Technology Performance Report: Duke Energy Notrees Wind Storage Demonstration Project

2015 Final Report

Contract ID: DE-OE0000195

Project Type: Regional Demonstration

Revision: Final Submittal

Company Name: Duke Energy

November 2015

This material is based upon work supported by the Department of Energy under Award Number DE-OE0000195.

CONTENTS

LIST OF FIGURES

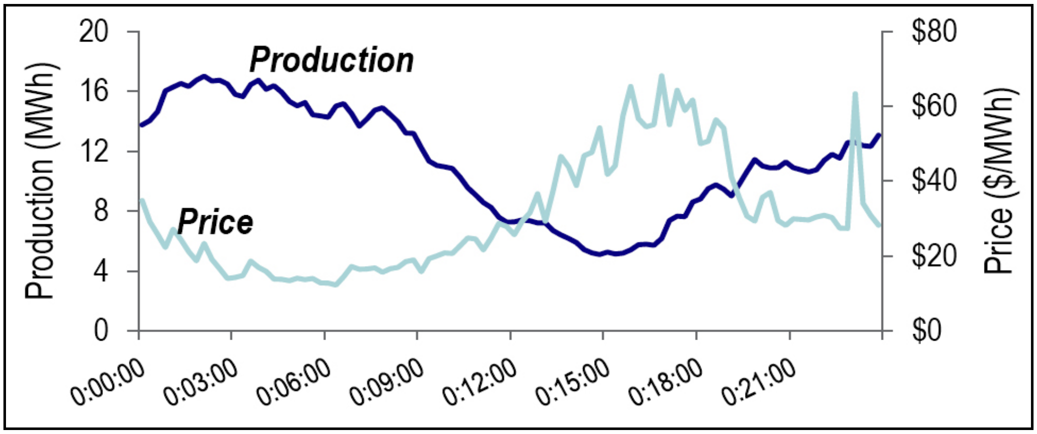
LIST OF TABLES

1

OVERVIEW OF THE ENERGY STORAGE PROJECT

Duke Energy Renewables owns and operates the Notrees Wind Farm in west Texas's Ector and Winkler counties. The wind farm, which was commissioned in April 2009, has a total capacity of 152.6 MW generated by 55 Vestas V82 turbines, one Vestas 1-V90 experimental turbine, and 40 GE 1.5-MW turbines. The Vestas V82 turbines have a generating capacity of 1.65 MW each, the Vestas V90 turbine has a generating capacity of 1.86 MW, and the GE turbines have a generating capacity of 1.5 MW each. The objective of the Notrees Wind Storage Demonstration Project is to validate that energy storage increases the value and practical application of intermittent wind generation and is commercially viable at utility scale. The project incorporates both new and existing technologies and techniques to evaluate the performance and potential of wind energy storage. In addition, it could serve as a model for others to adopt and replicate.

Wind power resources are expected to play a significant part in reducing greenhouse gas emissions from electric power generation by 2030. However, the large variability and intermittent nature of wind presents a barrier to integrating it within electric markets, particularly when competing against conventional generation that is more reliable. In addition, wind power production often peaks at night or other times when demand and electricity prices are lowest (Figure 1-1). Energy storage systems can overcome those barriers and enable wind to become a valuable asset and equal competitor to conventional fossil fuel generation.



Source: Duke Energy

Figure 1-1
Wind Power Production vs. Price of Electricity over a Typical Day

The Notrees Wind Storage Demonstration Project installed an advanced battery energy storage system (BESS) with a capacity of 36 MW/24 MWh to optimally dispatch energy production from the wind farm. Such optimization could help energy storage operators capture energy arbitrage, improve grid stability, and demonstrate renewable firming value. Additional carbon dioxide (CO_2) reduction benefits could also be realized, as energy storage will eliminate the need for fossil-fuel-based secondary generation that currently supports many wind farm operations.

In broad terms, the energy storage system was intended to:

- Integrate with intermittent renewable energy production.
- Improve the use of power-producing assets by storing energy during non-peak generation periods.
- Demonstrate the benefits of using fast-response energy storage to provide ancillary services for grid management.
- Confirm that an energy storage solution can dispatch according to market price signals or pre-determined schedules utilizing ramp control.
- Verify that an energy storage solution can operate within the market protocols of the Electric Reliability Council of Texas (ERCOT).

The BESS selected for the project was Xtreme Power's 36-MW/24-MWh Dynamic Power Resource™ (DPR) advanced lead-acid unit. The BESS, including its power conditioning system and balance of plant, is described in Chapter 2.

The Notrees Wind Storage Demonstration Project entailed an investment of more than $43 million in allowable costs from 2011 through 2014. It consisted of two phases, each of which encompassed several tasks. Site preparation began on October 1, 2011. Energy storage equipment was delivered to the site in February 2012, and installation was completed in December 2012. The project completed commercial operation testing in February 2013 and began supplying frequency regulation services to ERCOT via a pilot Fast-Responding Regulation Service (FRRS) program in February 2013, with 24 months of monitoring and analysis to follow. The FRRS pilot program concluded in February 2014, after which the BESS continued to provide Regulation services. Details regarding the system's performance are provided in Chapters 4, 5 and 6.

1.1 Phases and Tasks

Phase 1: Project Definition, NEPA Compliance and Economic Analysis

Task 1.1: Update the Project Management Plan (PMP), a management tool that continually evolves through review and reassessment, and will be updated with any significant project revisions. **Status:** The PMP was submitted to DOE on June 29, 2011.

Task 1.2: Work on National Environmental Policy Act (NEPA) compliance as required. If DOE determines that the project qualifies for Categorical Exclusion under its NEPA regulations, no additional NEPA analyses will be needed to proceed. **Status:** Duke Energy received a Categorical Exclusion in 2009 when it was selected for the project.

Task 1.3: Develop Interoperability and Cyber Security (I&CS) Plan for DOE approval. The plan will address interoperability and cyber security in every phase of the engineering life cycle of the project, including design, procurement, construction, installation, commissioning, and operation, as well as the ability to provide ongoing maintenance and support. **Status:** The I&CS Plan was submitted to DOE on May 5, 2011.

Task 1.4: Develop Metrics and Benefits Reporting Plan for DOE approval to assess the performance of the project. The plan will address improvements in or changes to grid/system configuration and performance, both technical and economic, compared to the pre-deployment baseline. **Status:** The Metrics and Benefits Reporting Plan was submitted to DOE on October 8, 2012, and final approval was received from DOE in November 2012.

Task 1.5: Determine the economic viability of the project through modeling and forecasts based on implementation in the ERCOT market using internal measurements, criteria, and standards. The decision to proceed beyond Phase 1 or terminate the project was based solely on the economic viability determination. **Status:** Task was completed June 20, 2011.

Phase 2: Project Implementation

Task 2.1: Quantify the value of wind-generated power storage, determining its costs and benefits in the ERCOT interconnection. This task will include but is not limited to:

- Supporting the business case for the application of energy storage in arbitrage of peak to non-peak energy.
- Supporting the business case for the application of ancillary services for grid management.
- Using energy storage devices to store energy during non-peak generation periods to make better use of existing grid assets.
- Confirming that energy storage increases the value of wind generation projects.
- Confirming that energy storage eliminates hurdles faced by wind generation when entering markets, such as an interconnect, due to its intermittency.

Task 2.2: Demonstrate the technical readiness of the equipment via design, installation, and testing of all necessary components to show the functionality of wind storage in the ERCOT interconnection. System testing will include but is not limited to:

- Verifying technical performance and validating system reliability and durability in a large-scale application that can be applied to and will benefit the increasing amounts of renewable energy in the United States.
- Ensuring that site supervisory control and data acquisition (SCADA) systems can properly control a power storage unit in addition to controlling the site generation.
- Confirming the technical capabilities of energy storage in a market setting.
- Demonstrating ramp-rate control to minimize need for fossil-fueled backup generator operation.
- Determining the ability to operate within the interconnect market structure with the delivery requirements currently in place.

Task 2.3: Demonstrate the reliability and capability to dispatch stored wind energy through at least 24 months of continuous testing and operation. The demonstration shall include, but is not limited to:

- Proving that wind can dispatch according to a market price signal and/or pre-determined power purchase agreement (PPA) schedule.
- Increasing the ability to dispatch wind-generated energy using the storage application. Provide multiple services including system balancing and improved wind energy delivery to the grid.
- Using successful results to drive strategic commitment to invest in wider-scale deployment.
- Advancing the state-of-the-art on integrating energy storage with wind generation at the source.
- Confirming commercial availability and viability: determining if energy storage solutions are commercially viable in supporting wind generation, and confirming the commercial availability of large energy storage solutions as necessary for wind farms.

