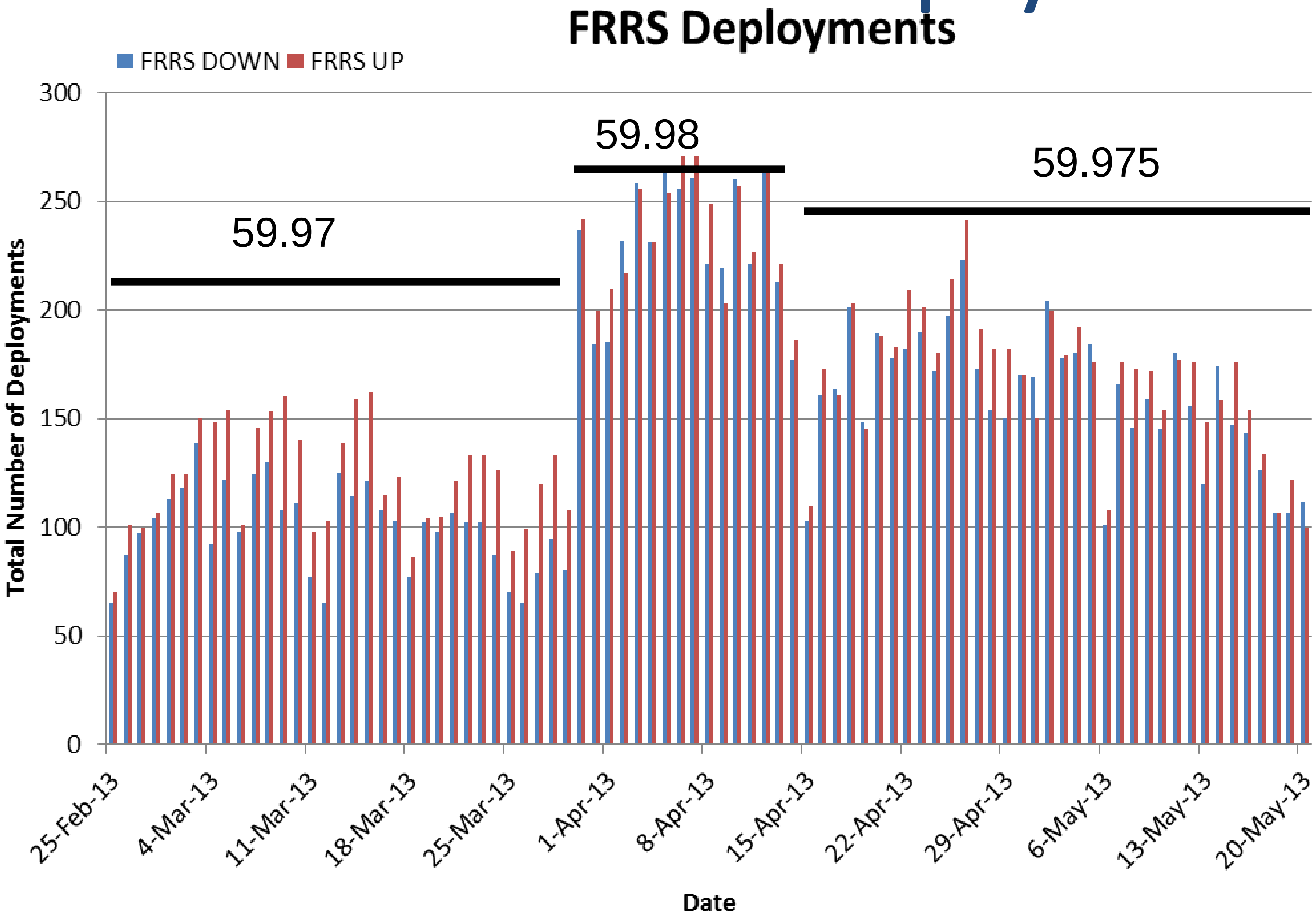
2. Determine the optimal means of deploying FRRS by testing various deployment methodologies

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

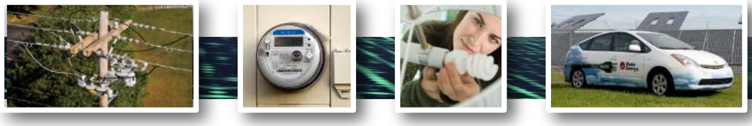
5. Provide data for ERCOT to determine the appropriate settlement treatment for Resources providing FRRS, including possible "pay-for-performance" methods such as those being developed in response to FERC Order 755.

Number of FRRS Deployments

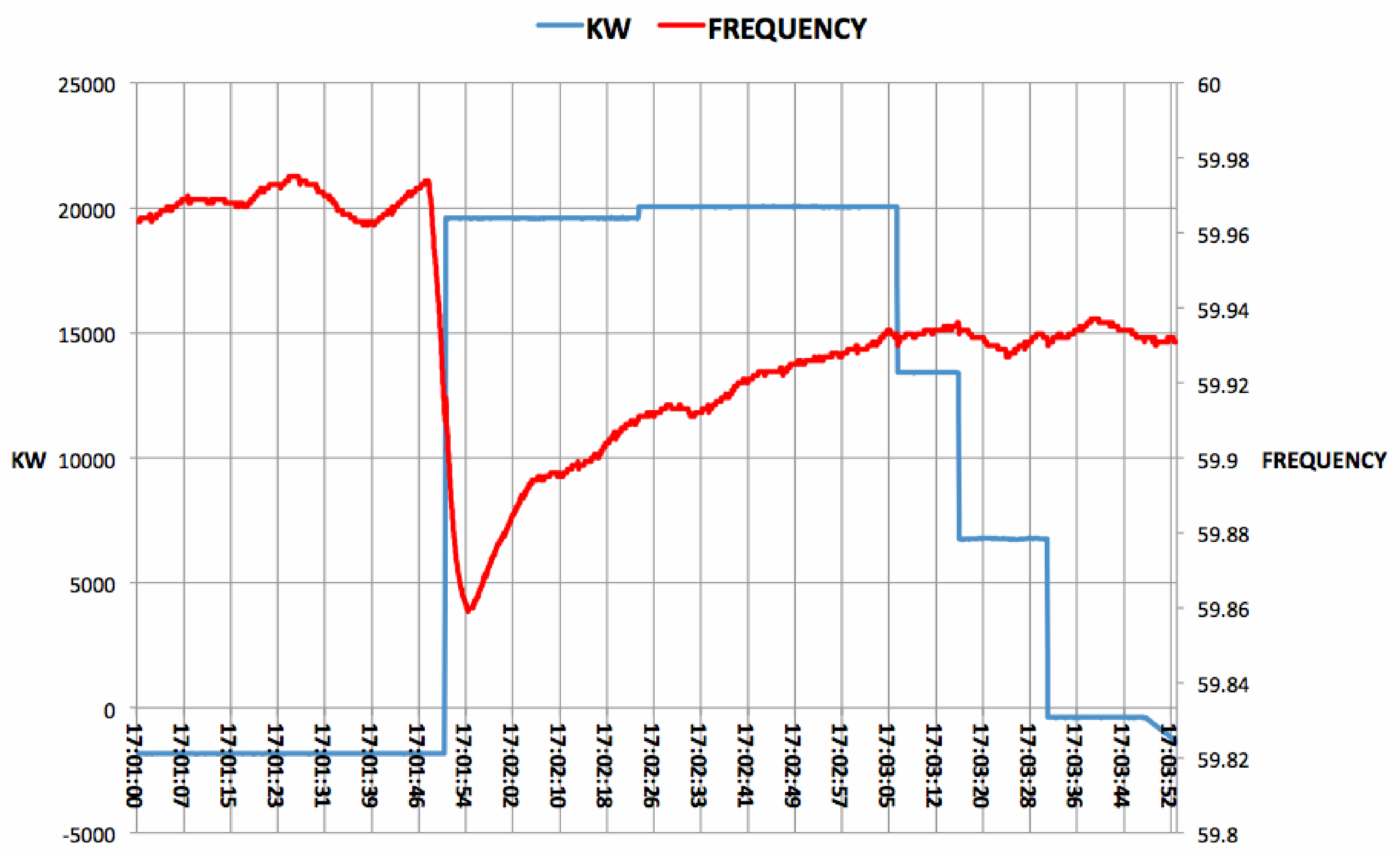


ERCOT

6/12/2013

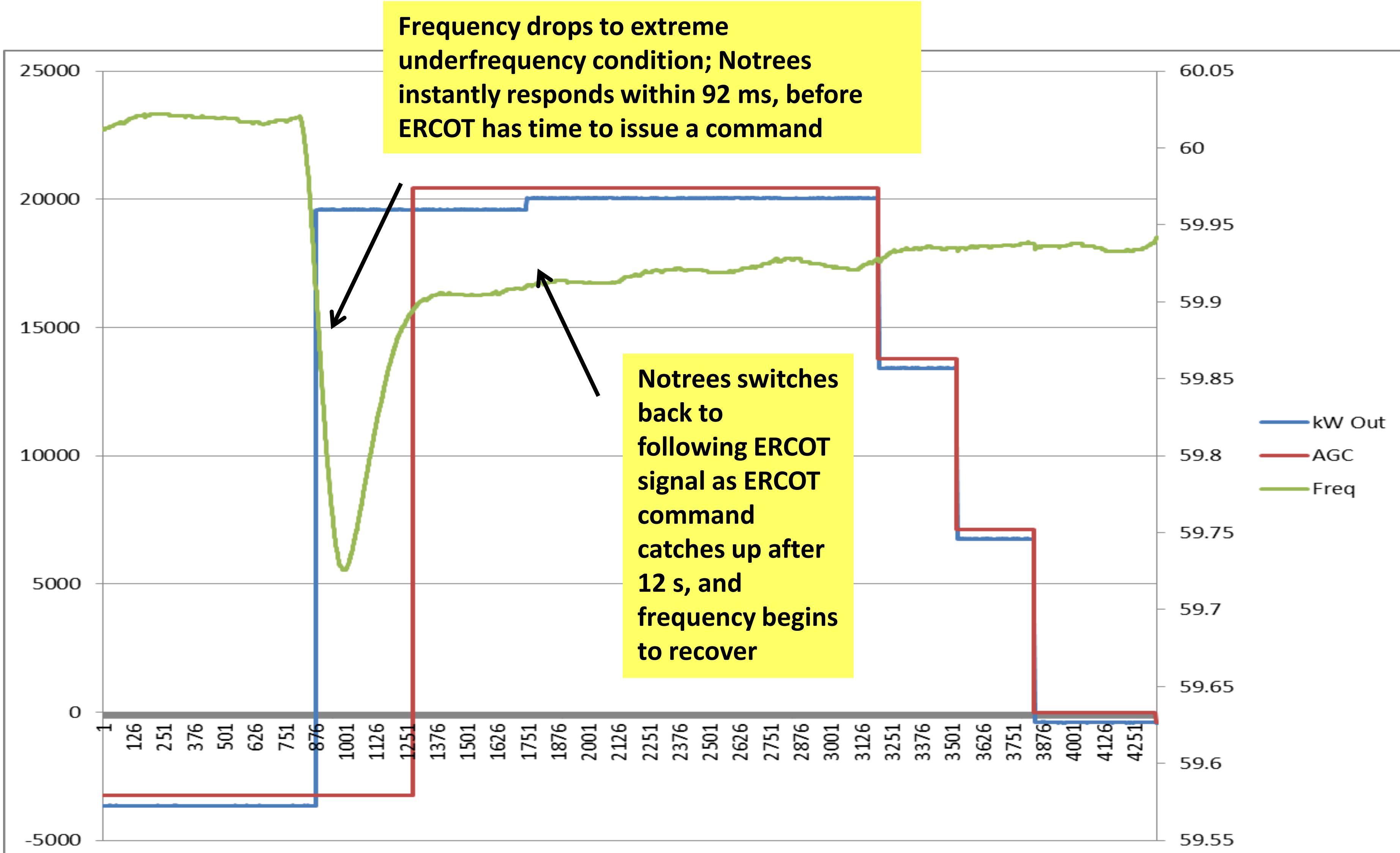


ERCOT FRRS Example



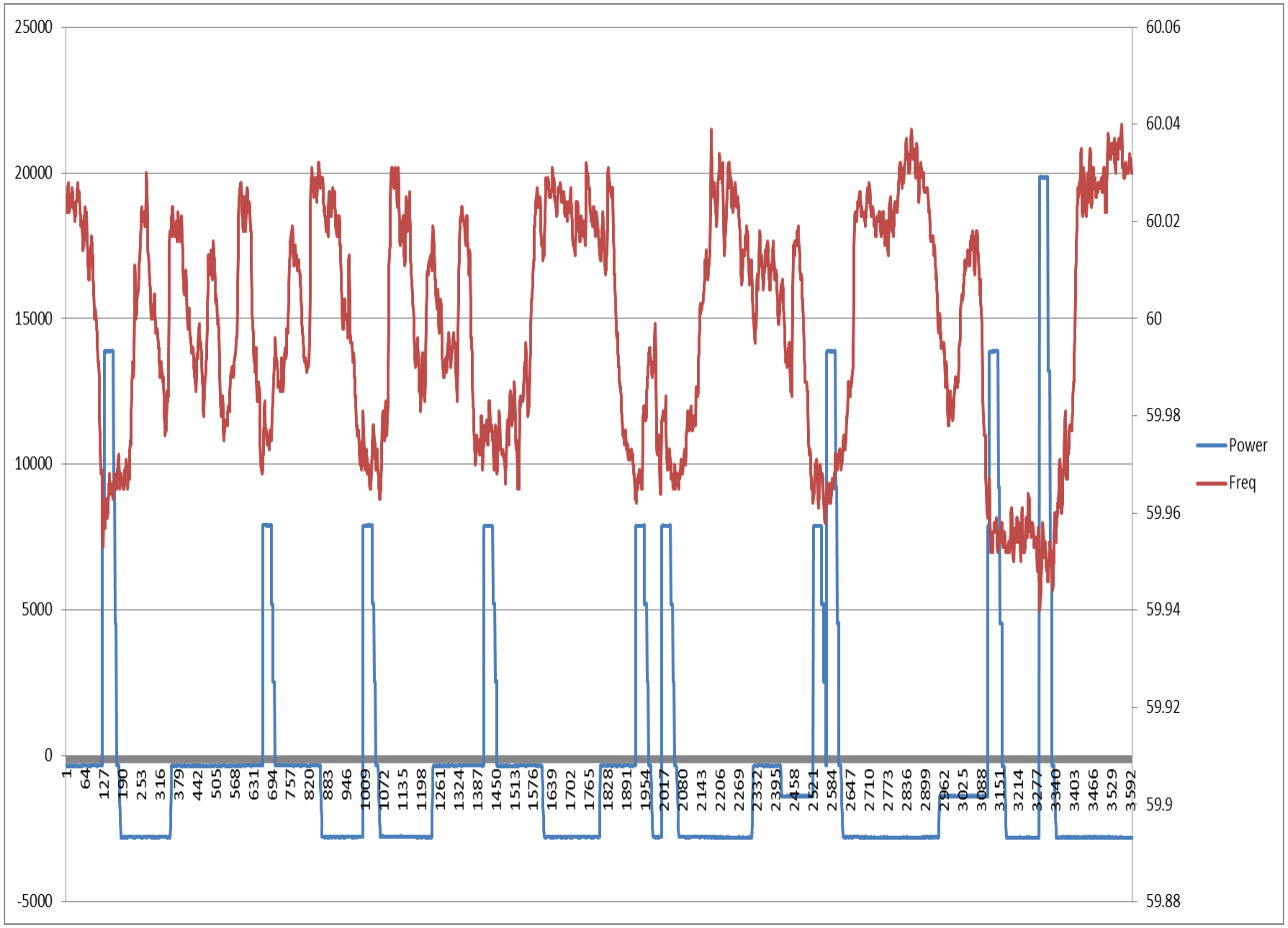
Source: ERCOT

Notrees deployment event (11/1/2013)