Phase 2 tasks were completed to the extent possible upon the conclusion of the project in December 2014, and the BESS continues operations through 2015. This report summarizes the results of those efforts to date.

1.2 Project Team

The Notrees Wind Storage Demonstration Project was led by Duke Energy, with support from the Electric Power Research Institute (EPRI). Duke Energy Renewables is the owner and operator of the Notrees Wind Farm, and provided operational expertise during the project's design, installation, commissioning, and operation.

EPRI supported Duke Energy in developing the project's Metrics and Benefits Reporting Plan (MBRP), documenting the vendor's factory/site-acceptance testing, monitoring and analyzing system performance and operational experience, developing the ERCOT System Benefit Analysis, and in preparing reporting, technology transfer, and case study deliverables.

The key vendor for the project was Xtreme Power, whose role consisted of manufacturing the BESS along with engineering, procurement, and construction. Xtreme Power filed for bankruptcy in January 2014, and was acquired by Younicos AG.

Transmission services were provided by Oncor, operator of the largest distribution and transmission system in Texas, which delivers power to approximately 3 million homes and businesses.

Roles and Responsibilities

Figure 1-2 provides more details about the composition of the project's executive sponsors, core team, and installations and operations support personnel.

Duke Energy personnel participating in the project include:

- Jeff Wehner, Vice President, Renewables Operations: Overall operational lead of Duke Energy's wind assets.
- David Mohler, Vice President, Emerging Technologies: Leads Duke Energy's research and development.
- Stuart Gibson, Manager–Production: Leads the Notrees Wind Farm operations, and will provide on-going operational support to the storage system.
- Jason Clanin–Engineering: Leads Duke Energy Renewables' design engineering and project management.
- Don Faris–Sourcing: Led the competitive sourcing process to identify the energy storage solution provider, Xtreme Power.
- Kevin Hooker, Director, Commercial Transmission: Leads Duke Energy's commercial efforts to develop, build, operate and maintain energy storage projects and provides on-going support for demonstration projects including energy storage.
- Michael Rowand, Director Technology Development: leads Duke Energy's technology efforts in energy storage.

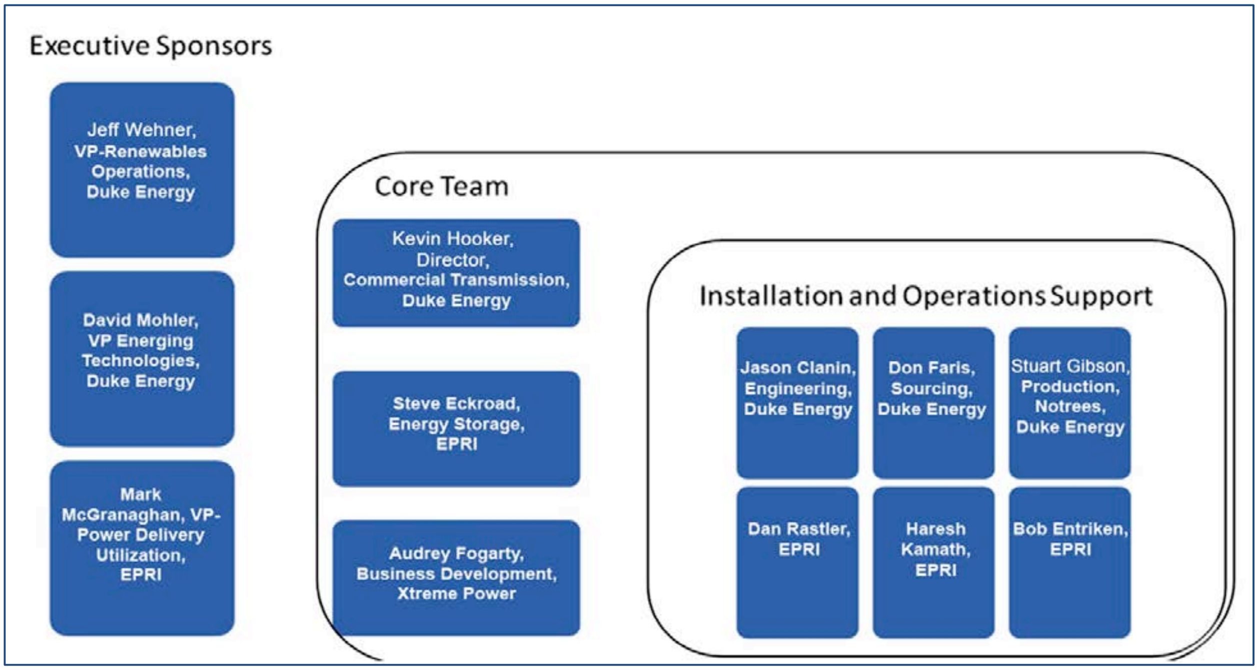


Figure 1-2
Organizational Structure of the Executive Sponsors, Core Team, and Installation and Operations Support

1.3 Project History

In November 2009, DOE awarded Duke Energy a $21.8 million cost-shared cooperative agreement for the Notrees Wind Storage Demonstration Project, funded through the American Recovery and Reinvestment Act (ARRA) of 2009. EPRI was a sub-recipient on the cooperative agreement. The project was one of 32 that DOE awarded a total of $620 million to demonstrate advanced smart grid technologies and integrated systems including large-scale energy storage, smart meters, and distribution and transmission monitoring devices. In January 2011, DOE and Duke Energy agreed upon the terms and conditions of the cooperative agreement.

EPRI assisted with the request for proposal (RFP) process that resulted in Xtreme Power's selection as the BESS provider. An economic viability model developed by Integral Analytics helped Duke Energy conduct an economic viability analysis, which was successfully completed in June 2011.

Project construction was completed in October 2012, performance testing completed in December 2012, and commercial operation testing completed in February 2013. In February 2013, the Notrees Wind Storage Demonstration Project began providing frequency regulation services to ERCOT via a Fast-Responding Regulation Service (FRRS) pilot program. The test plan called for gathering 24 months of data, which was completed in February 2015. This report is the final Technology Performance Report (TPR) for the project as required by DOE.

In September 2013, the Notrees Wind Storage Demonstration Project received the top utility-scale energy storage innovation award at the 2013 Energy Storage North America (ESNA) Conference and Expo in San Jose, California. Award winners were judged on services provided to the grid, financing options, ownership model, and technology strengths.

1.4 EPRI Reporting on the Project

This final TPR provides an overview of the Notrees Wind Storage Demonstration Project and its objectives, characterizes the BESS technology, and summarizes project activities from on-site construction in 2012, through commercial fast-responding regulation service (FRRS) operations in 2013 and 2014, to the conclusion of the demonstration in December 2014. Previous EPRI Technical Updates on the project served as interim reports on the demonstration in progress.

2

ENERGY STORAGE TECHNOLOGIES AND SYSTEMS

2.1 Xtreme Power Company Overview

Xtreme Power, Inc. was founded in 2004 and was headquartered in Kyle, Texas. It was backed by investors SAIL Venture Partners, Bessemer Venture Partners, Dow Chemical Company, Fluor Corp., BP Alternative Energy, Dominion Resources, POSCO ICT, SkyLake & Co., and Spring Ventures LLC. The company characterized itself as a system supplier/developer that provided turnkey utility-scale energy storage solutions based on its proprietary advanced lead-acid energy storage technology, commercialized as the DPR (Dynamic Power Resource) unit.

Xtreme Power took a vertically integrated approach to system design, designing the entire system in-house, including the battery cell, power electronics, balance of plant, and the controlled dispatch of the system as required by the customer. However, in April 2013, Xtreme Power announced that it would stop making battery cells and focus on software for integrating and controlling battery systems.

In January 2014, Xtreme Power filed for Chapter 11 bankruptcy in the U.S. Bankruptcy Court. In April 2014, Younicos Inc., a wholly-owned subsidiary of Younicos AG, a Berlin-based company, announced that it had acquired Xtreme Power's assets with a winning bid in a Chapter 11 auction supervised by the U.S. District Bankruptcy Court of West Texas. Through this transition, the Notrees BESS continued to operate normally.