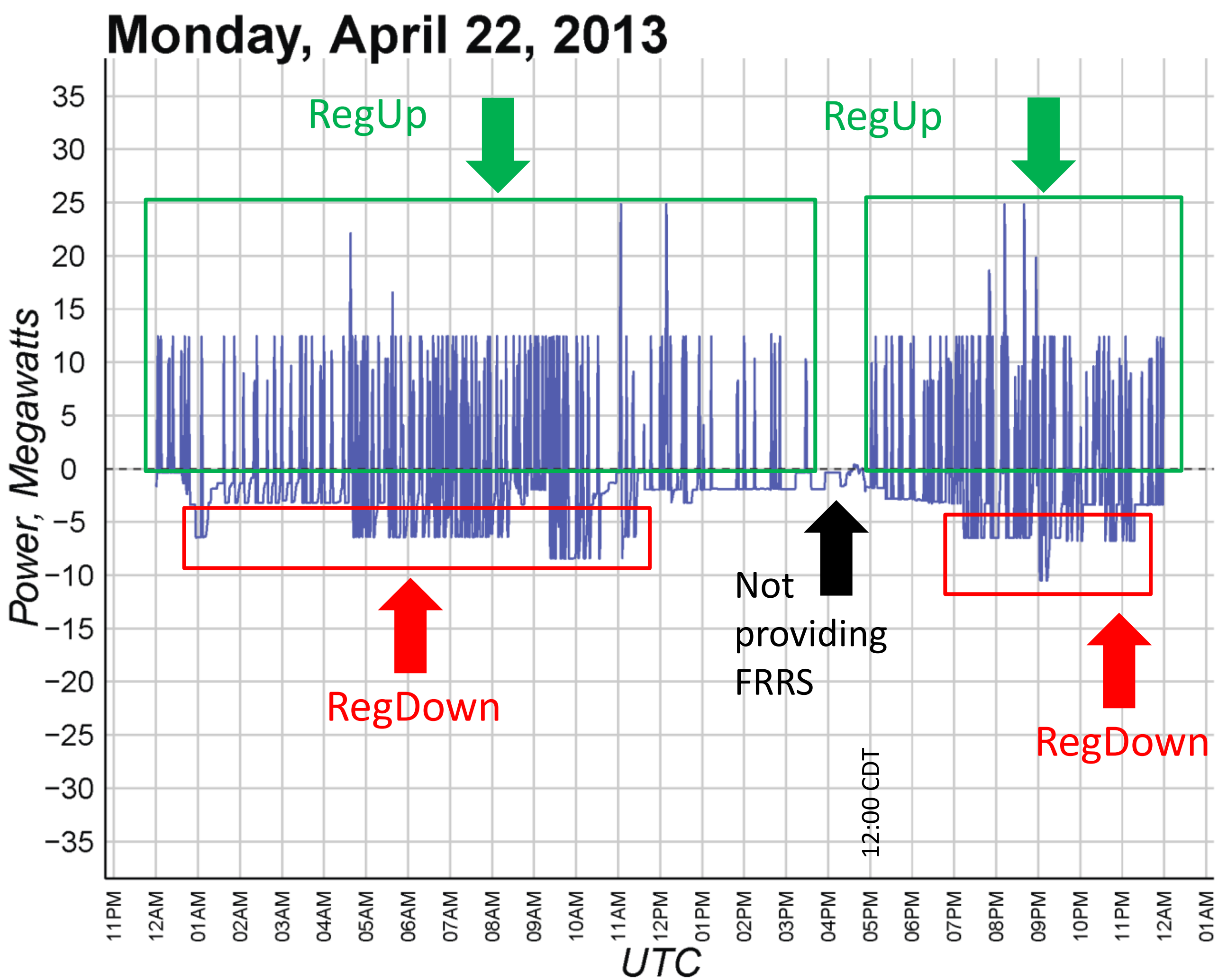


Typical duty cycle profile – 1 hour snapshot

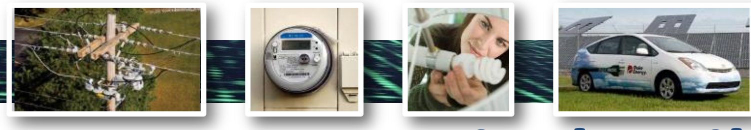
Deployment for bid 20MW and frequency



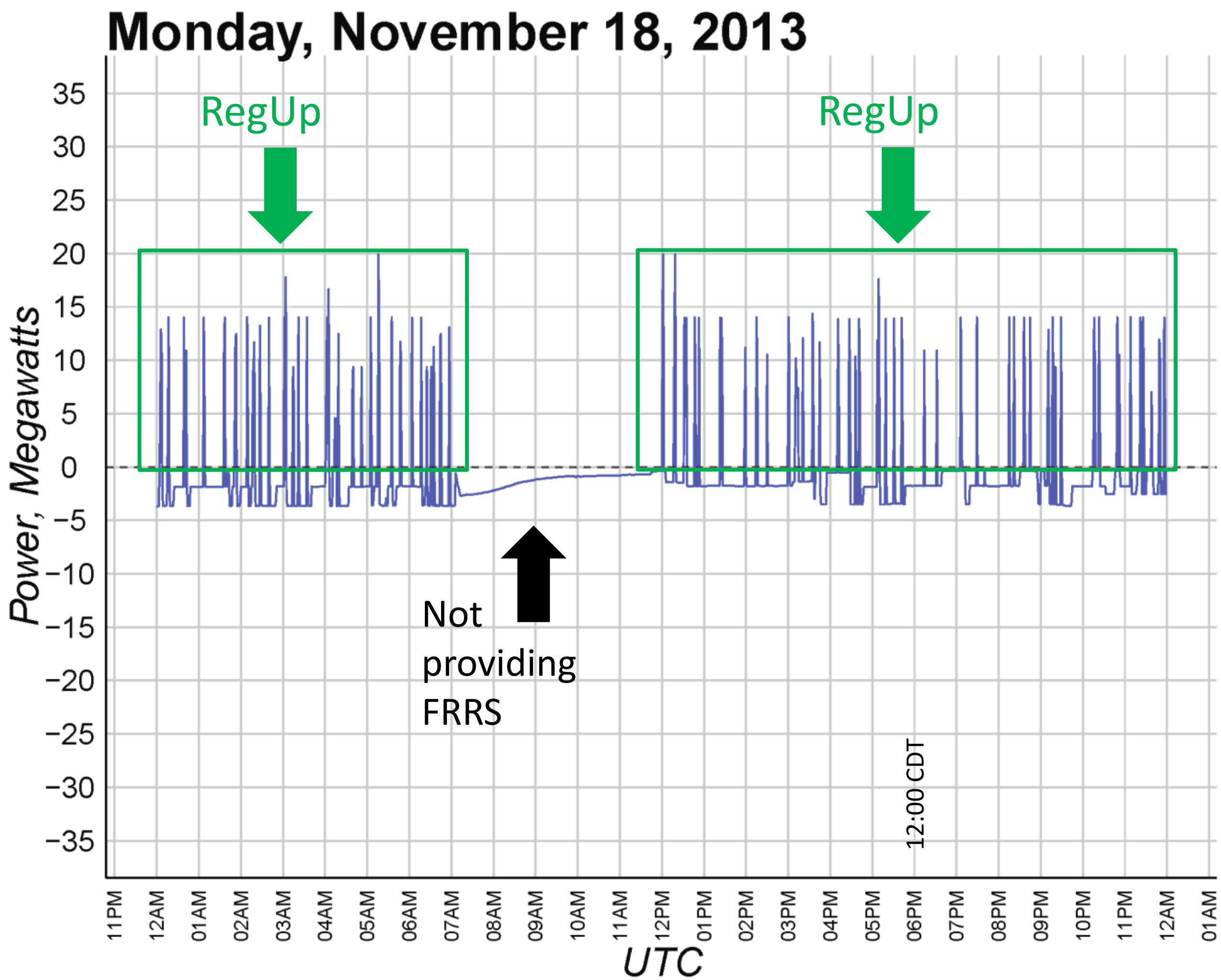
Typical Daily Battery Operation



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

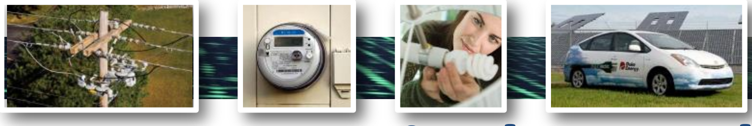


Typical Daily Battery Operation

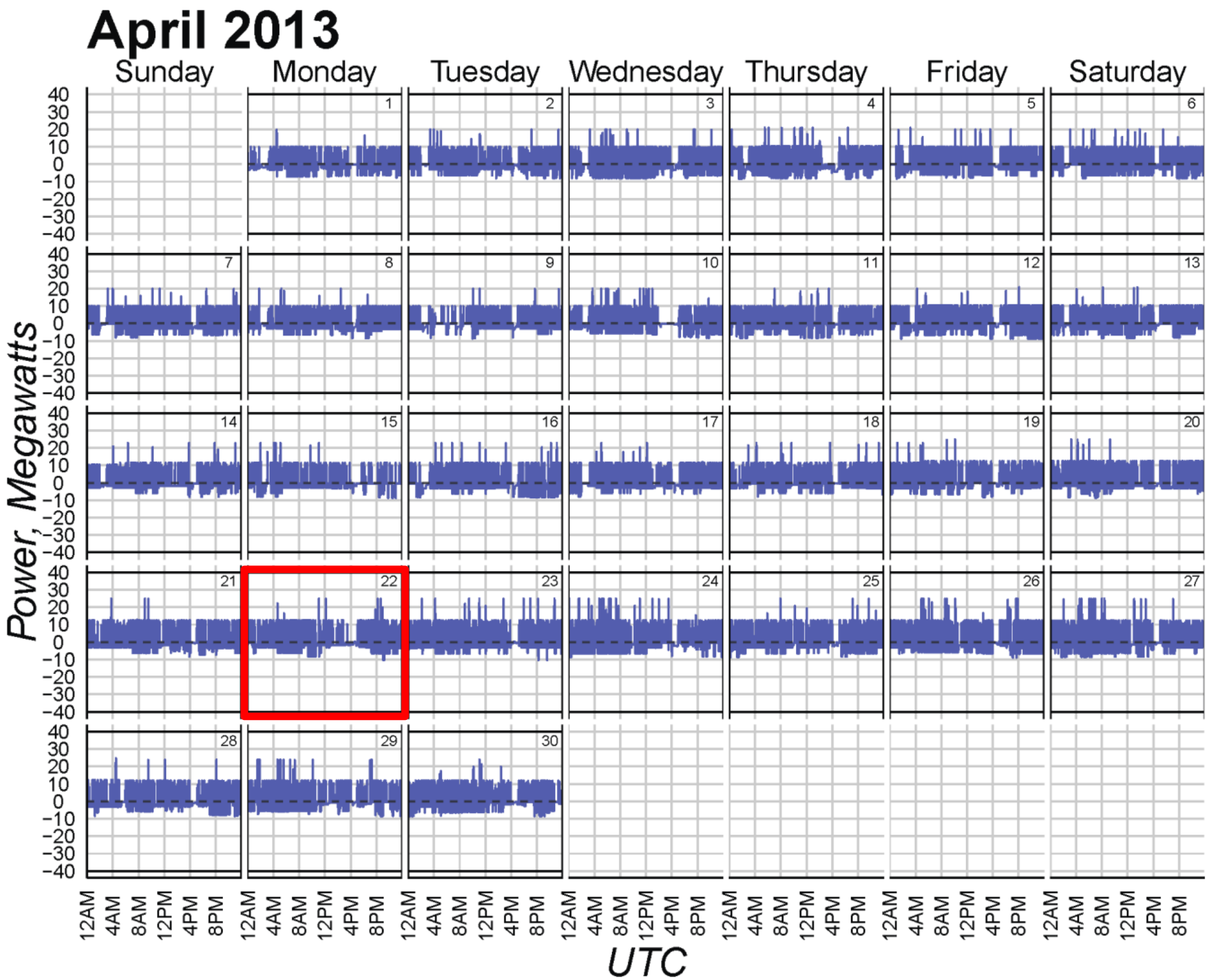


BESS stopped providing RegDown after 6/7/2013

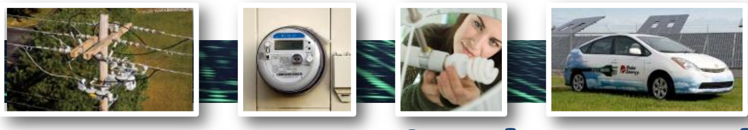
Energy Received	−40.7 MWh
Energy Delivered	24.0 MWh
Net Energy	−16.7 MWh
% Energy Delivered/Received	58.9%
Minimum Power	−3.7 MW
Maximum Power	19.9 MW
Time Charging	21.7 hours
Time Discharging	2.3 hours
% Time Charging	90.6%
% Time Discharging	9.4%
Mileage	2517.1 MW



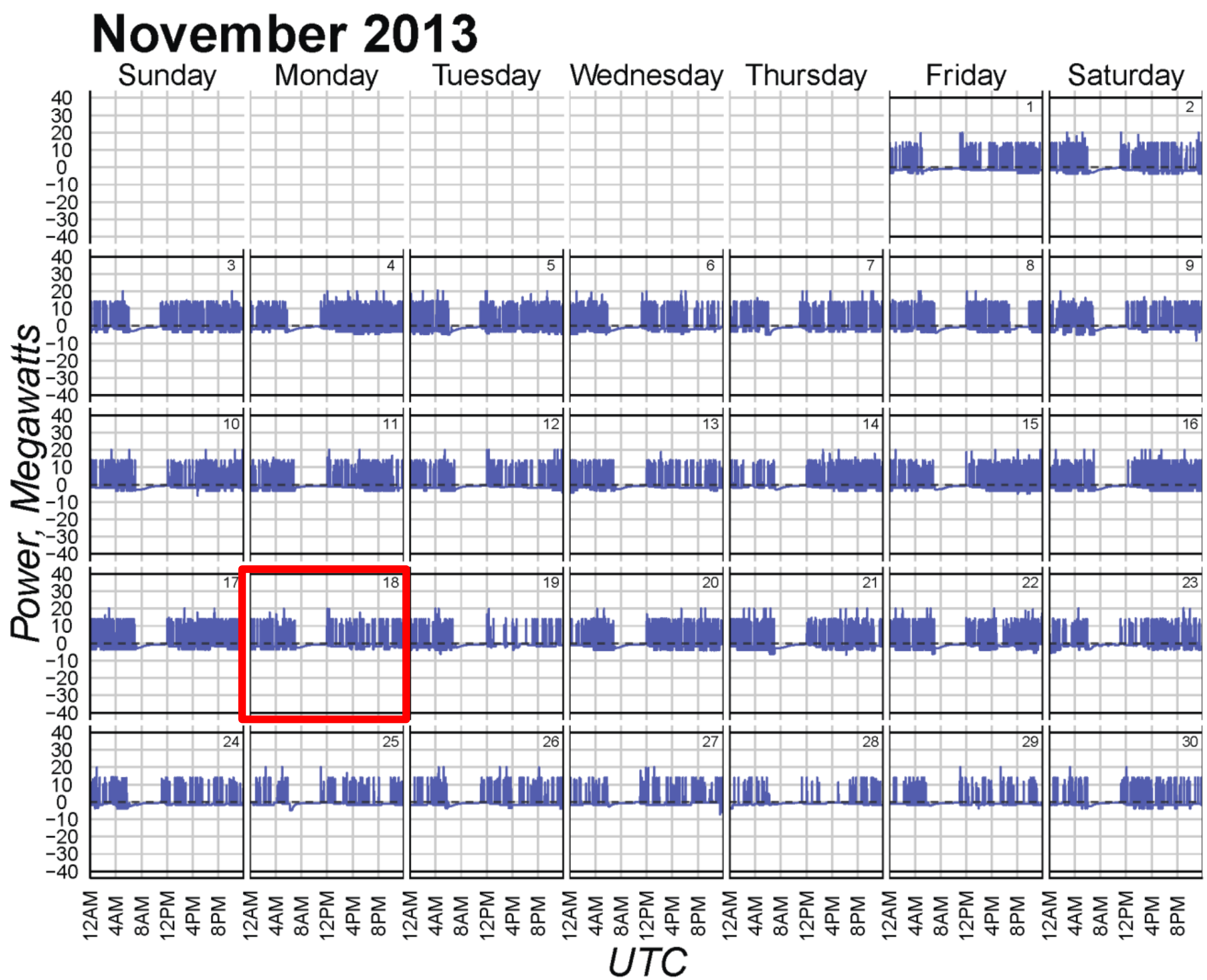
Typical Monthly Battery Operation



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



Typical Monthly Battery Operation



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

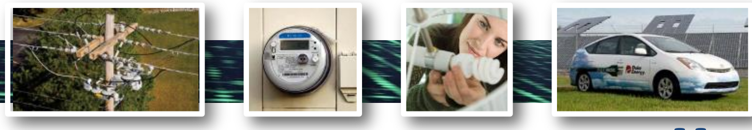
Based on the first three months of observations;