Beyond the wind power integration/distribution support functionality, Xtreme Power targeted its DPR product to serve multiple transmission and distribution applications, including solar integration, microgrid, and smart-grid applications. Xtreme Power did not sell individual batteries for test or application; all energy storage equipment was sold and installed as an integrated system. This marketing approach, which involves turnkey systems complete with the SCADA required for management of the system, is typical of previously successful energy storage systems entering the utility market space.

Precedent Applications

Xtreme Power has deployed its DPR systems to provide energy storage for other wind power projects, notably three collaborations with First Wind in Hawaii:

- The Kaheawa Wind Power Project in Maui, Hawaii: a 1.5-MW/1-MWh DPR unit integrated with a 30-MW wind farm.
- The Kahuku Wind Power Project in Oahu, Hawaii: a 15-MW/10-MWh DPR system integrated with a 30-MW wind farm.
- The Kaheawa Wind Power II Project in Maui, Hawaii: a 10-MW/20-MWh DPR system integrated with a 21-MW wind farm.

The first Kaheawa project was installed to prove the renewable integration concept, and successfully controlled ramp rates and passed curtailment capture tests (Figure 2-1). The Kahuku project was subsequently located at the end of a 12.47-kV radial line and is required to control ramp rates to ±1 MW/min. A fire destroyed the battery facility at Kahuku in August 2012. The Kaheawa II project addresses the issue of curtailment as renewable energy penetration rates increase on Maui. In addition, it provides ramp control, and frequency and voltage regulation services.

Figure 2-1
1.5-MW/1-MWh Kaheawa Wind Power Project in Maui, Hawaii

2.2 Xtreme Power PowerCell™

Xtreme Power's battery technology was an enhanced version of the Electrosource Horizon battery, an advanced starved-electrolyte lead-acid battery developed for electric vehicle applications. The company acquired the assets of Electrosource in the early 2000s and continued to develop the technology. The fundamental component of the DPR is Xtreme Power's PowerCell™, a 12-volt, 1-kWh (at a three-hour discharge rate) dry cell battery with an energy density greater than 39 Wh/kg (Figure 2-2).

Figure 2-2
Xtreme Power's PowerCell

The PowerCell is based on the concept of substantially increasing plate surface area while still providing adequate active material to support an energy application. The innovative plates are composed of metal-alloy-coated, ballistic-grade fibers woven together to offer structural integrity as well as multiple pathways for ultra-low-impedance current flow both in and out of the battery. These proprietary alloys form bi-polar plates that provide significant nanoscale surface area for chemical reactions to take place, resulting in extremely low internal resistance (less than 10 milliohms). Each PowerCell is 30 x 5 x 5 inches (76 x 13 x 13 cm) in size and weighs 54.6 pounds (24.8 kg).

Because of the extensive surface area of the PowerCell's plates, the battery has the ability to absorb high power in charge mode, as well as deliver high power to the load. These operational conditions can be supported while operating the system at a partial state of charge (SOC) with no detrimental sulfation buildup in the battery and no thermal hot-spot development.

The PowerCell can deliver a greater number of deep cycles than is currently offered by traditional lead-acid energy batteries. Its design inhibits or eliminates many of the failure mechanisms characteristic of traditional lead-acid designs when operated in the partial-SOC energy/power environment required in a regulation application, where it is necessary to charge and discharge at variable and sometimes high rates to regulate power flows in transient environments typical of a wind farm. Nominal DC voltage ranges from 950 to 1200 V_{DC}, with 750 V_{DC}/1250 V_{DC} charge-discharge characteristics. Maximum continuous current is 2500 A for 30 seconds, while maximum battery discharge is 4 hours for a total of 1000 deep cycles. Typically, however, the Xtreme battery is operated at a 45% SOC to enable constant up/down charge or discharge functionality, depending on the application being performed.

The warranty curve for the PowerCell illustrates the relationship between the battery's discharge rate cycle life and the change in SOC (Figure 2-3). While PowerCell life cycle is warranted according to the graph below, previous PowerCells have demonstrated greater than 3 million cycles in the field.

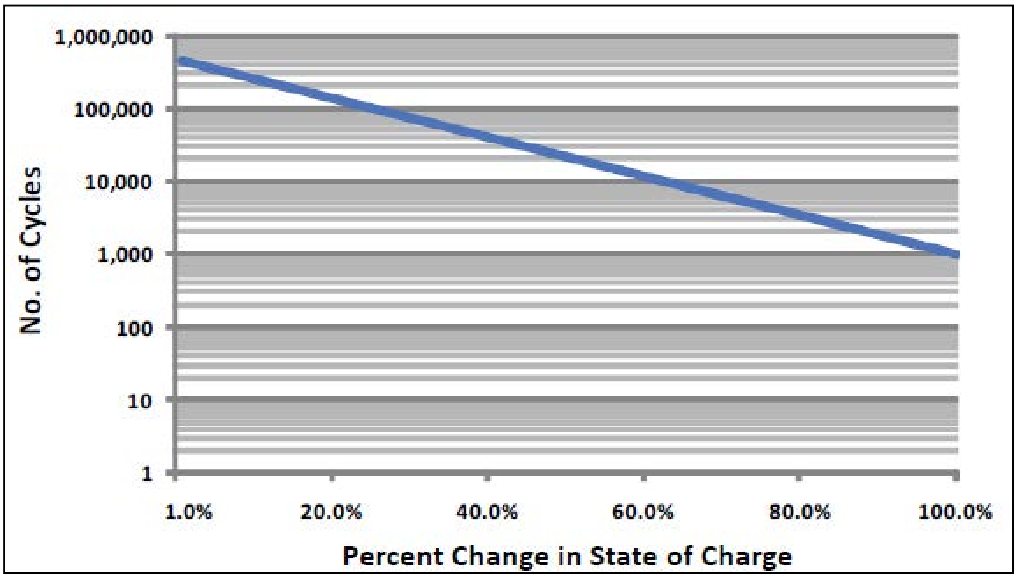


Figure 2-3
Xtreme Power's PowerCell Warranty Curve

2.3 PowerCell Module

A PowerCell Module has two major components: a PowerCell Pack, which provides 1.0 MWh of energy storage, and a Power Unit, which is a 1.5-MVA power conditioning system (PCS). Although this equipment may be deployed in a 40-foot transportable container, for the Notrees Wind Energy Demonstration Project it was installed inside a large building constructed near the wind farm, with appropriate aisle spacing between the battery packs and PCS. Each component of the PowerCell Module is described below. The Notrees project employs 24 PowerCell Modules to comprise a Dynamic Power Resource™ (DPR) energy storage system.

As illustrated in Figure 2-4, PowerCells are arrayed in two parallel racks, each holding 500 kWh of storage, connected to the PCS. Figure 2-5 is a photo showing rows of PowerCell Packs (left) and PCS units (right) as installed at the Notrees site.