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

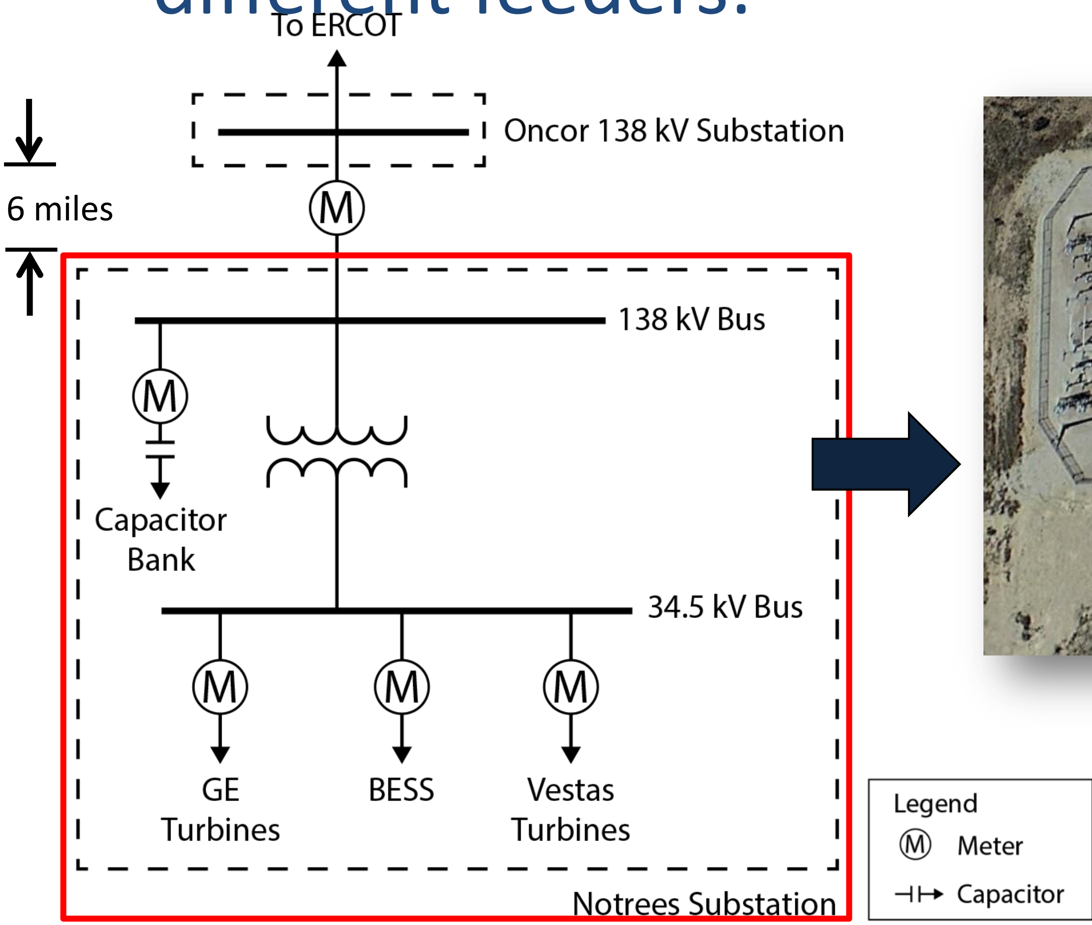


Data Collection and Analysis

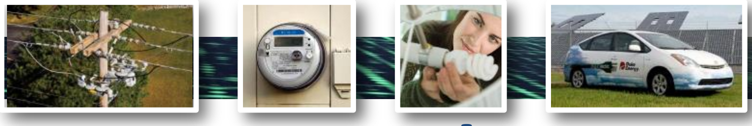
- This project requires a variety of data sets from several different sources:
  - Battery AC/DC measurements → XP (Now Younicos)
  - Ancillary services prices/awards → ERCOT
  - Settlement information → Duke/Oncor
  - Wind farm, battery output → Duke

Duke Notrees Substation Data

- The Notrees substation is metered at several different feeders:



Simplified one-line diagram



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

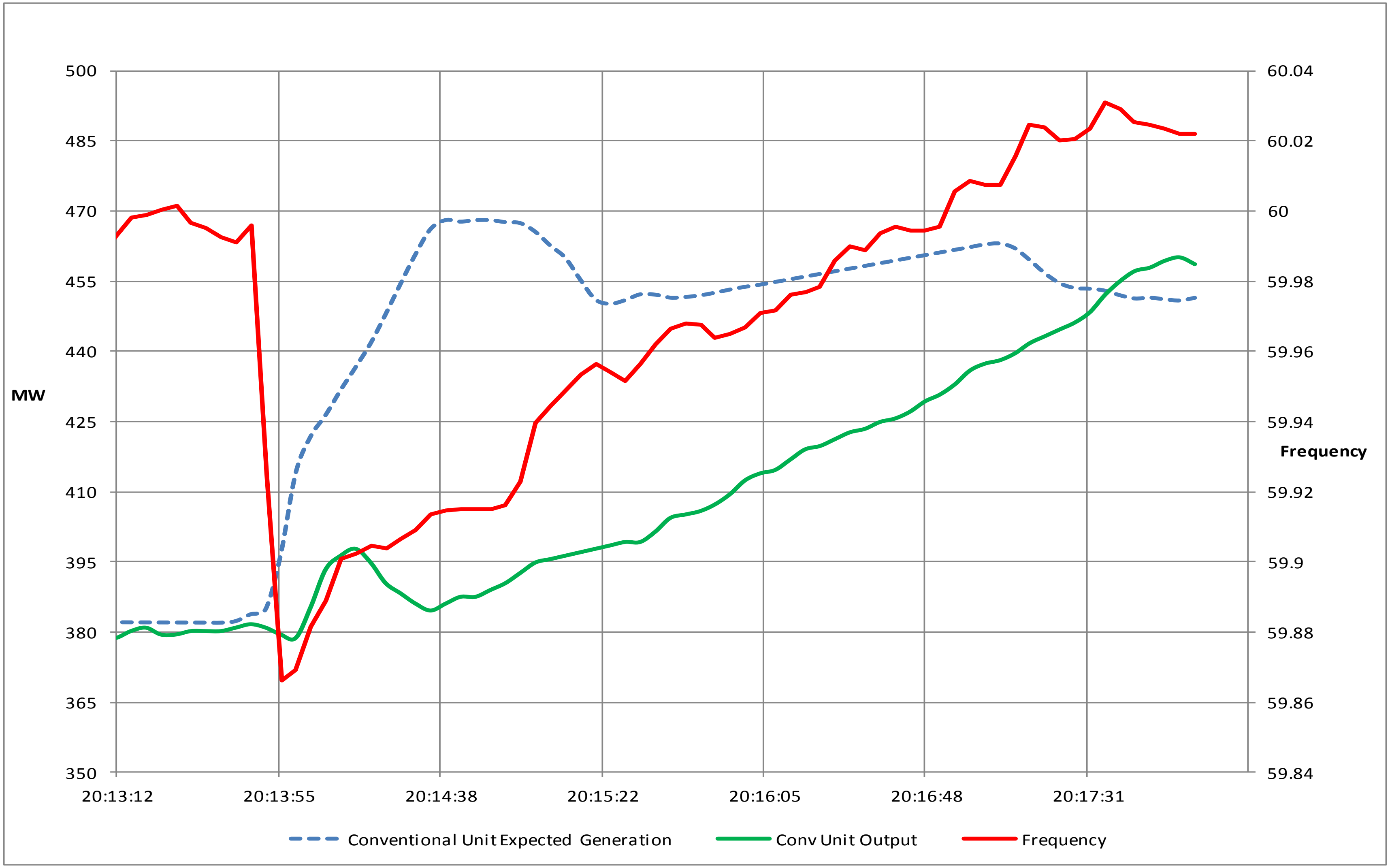
Summary Statistics Definitions

- 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

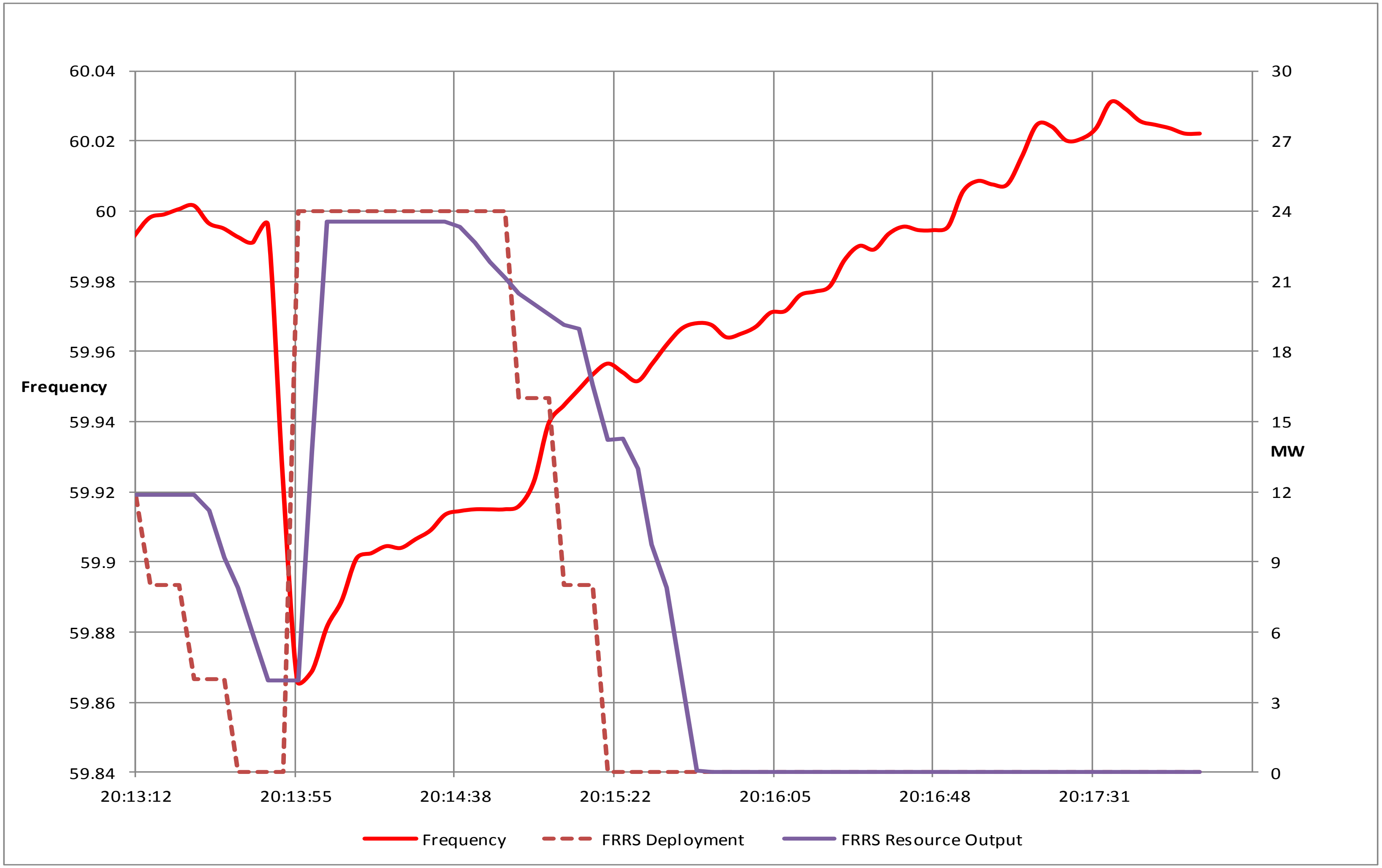
Summary Statistics Definitions

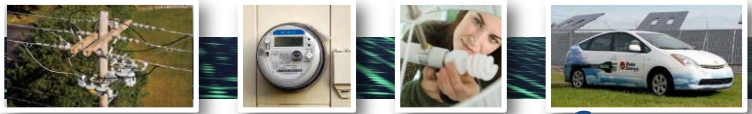
- % Energy Delivered/Received = Amount of energy delivered by the BESS divided by the amount of energy received, reported as a percentage.
- Time charging = Amount of time when the BESS power is less than zero.
- Time discharging = Amount of time when the BESS power is greater than zero.
- Mileage = Sum of absolute values of changes in power output per time step.