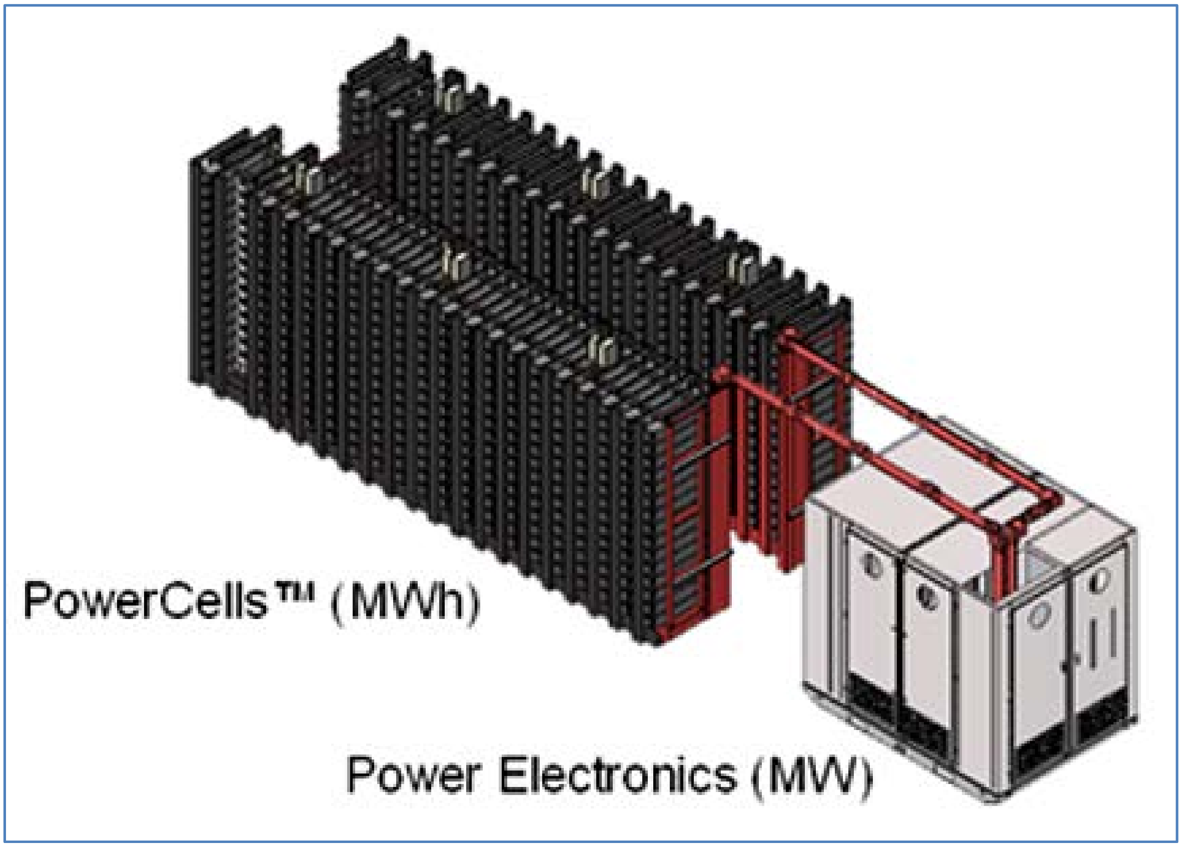


Figure 2-4
Components of a PowerCell Module: A paired PowerCell Pack and PCS

Figure 2-5
PowerCell Modules Installed at Duke Notrees Wind Storage Project (batteries at left, PCSs at right)

PowerCell Pack

A PowerCell Pack consists of 1200 individual PowerCells arranged in a matrix of 15 parallel stacks, 80 in series, housed in a "double-high" rack configuration. Each 1.0-MWh PowerCell Pack has the following characteristics:

- PowerCell Pack Nominal DC Voltage Range: 800-1100 V_{DC}
- PowerCell Pack Minimum Discharge DC Voltage: 750 V_{DC}
- PowerCell Pack Maximum Charge DC Voltage: 1250 V_{DC}
- PowerCell Pack Maximum Continuous Current: 2000 A
- PowerCell Pack Maximum Overload Current: 2812 A
- PowerCell Pack Input DC Ripple Current: <2% rms.

Power Unit

Provided as part of Xtreme Power's turnkey package, the Power Unit is a bi-directional PCS manufactured by Dynapower Corp. It is a 1.5-MW/1.5-MVA four-quadrant bidirectional inverter/charger that accepts P (active or real power) and Q (reactive power) commands. It is specifically designed for energy storage applications with the following characteristics in grid-tied operation:

- Rated Output Real/Reactive Power: 1.5 MW/1.5 MVA
- Nominal Frequency: 60 Hz
- Rated output voltage: 480 V_{AC}, three-phase
- Rated Output Current: 1800 A rms
- Maximum Continuous Output Current: 2000 A rms

- Maximum Overload Output Current: 2700 A rms
- Weight: 7200 pounds (approximately 3300 kg)
- Dimensions: 89H x 48D x 116W inches (approximately 230H x 120D x 290W cm).

The inverter includes integrated cooling and system controls, as well as a full complement of switchgear including AC circuit breaker, AC contactor, DC load break contactors (allowing for the connection of individual battery strings), and DC manual isolation switch, all housed in a heavy-duty industrial enclosure.

The PCS provides control functionality and system status information, and instructs the BESS's multiple modes of operation. It has an estimated efficiency in the 95% range. Fundamentally, it is responsible for preventing permanent damage to the battery due to excessive charging and/or discharging commands in all modes of operation. Remote battery monitoring and management is achieved through the Real-Time Control System, which is described below. In addition, the PCS has the following attributes:

- *System Voltage Protection and Regulation*—Overcurrent and overvoltage transient protection. The DPR meets BIL surge requirements, based upon IEEE Std. C62.45-2002, IEEE Std. C62.41.2-2002, and IEEE Std. C37.90.1-2002.
- *Outage Protection*—All microprocessor-based equipment on the DPR is protected against temporary power interruptions. Unless a backup DC power source is available, all controllers are powered via a centralized uninterruptible power supply that is capable of providing full power for a 10-minute outage. For outages exceeding 10 minutes, backup power is supplied by either a backup power source or the islanding operation of the DPR.
- *Breakers*—PCS-controlled operation of DC and AC breaker operation. The DC breakers are sized to isolate each PowerCell rack from the PCS during routine maintenance or equipment replacement. Meanwhile, AC breakers are sized to disconnect the DPR from the utility in the event of a system disconnect command from the user or DPR malfunction.
- *Battery Ground Detection*—The DPR includes a battery ground detection system, which monitors the system for ground fault conditions. In the event of a fault, the PCS disconnects itself from the battery and issues an alarm.

2.4 Xtreme Power Dynamic Power Resource™

The Xtreme Power Dynamic Power Resource™ (DPR) advanced lead-acid BESS comprises an entire integrated system of 24 DPR Modules, each of which consists of a 1.0-MWh PowerCell Pack storage system and a 1.5-MVA Power Unit PCS. The DPR has a nameplate continuous-power rating of 36 MW and a nominal energy storage capacity of 24 MWh, when discharged over a period of 3 hours.[1] It is controlled directly by a "Real-Time Control System" (RTCS) that is critical to the management of the DPR.

---

[1] Operations at the Notrees battery facility call for maintaining the battery between the 20% and 80% state-of-charge levels at all times, resulting in a discharge capability of 14.4 MWh when discharged over a period of 3 hours.

2.5 Real-Time Control System

The RTCS is a modern control system architecture that supports monitoring, control, and optimization of the complex system made up of the power unit modules, balance-of-plant equipment, SCADA applications, substation automation, and generation control system. The RTCS enables power leveling, power smoothing control, voltage and frequency regulation, and fault and emergency shutdown services. It also features a Web user interface, a graphical user interface (GUI) for the operator, a data acquisition system, a database, a remote terminal unit (RTU) interface, and a supervisory control system (Figure 2-6).