Response from Conventional Resource

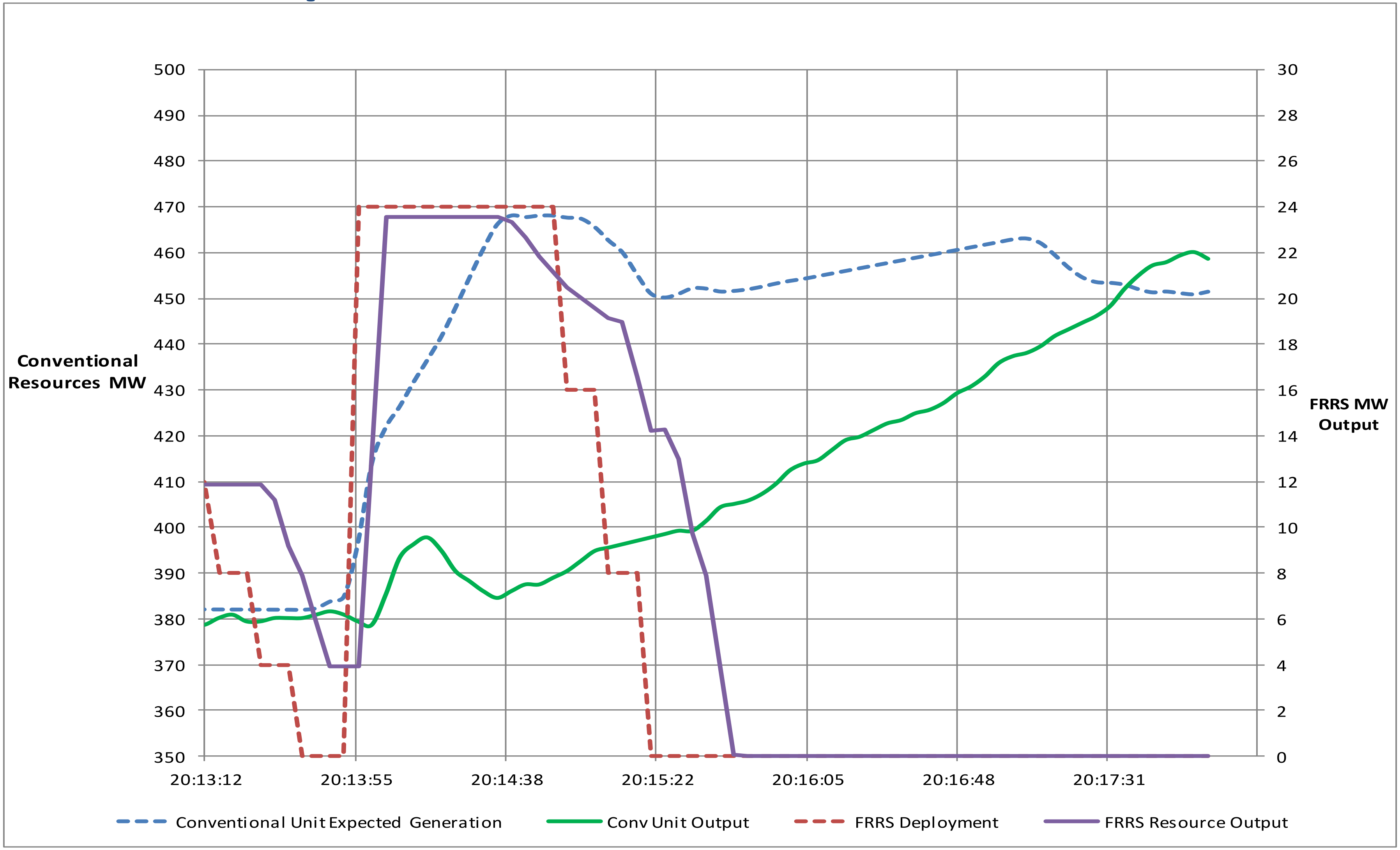


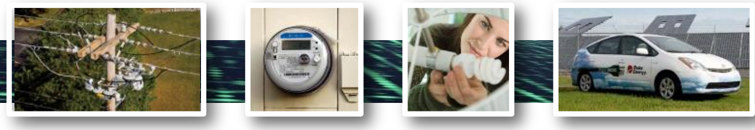
Response from FRRS Resource



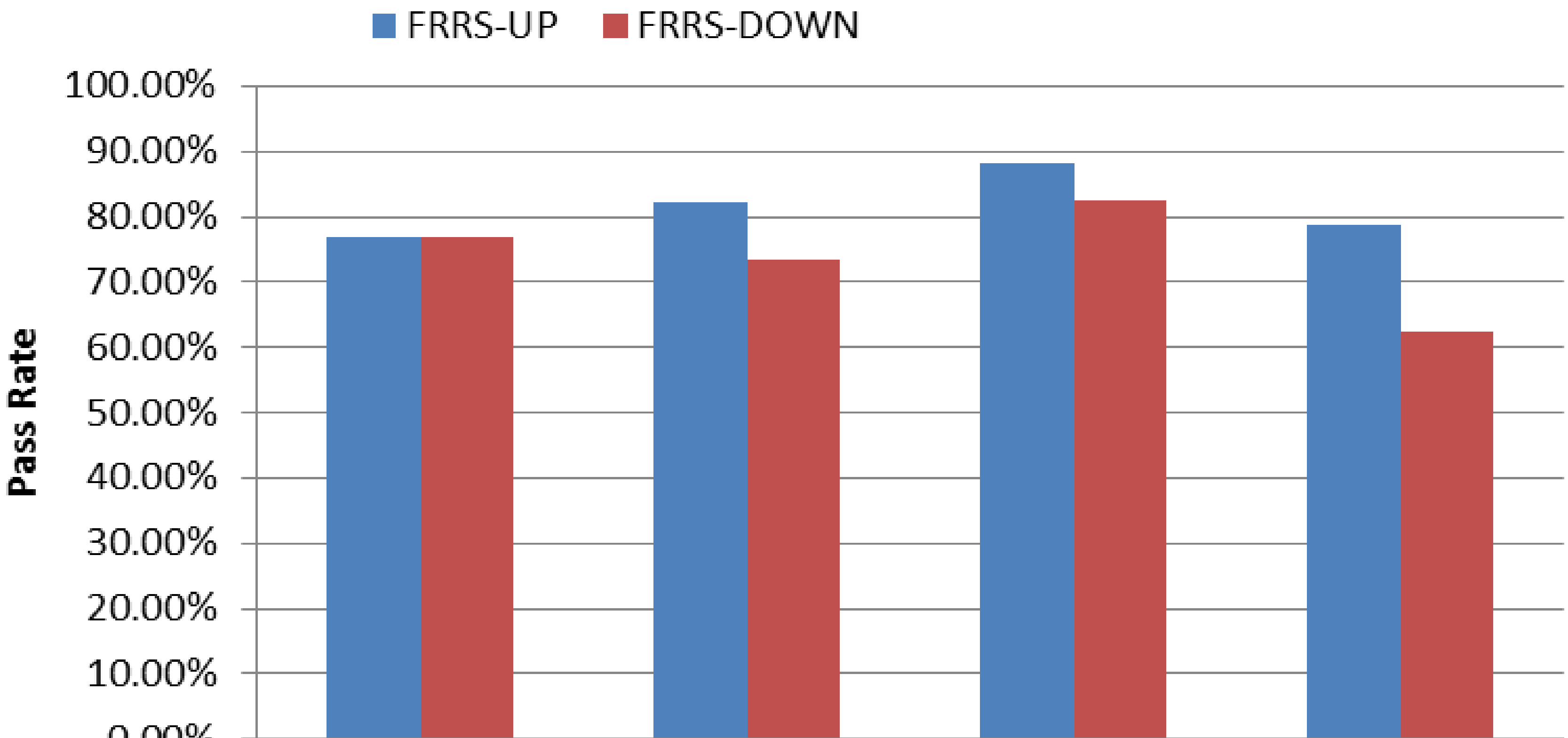


Response from Conventional and FRRS





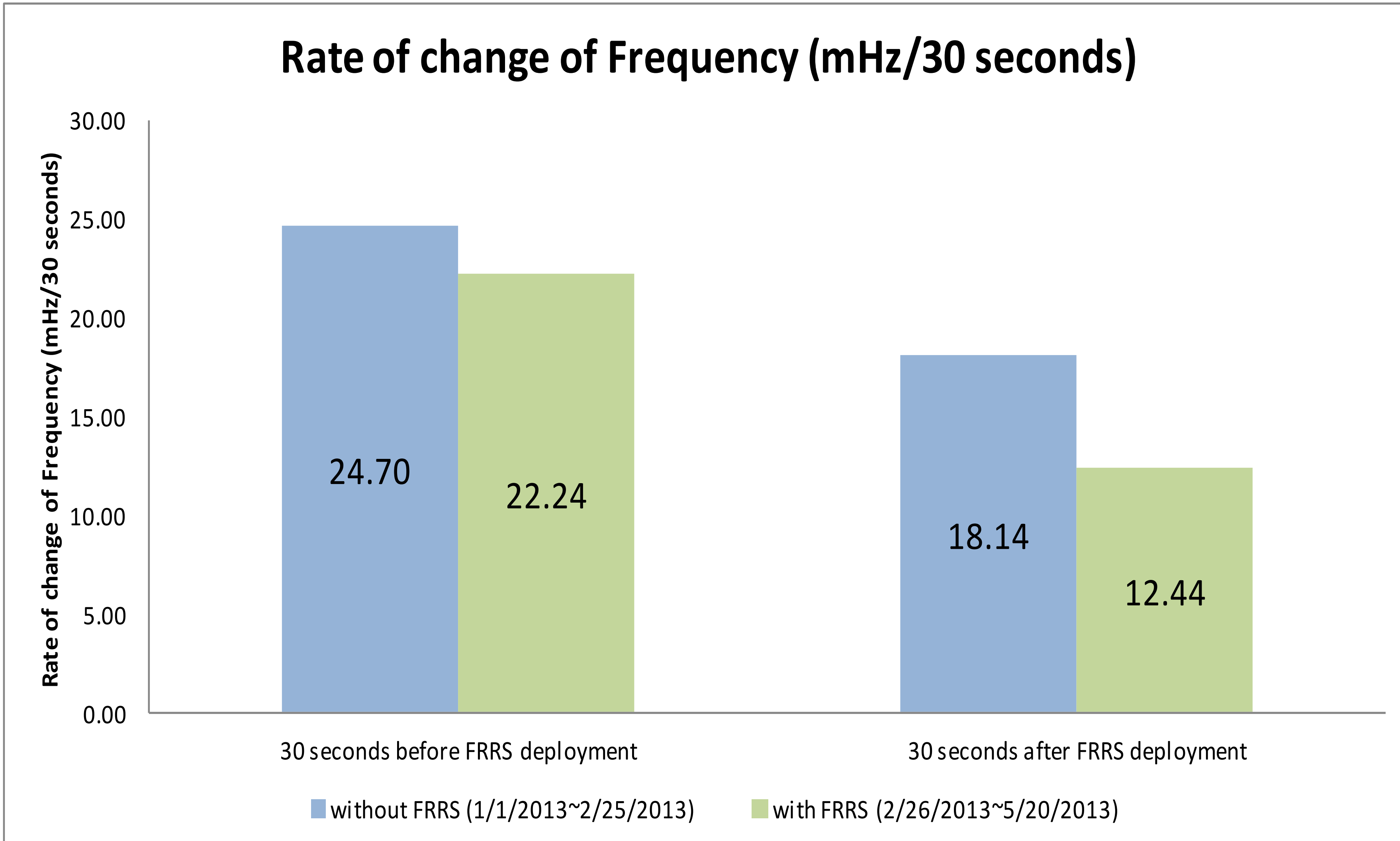
FRRS Performance

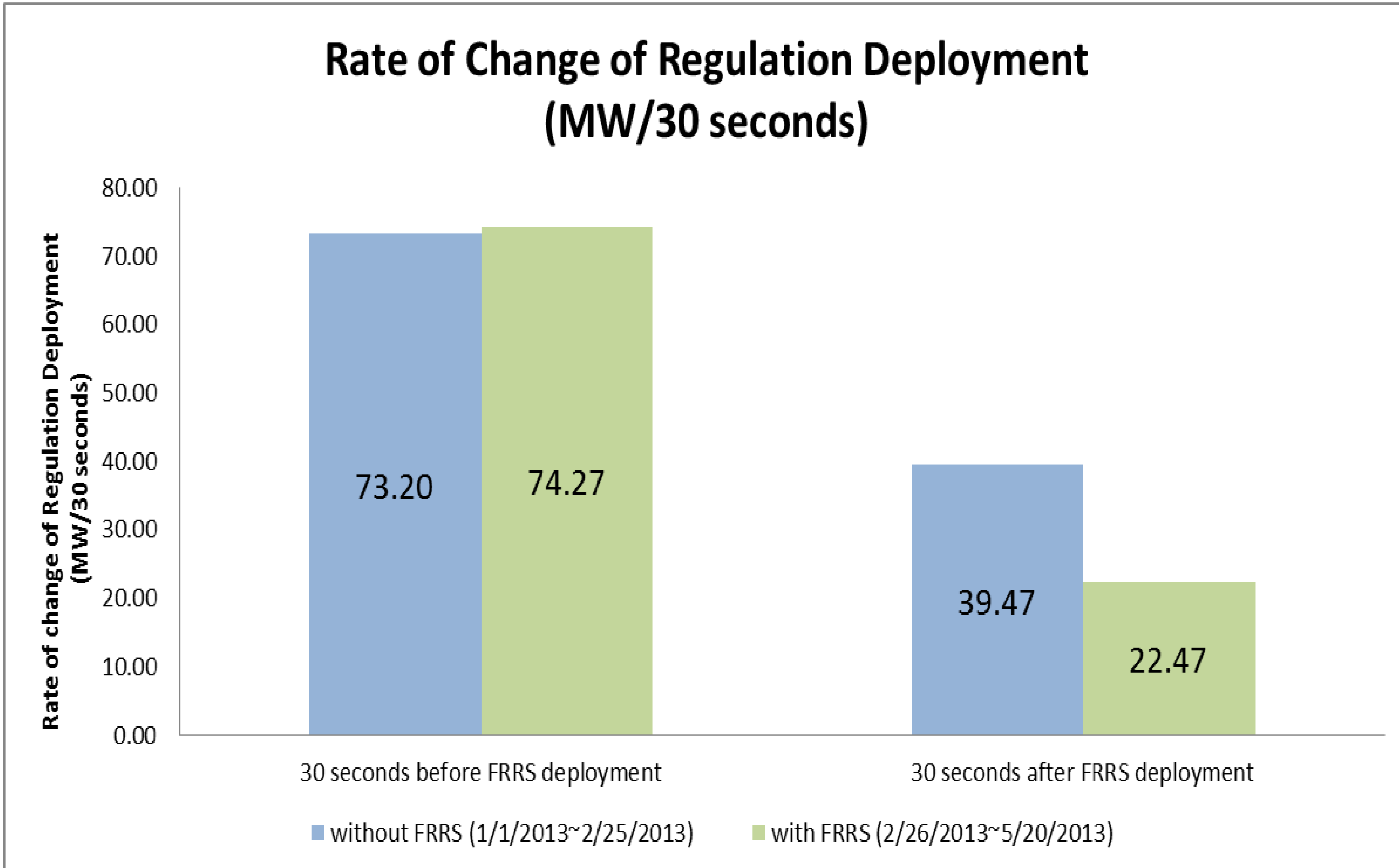


	February	March	April	May
FRRS-UP	76.83%	82.17%	88.15%	78.88%
FRRS-DOWN	76.83%	73.48%	82.39%	62.34%

RoCoF

DUKE ENERGY



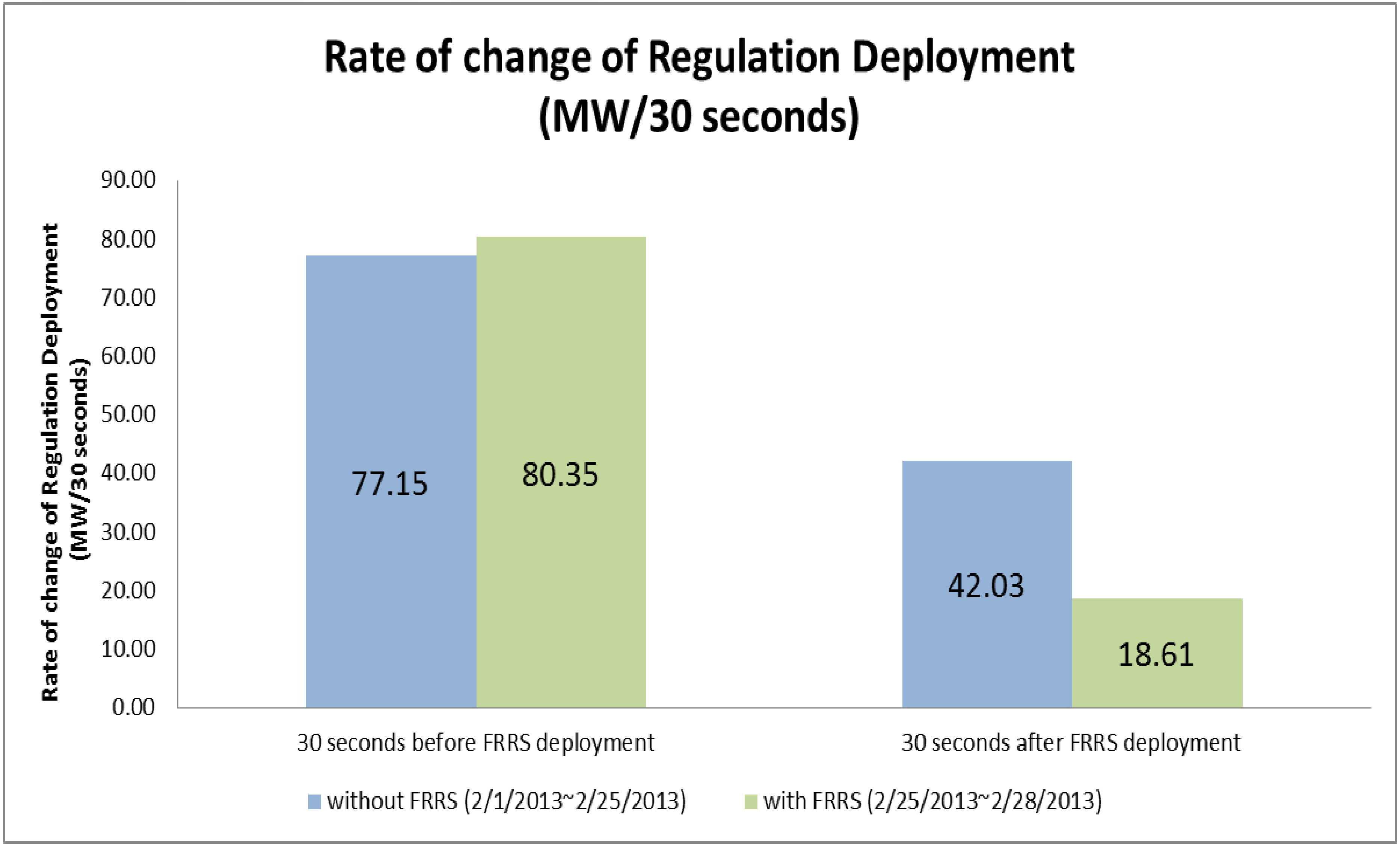

Rate of Change of Regulation Deployment
(MW/30 seconds)
Rate of change of Regulation Deployment (MW/30 seconds)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
73.20
74.27
39.47
22.47
30 seconds before FRRS deployment
30 seconds after FRRS deployment
without FRRS (1/1/2013~2/25/2013)
with FRRS (2/26/2013~5/20/2013)




Log of Parameter Changes

FAST RESPONDING REGULATION SERVICE PILOT PROJECT PARAMETER SETTINGS

Effective Date and Time	Operating Day 2-25-13 HE 11	Operating Day 3-30-13 HE 1	Operating Day 4-13-13 HE 1	Operating Day 6-3-13 HE 12
Band 1 High Trigger Frequency (Hz)	60.03	60.02	60.025	60.025
Band 2 High Trigger Frequency (Hz)	60.05	60.05	60.05	60.05
Band 3 High Trigger Frequency (Hz)	60.09	60.09	60.09	60.09
Band 1 Low Trigger Frequency (Hz)	59.97	59.98	59.975	59.975
Band 2 Low Trigger Frequency (Hz)	59.95	59.95	59.95	59.95
Band 3 Low Trigger Frequency (Hz)	59.91	59.91	59.91	59.91
Capacity Deployment in Band 1 (%)	50	50	50	60
Maximum Deployment Time per Band (sec)	120	60	60	60
Recall Interval (sec)	12	12	12	12
Single Event Reset High Trigger Frequency (Hz)	60.01	60.01	60.01	60.01
Single Event Reset Low Trigger Frequency (Hz)	59.99	59.99	59.99	59.99