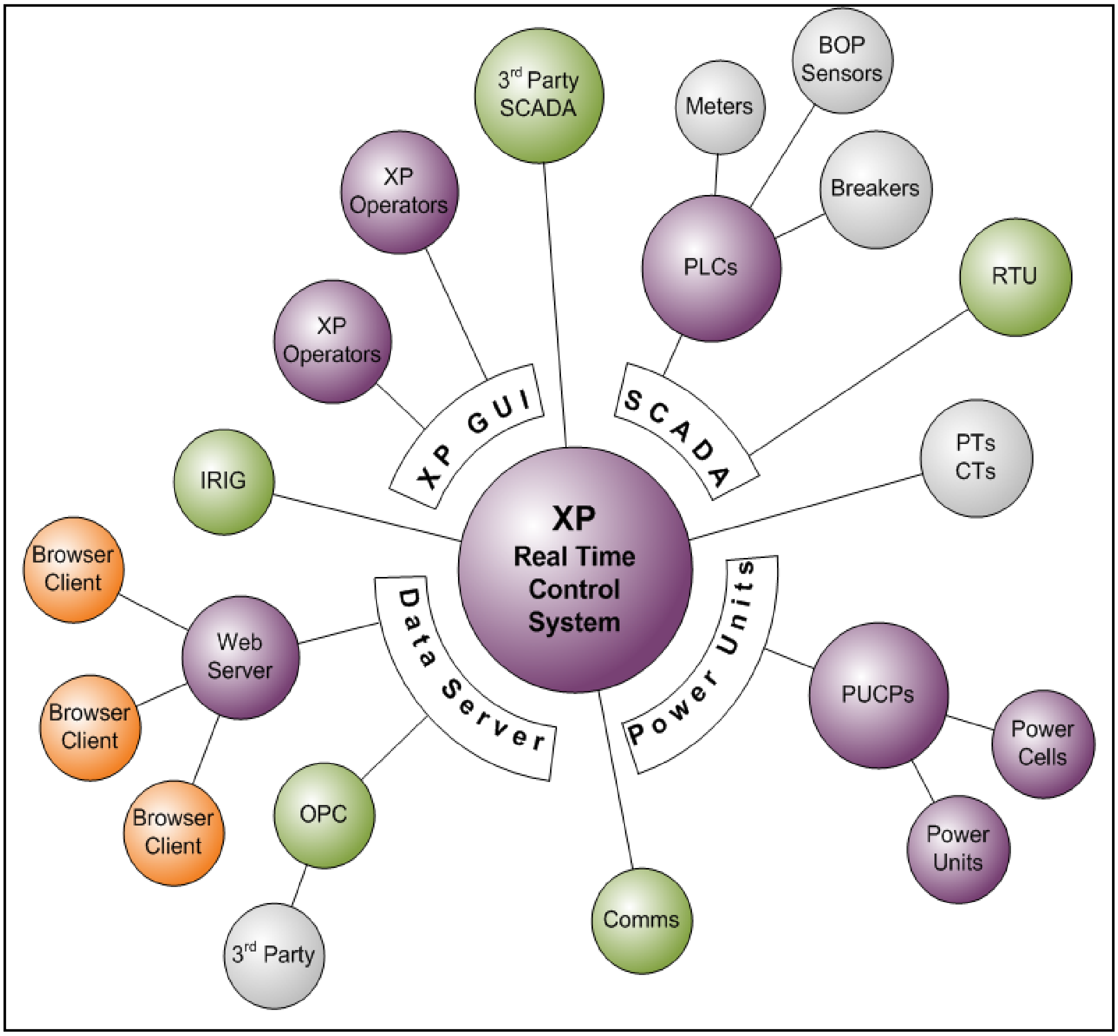


Figure 2-6
Conceptual Diagram of Real-Time Control System

The RTCS monitors the status of the conditions both internal and external to the DPR, maintains a safe operating environment, and allows users to remotely change settings in real-time. It is composed of three main components that together control the DPR equipment and record all appropriate data:

- *Web-based Human Machine Interface (HMI)* for remote operation and monitoring, integrated into an existing control system or accessible through a Virtual Private Network (VPN)

- *Supervisory Control and Data Acquisition (SCADA)* that communicates with Remote Terminal Units (RTUs) and Programmable Logic Controllers (PLCs), which collect information from external sensors, meters, and breakers to relay data necessary for safe and accurate operation of the DPR.
- *Data Server*, which transfers and stores data in a secure SQL Historian database that allows customers to access controls and permissions, interface with the XP GUI, view graphical representations of historical and live operational data, and export to CSV format.

Key characteristics of the RTCS include:

- Custom algorithms for specific applications and services
- Fixed operating modes or dynamic response to changing market conditions
- Real-time configurable program logic
- Redundant controls: multi-tiered control system (SCADA, PLC, FCB)
- Local or remote control modes
- Automated or manual operation modes
- Automated sub-microsecond response time
- Can represent either master or slave control system
- Around-the-clock intelligent fault response system with text notification: e-mail for alarm and faults, and hierarchical acknowledgement of base fault reporting
- OPC interface to PI and other Ethernet based systems
- National Cyber Security standards compliance.

Specific RTCS functionality includes:

- Voltage Regulation: voltage setpoint (dynamic VAR compensation), PF mode
- Frequency Regulation: droop control, synthetic/virtual inertia, lead/lag frequency control
- Responsive Reserves: loss of load, loss of generation
- Remote Setpoint: AGC, RTU, market signal
- Schedule-Based Leveling: generation (firming), load (demand management)
- Emergency Shutdown Services: fault response.

2.6 HMI and SCADA

The communications system used by the PCS enables local and remote system monitoring, control, and data archiving. A user may access the PCS via two communication mechanisms: the PCS human machine interface, and a remote SCADA connection.

The DPR PCS is equipped with a HMI that enables a variety of functionality, including monitoring, control, and troubleshooting. From the HMI screen, a user can perform a controlled startup and shutdown of the DPR. In addition, the main HMI screen displays a one-line diagram of the DPR, as well as the performance of individual components and the combined output of the entire system. The HMI automatically refreshes these values every second. In addition, ambient temperature for the battery temperature control system is provided. Furthermore, the HMI provides system performance trending information, a system status alarming screen, and an event log. The HMI is browser-based and accessible both locally and remotely from any network-connected computer with the proper access credentials.

The SCADA connection uses the Distributed Network Protocol 3 (DNP3) to request system status information and issue operating commands. The PCS acts as the DNP client to a minimum of two DNP servers. The SCADA connection complies with all required security requirements. System status and control setpoints are accessible from both the local HMI as well as the remote SCADA connection.

2.7 Location

The Notrees Wind Storage Demonstration Project’s DPR is located on the low side of the substation and connects to the existing wind farm substation through a separate breaker (Figure 2-7). The DPR has its own independent control system, but the control system was designed by Xtreme Power to work in conjunction with other on-site resources to optimize battery performance and provide support services to the grid and the wind farm as deemed appropriate. Figure 2-8 indicates the location of the DPR on the project site at a large scale.

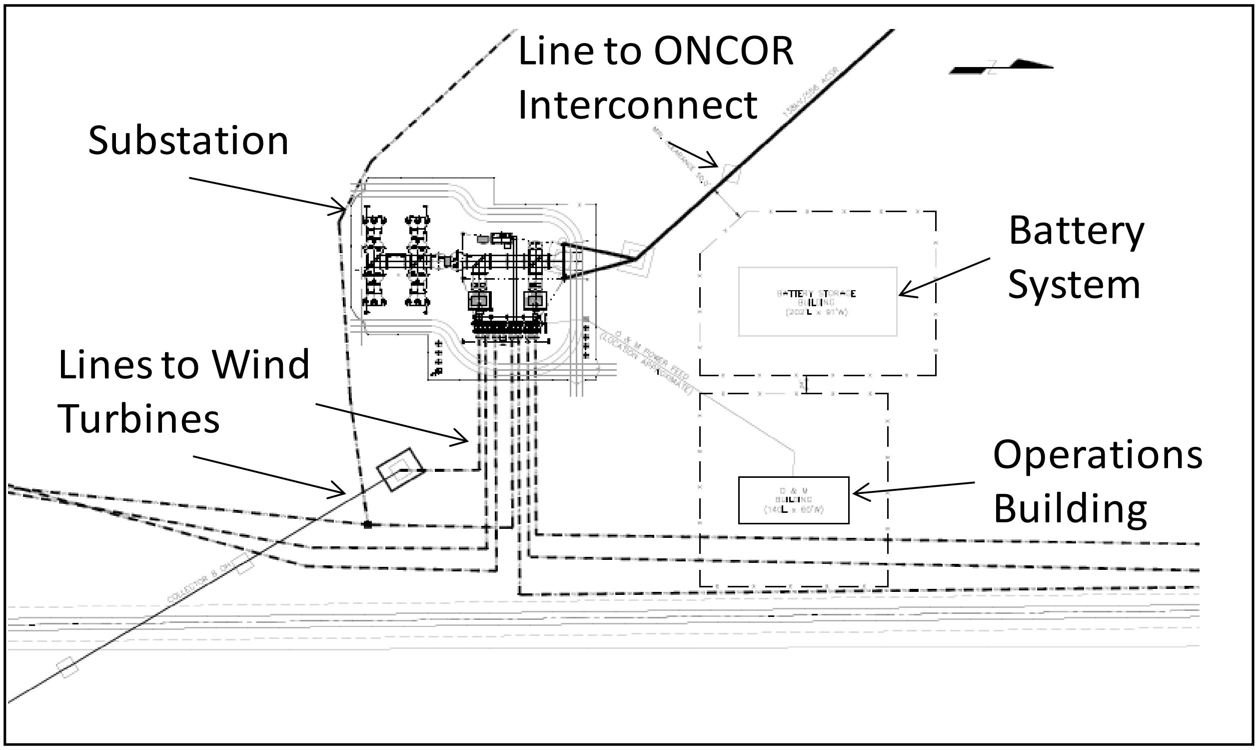


Figure 2-7
Location of Dynamic Power Resource in Relation to Substation and Operations Building