Rate of change of Regulation Deployment
(MW/30 seconds)
Rate of change of Regulation Deployment
(MW/30 seconds)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
77.15
80.35
42.03
18.61
30 seconds before FRRS deployment
30 seconds after FRRS deployment
without FRRS (2/1/2013~2/25/2013)
with FRRS (2/25/2013~2/28/2013)

ERCOT FRRS Monthly Stats

	Total FRRS Deployment Durations (Hour)	Total FRRS Deployment Durations (Hour)
Month	**Down**	**UP**
February (start on 2/25)	11.42	11.17
March	106.53	120.76
April	128.86	127.89
May	90.74	92.87
June	77.3	82.27
July	74.66	79.06
August	68.95	72.26
September	77.11	86.36
October	64.33	77.03
November	61.04	74
December	42.38	59.7

Source: ERCOT

April and May 2013 Performance

April, 2013	FRRS-UP	FRRS-DOWN
FRRS Resource A	98.51%	64.77%
FRRS Resource B	77.78%	100.00%
Total Average	88.15%	82.39%

May 1 – May 20, 2013	FRRS-UP	FRRS-DOWN
FRRS Resource A	97.61%	50.00%
FRRS Resource B	60.15%	74.69%
Total Average	78.88%	62.34%

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

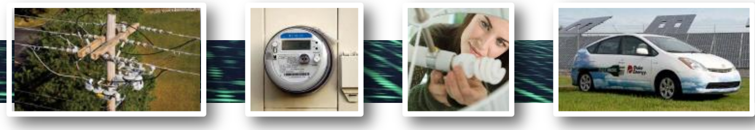
So, the pilot was constructed to observe maximum frequency impact of 0.02 Hz or 20 mHz

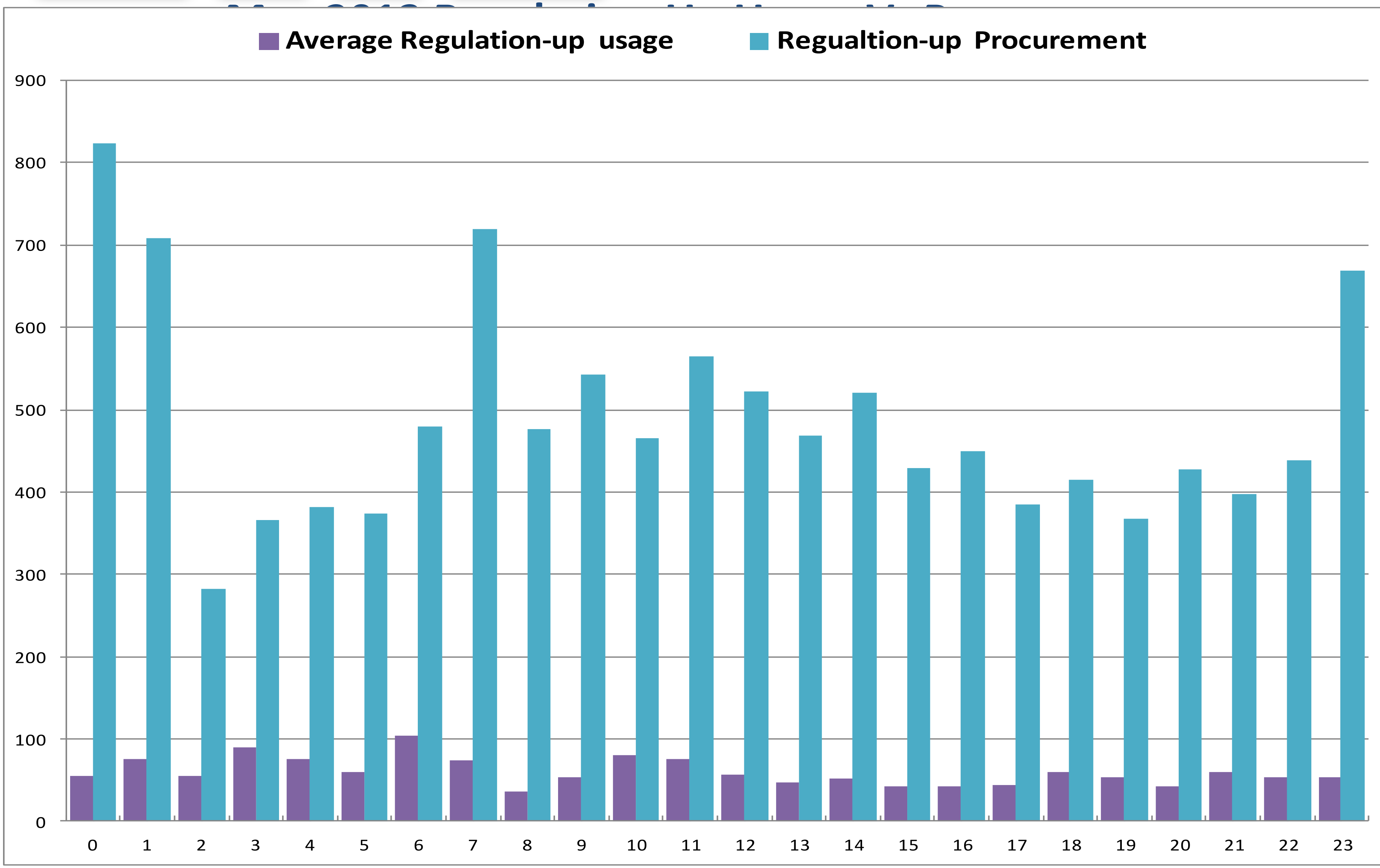
$$20\% \text{ of } 0.1 \text{ Hz} = 20\% \text{ of } 100 \text{ mHz} = 20 \text{ mHz}$$

$$\text{Resonable FRRS} - \text{UP maximum capacity} = \frac{322 \text{ MW}}{0.1 \text{ Hz}} \times 0.02\text{Hz}$$

$$= 64.4 \text{ MW} \sim 65 \text{ MW}$$

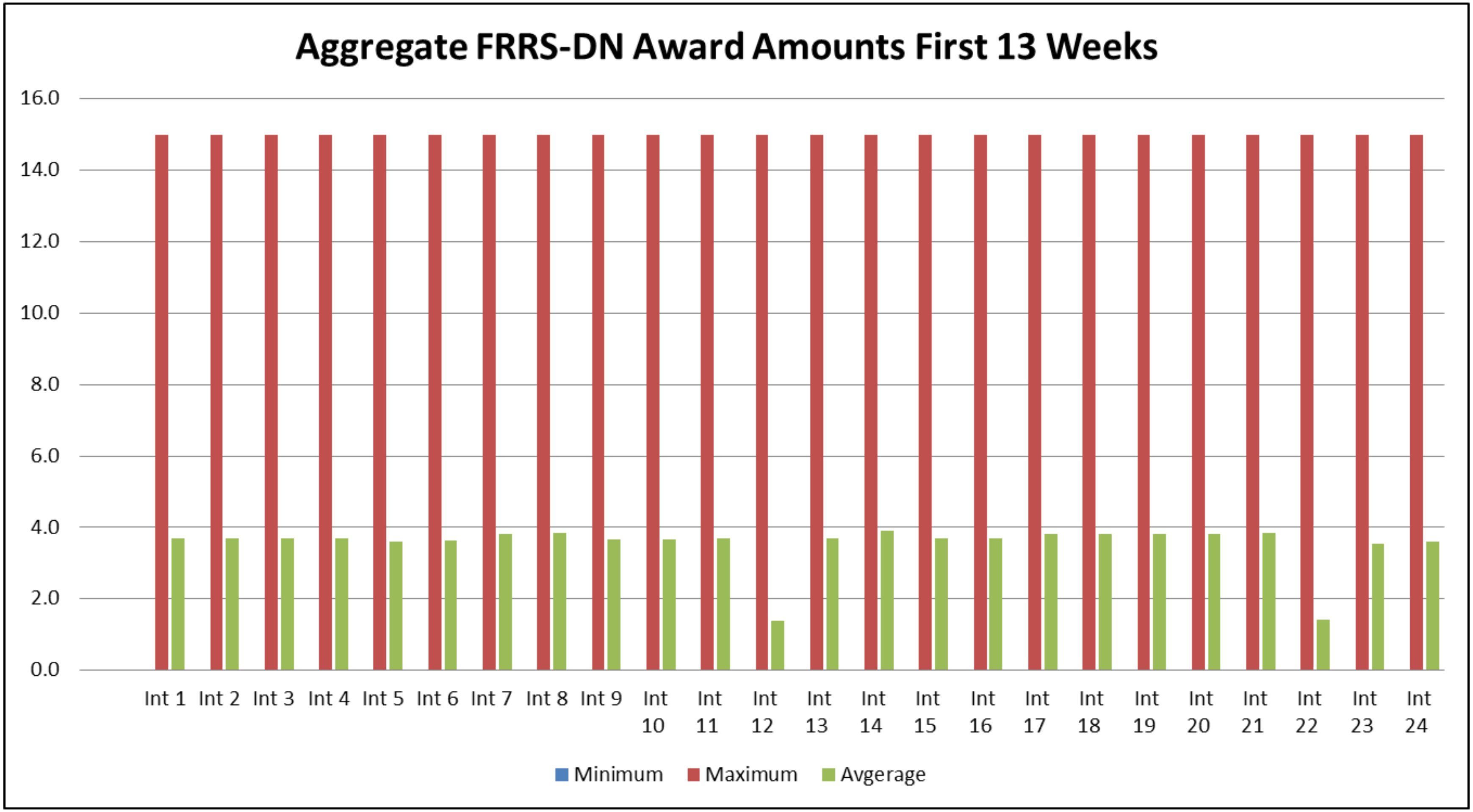
Maximum FRRS-Down designed to correct only 0.01 Hz or 10 MHz which resulted in 32.5 MW and was rounded to 35 MW.