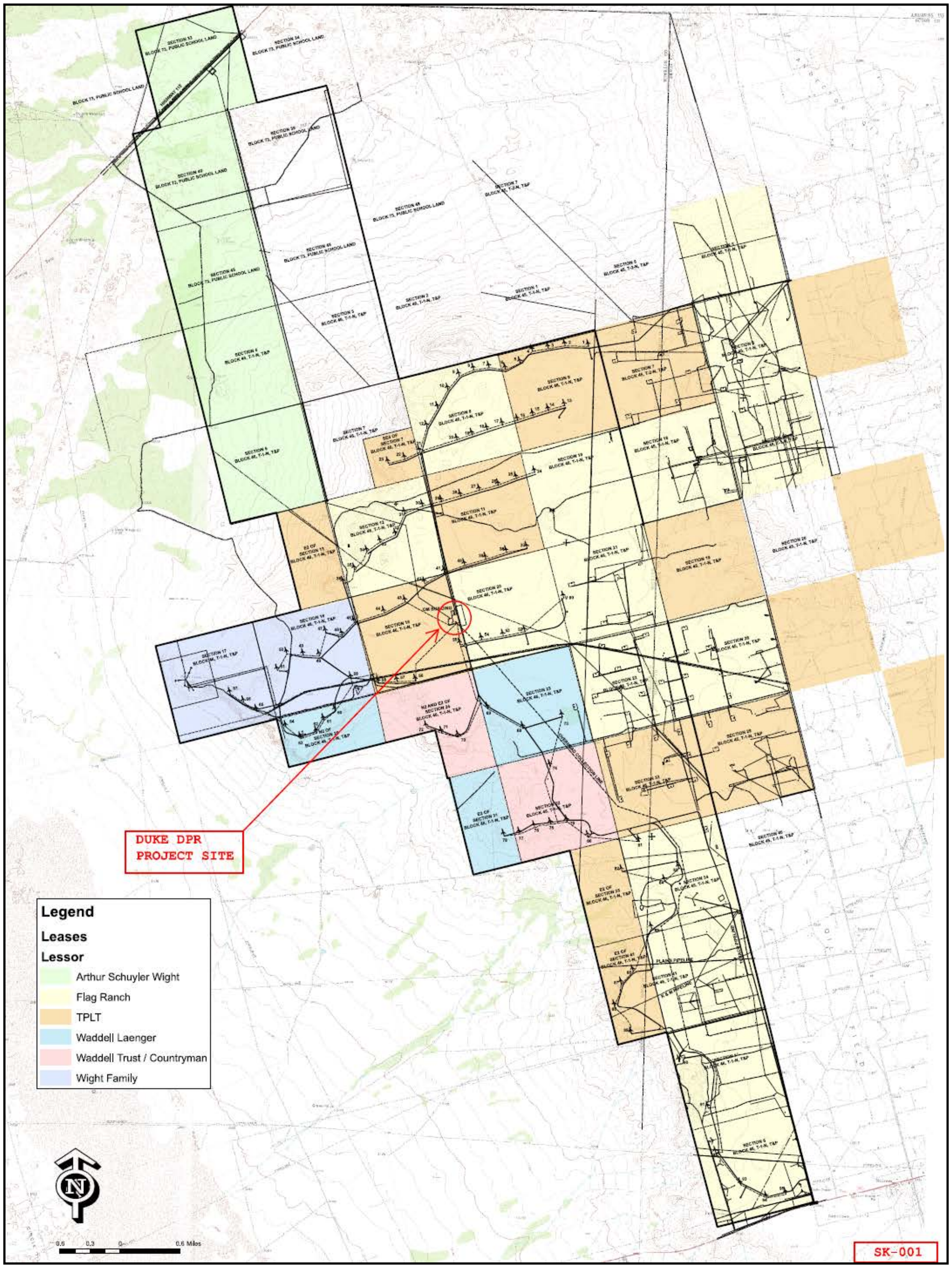


Figure 2-8
Location of DPR Facility on Project Site

Figure 2-9 provides a one-line diagram for the DPR energy storage facility, while Figure 2-10 shows how the 24 PowerCell Modules are arranged within the Battery System building indicated in Figure 2-7.