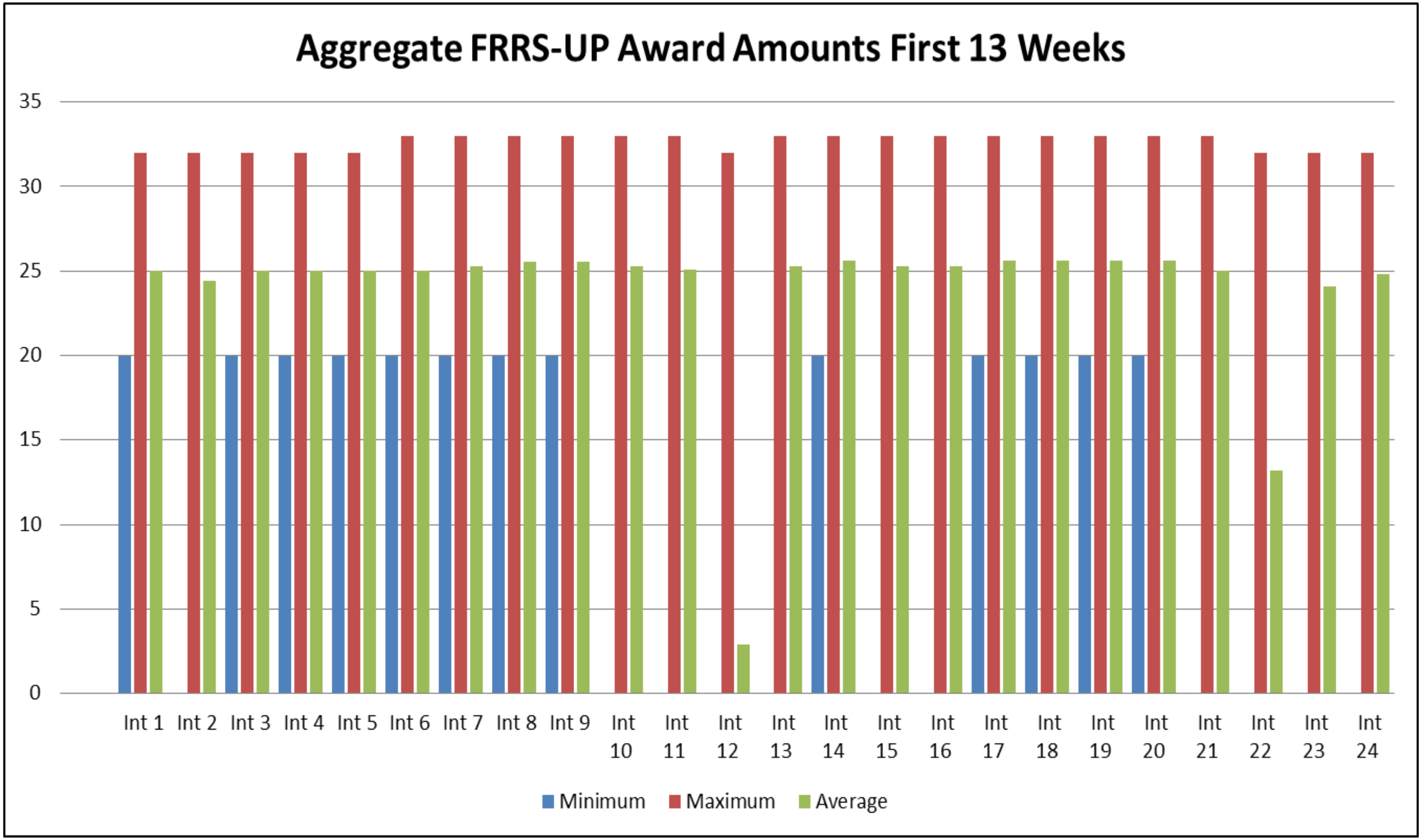


Average Regulation-up usage
Regualtion-up Procurement
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

FRRS-DN Award Amounts

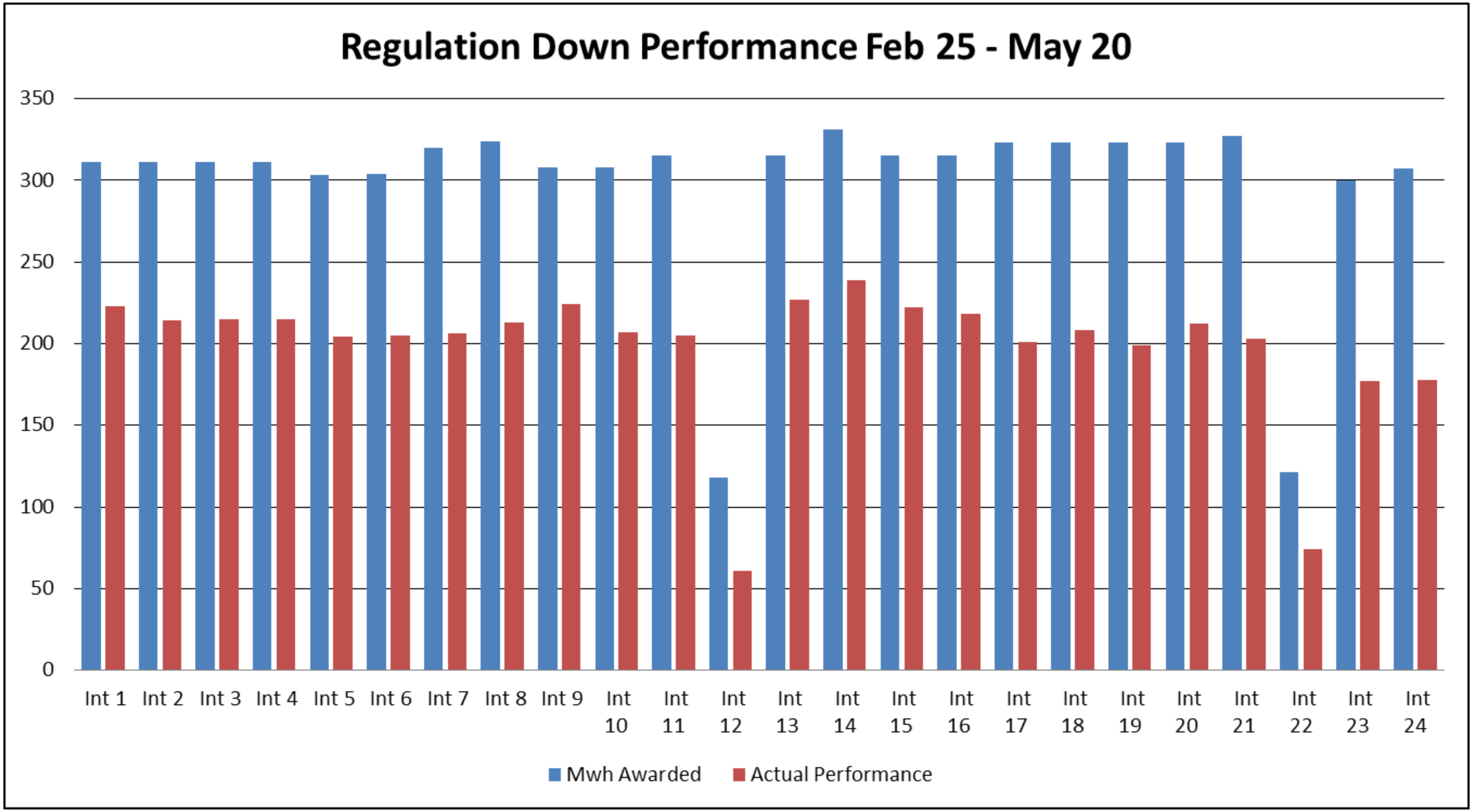


FRRS-UP Award Amounts

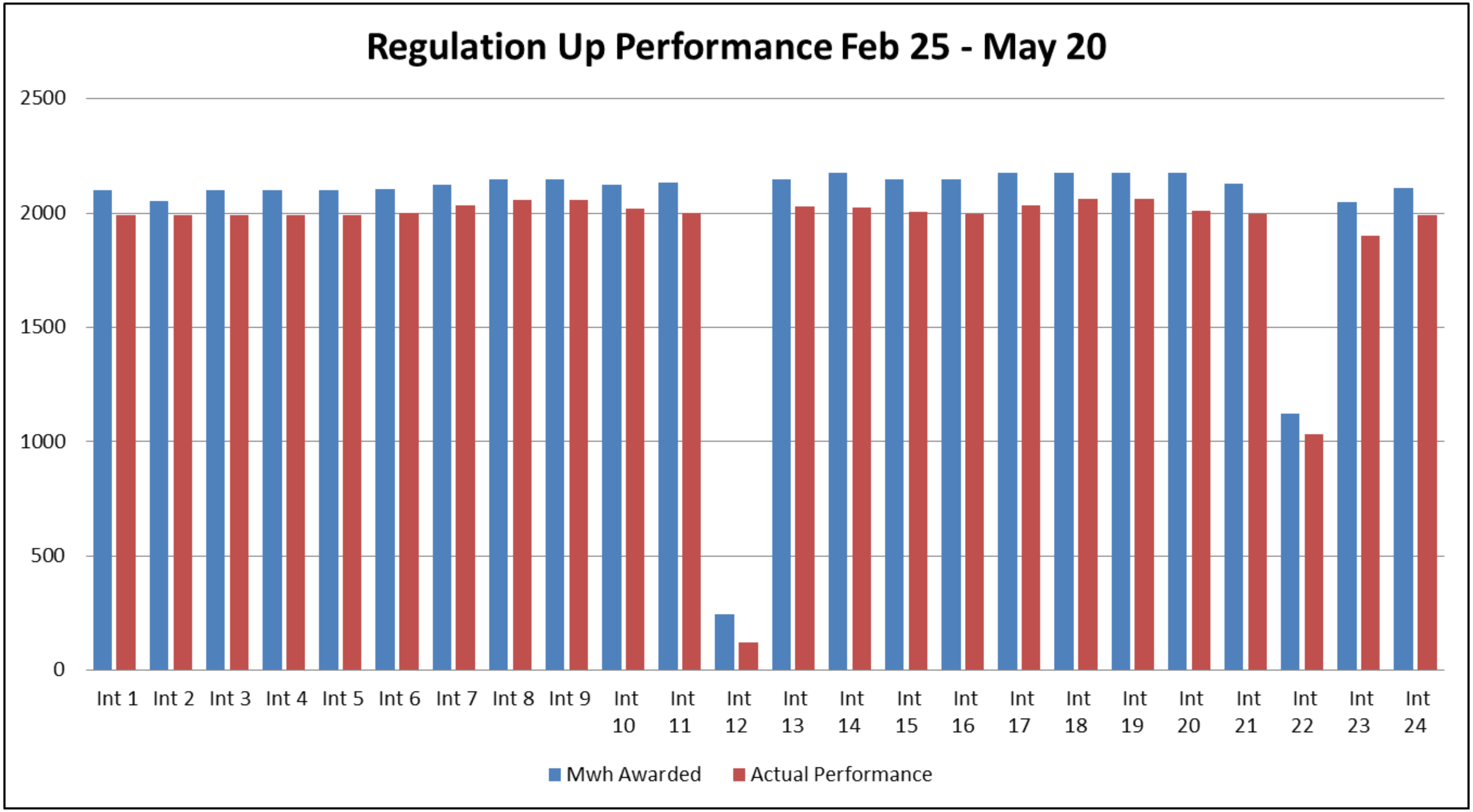


as of May 29 1100hrs

FRRS-DN Performance

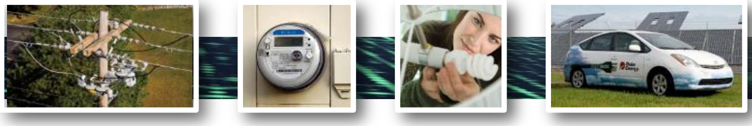


FRRS-Up Performance



Performance Rate for First 13 Weeks

FRRS MwH Awards vs Actual Performance			
Date Range Feb 25 - May 20			
FRRS Service	MwH Awarded	Performance	Overall Rate
Total RegDN	7,167	4,750	66%
Total RegUP	48,206	45,378	94%



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**

Public Utility Commission Texas

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