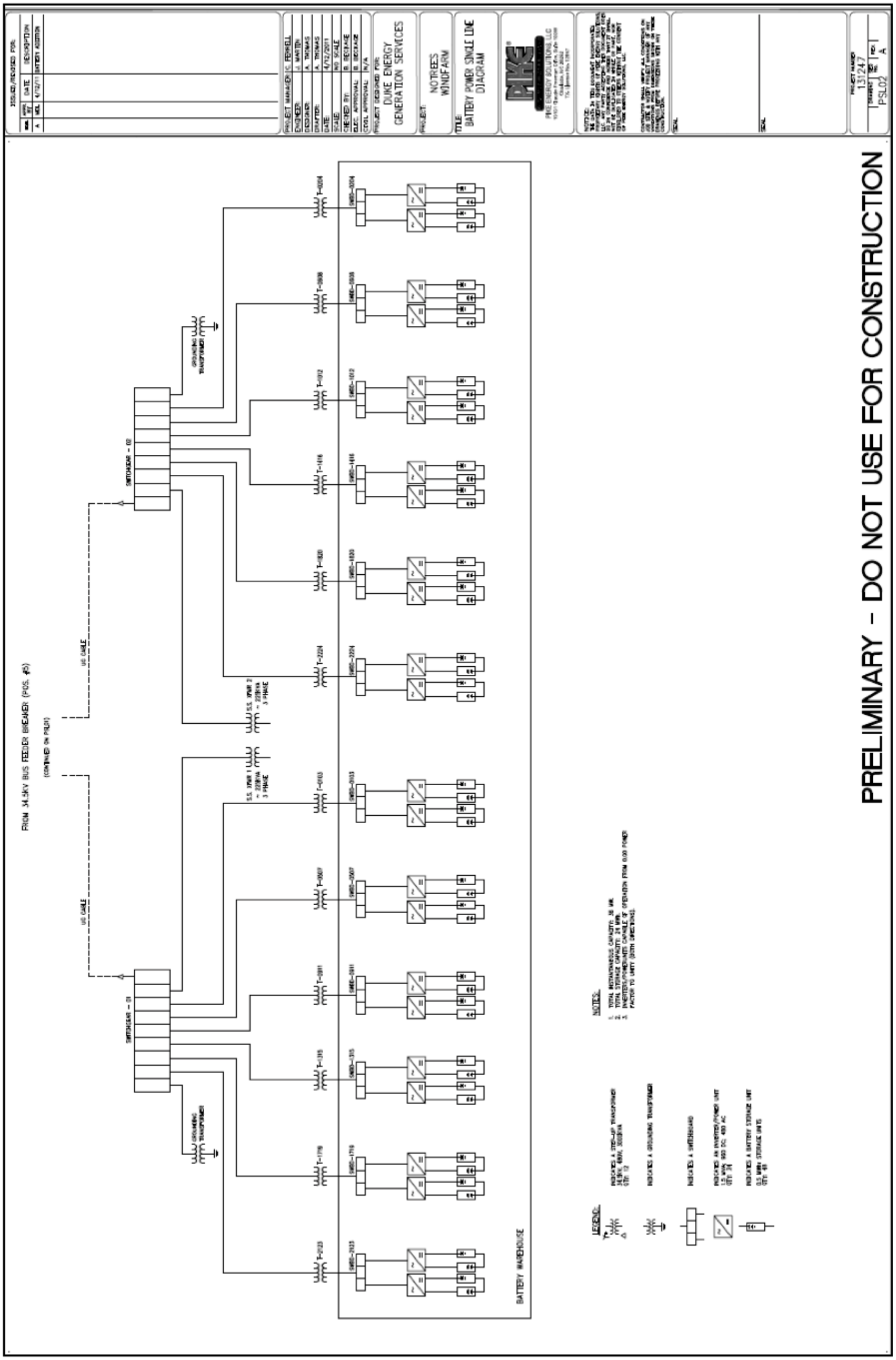


Figure 2-9
One-Line Diagram for DPR Energy Storage Facility

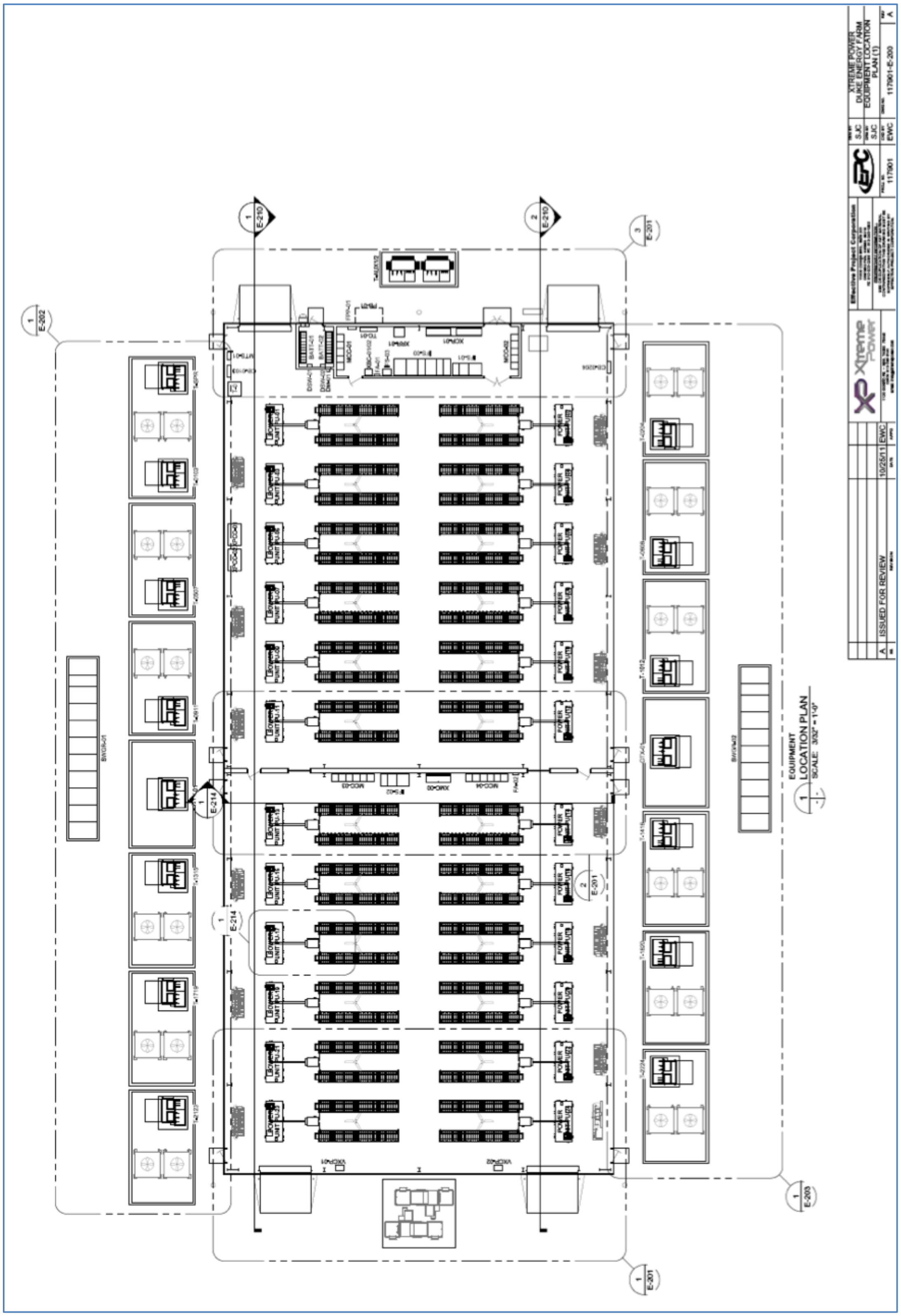


Figure 2-10
Equipment Location Plan within the Project Building

3

ANALYSIS METHODOLOGIES AND OBJECTIVES

3.1 Analysis Objectives

Energy storage can maximize the value of wind energy through multiple value streams, including:

Time Shifting: Energy is stored when prevailing prices are low, the transmission system is congested, or there is a risk of curtailment. It is later released when it can be most beneficial to ERCOT customers—for example, when locational market prices are at their highest.

Area Regulation: A portion or all of the energy storage capacity can be committed to provide regulation service. The Notrees Wind Storage Demonstration Project first focused on this service to demonstrate proof of concept.

Electric Supply Reserve Capacity: A portion or all of the energy storage capacity can be committed to provide various forms of operating reserve.

Voltage Support: Energy storage can also be dispatched to provide local voltage support as a special feature of the inverters. A BESS may provide reactive power for voltage regulation to help maintain voltage at a specified level. Voltage regulation can be provided via a Power Factor Setpoint or a Voltage Setpoint control, which can be either static or dynamic. Voltage regulation is performed relative to the voltage or power factor as measured at the point of common coupling (PCC).

Transmission Congestion Relief: As with the Time Shifting application, a BESS can charge when exports are limited by system congestion. This practice can relieve congestion, allowing more renewable-based energy to be moved to utility customers.

Renewable Energy Time Shift: Similarly, energy storage can be used to maximize renewable energy production in wind farms. In addition to transmission congestion, there may be other occasions and/or phenomena that limit renewable energy production, which could be alleviated through smart operation of the storage.

Renewables Capacity Firming: Storage can be scheduled to support the ability of the wind farm to meet a predetermined schedule. When this mode is active, the BESS could respond directly to wind production, charging when over schedule and discharging when under schedule. For optimal use of the storage, it will be necessary to have short-term wind energy production forecasts to properly set the levels of charging and discharging at any point in time.

Wind Generation Grid Integration, Short Duration: This category of integration support spans time frames from 10 seconds to 15 minutes. It provides benefits to power quality and reductions to wind generation output, when netted against the storage operations.

More general benefits including creating jobs and supporting the deployment of new products, services, technologies, and infrastructure, which will help improve the use of wind power and support system reliability. The facility will systematically control the storage in conjunction with the natural production patterns of the wind generation using wind and price forecasting algorithms, optimized storage dispatching, communications, and market participation to effectively improve the utilization of generation and transmission assets, the reliability and resilience of electric transmission systems, and effectively reduce the frequency and duration of wind power curtailments.

3.2 Methods for Determining Technical Performance

The Notrees Wind Storage Demonstration Project collected baseline data using existing metering equipment for the Notrees Wind Farm and additional metering equipment installed with the BESS. The Notrees Wind Farm has two phases that are offered into ERCOT jointly, metered separately, but settled jointly. The battery system was included in the joint wind farm offering and settlement, but was metered separately. The West Texas region is notable for its rapid load growth, due to rapid growth in the oil and gas sector, which makes the presence of this BESS insignificant in the presence of these other local system changes.

The data collected and analyzed during operation of the BESS at the Notrees Wind Farm included the following (data marked with an asterisk (*) were available for each inverter, at the switchgear level, at the full DPR system level, and as a full system measured at the 34.5-kV bus at the substation):

- Real power (kW) from the DPR *
- Reactive power (kVAR) from the DPR *
- Apparent power (KVA) from the DPR *
- Real power (kW) from charging source *
- Reactive power (kVAR) from charging source *
- Apparent power (KVA) from charging source *
- Power factor
- Total DC voltage—The DC voltage of a PowerCell pack acting as the energy resource behind a single module.
- DC Current—The DC current measured due to power flow between PowerCell pack and Power Electronic Converter
- Ambient temperature readings for the DPR
- Inverter Status
- State of charge
- Cycle Counter: An accumulator which counts the number of cycles used by the PowerCell pack
- Capturing how the energy and power density changes over time (how the Wh/L and W/L, along with the Wh/kg and W/kg, degrade as the battery operates)
- Using the above data to capture the overall system efficiency (AC-to-AC, DC-to-DC)
- Understanding the system degradation over time
- Capturing how quickly the system can respond to an input power command signal as received by the DPR control system
- Understanding the overall construction and installation process for a battery system of this size, and what issues occur when tying such a large battery into the grid
- Capturing the life of various components of the battery system
- Capturing on-going operation and maintenance requirements for the battery

- Understanding any environmental, health and safety issues when operating a large battery system
- Understanding how to best dispatch and operate the battery in the ERCOT market
- Understanding how storage capacity/energy available varies with charge/discharge rate (MW)
- Collecting all data necessary to determine energy contributions from the wind farm and battery separately as necessary to perform financial settlements
- Calculating efficiency, and the impact of auxiliary equipment versus true battery/inverter system efficiency. How to manage the system to optimize overall efficiency (i.e., can the battery be dispatched such that idle time is minimized and is nearly always in a charge/discharge cycle).
- Understanding how to best manage state of charge

3.3 Methods for Determining Grid Impacts and Benefits

Duke Energy and ERCOT operated a data acquisition system (DAS) to monitor the Notrees Wind Farm. Additional systems for collecting and analyzing data from the baseline system and the BESS were designed and installed (see Section 3.5). This supplemental functionality was designed to not only meet the needs of Duke Energy and ERCOT, but to satisfy DOE Smart Grid reporting requirements for baseline and impact metrics.

The Dynamic Power Resource BESS was required to meet project specifications for under-voltage ride-through, over-voltage ride-through, under-frequency ride-through, over-frequency ride-through, and harmonic distortion. Available services will include up regulation, down regulation, Automatic Generation Control (AGC) response, frequency regulation, ramp rate control and curtailment capture. Each is described below.

Regulation Up

The Regulation Up reserve product in ERCOT is defined as the DPR injecting power to the grid in response to AGC signals and/or regulation control. The DPR was designed to be capable of delivering the Up Reserve capability continuously for 45 minutes and then ramping down linearly over the next 45 minutes such that at the end of 90 minutes the DPR is neither absorbing nor producing power. Actual operation of the DPR depended on actual grid conditions, ramp rate control, and frequency regulation, as well as AGC commands.

Regulation Down

The Regulation Down reserve product in ERCOT is defined as the DPR absorbing power from the grid in response to AGC signals and/or regulation control function. The DPR was capable of moving from neither absorbing nor producing power to its maximum Down Reserve power level in less than 50 msec.

AGC or Setpoint Response

The DPR could respond to the AGC setpoint under all system frequency conditions, in accordance with ERCOT interconnection rules. AGC signal was a setpoint signal.

Frequency Regulation

The DPR was designed to provide frequency regulation in accordance with ERCOT interconnection rules when frequency at the point of interconnection moves outside the range of the dead band, nominally defined as the range of 59.9 to 60.1 Hz.

Ramp Rate Control

The ramp-rate control function operates by monitoring the real power output of the sum of the wind turbine feeder circuits and responding to any changes in the real power flow of those circuits. When ramp control function is enabled, the DPR could either generate or absorb real power to attempt to keep the output of the total combined system within the specified Ramp Rate Upward or Ramp Rate Downward target. Any changes in the wind farm’s real power output would cause an immediate and opposite change in the DPR output. Controls kept the state of the system’s charge within +/-5% of this target by adjusting the Ramp Rate Upward and Ramp Rate Downward to maximize charging or discharging depending on the bias direction required (Figure 3-1).

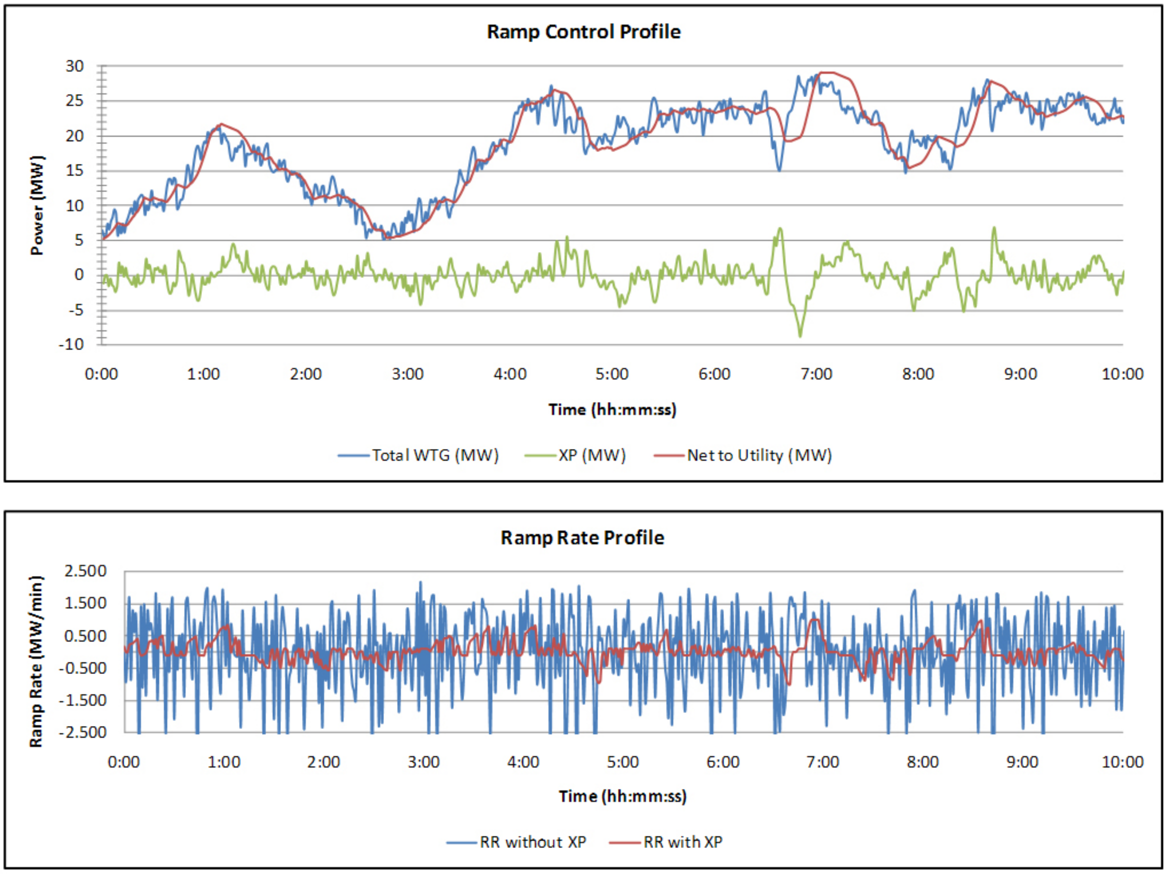


Figure 3-1
Examples of Ramp Rate Control Provided by Xtreme Power DPR, based on Actual Operating Data

Curtailment Capture

The DPR system was designed to follow a strictly programmed algorithm when capturing wind power during curtailment periods—that is, when the wind farm produces more electricity than the grid requires—and delivering that power to the grid when the signal is lifted.

3.4 Metering and Communication with ERCOT

Duke Energy coordinated its efforts with ERCOT to support data collection and analysis related to generation resources and costs. The project team also worked with ERCOT to develop best practices for system-benefit reporting and the potential support from stakeholders.

Under the arrangements for grid metering, real-time operation and performance of the DPR on the ERCOT grid were telemetered and monitored by ERCOT at the ERCOT-Polled-Settlement meter installed at the wind farm point of interconnection. Additional metering was installed at the DPR on the low side of the wind farm substation to facilitate direct monitoring by Duke Energy of DPR activity.

Duke Energy managed the real-time communication of DPR telemetry and operations to ERCOT in conjunction with the real-time communication already provided for Notrees wind farm, in addition to communicating any scheduling information required by ERCOT for notification of DPR operations. Real-time information and/or instructions for DPR operation from ERCOT were received by Duke Energy and relayed directly by Duke Energy to the DPR control system.

3.5 Data Processing System Requirements

In 2013, EPRI drafted requirement specifications for software being developed to analyze data collected from the Duke Notrees BESS and the ERCOT electricity markets. The purpose of the specifications was to guide EPRI in its development of the analysis software, as well as to guide Duke Energy regarding the requirements and processes for collecting and transmitting data to EPRI for analysis and reporting to DOE.

This section describes the requirement specifications for software developed to analyze data collected from the Duke Notrees BESS and the ERCOT electricity markets. These specifications were used by the developers of the analysis software and technical personnel at Duke Energy who are responsible for retrieving and transmitting the required data to EPRI, and for ultimately submitting the resultant Build and Impact Metrics Reports to DOE.

The Data Processing System (DPS) software developed by EPRI received information from the Notrees Project's Data Acquisition System (DAS), which is documented in the Metrics and Benefits Reporting Plan (MBRP). The MBRP further defines the DOE report contents and the data provided by the DAS in support of DOE reporting. It also describes how the data processing and analysis fills the gap between the DAS and DOE reporting.

The DPS executes the following steps:

1. Acquires input data from the Duke Notrees BESS DAS
2. Validates the data with configurable filters
3. Corrects data with agreed heuristics

4. Creates reports for the project team and ultimately for inclusion into the DOE reports.

Following Step 4, the project team reviewed and analyzed the data reports. The data analysis comprised the main part of the regular reporting.

The following subsections describe the overall system requirements as originally specified, from data acquisition at Notrees BESS and the ERCOT market to the provision of Build and Impact Metrics Reports to DOE. The overall system is described at the highest level according to its external interfaces, functional requirements, performance requirements, and design constraints.

External Interface Requirements

The tables in Appendix A list the required measurement channels, units, and reporting rates for data acquired from the Energy Management System (EMS) and transferred between Xtreme Power, ERCOT, Duke, and EPRI for this project.

Functional Requirements

The function of the Notrees Data Processing System is to collect data from Duke Energy and produce reports for review and submittal to DOE by Duke Energy. The reports will describe the Build and Impact Metrics as described in the MBRP and any additional insights obtained from an analysis of the results. These requirements are elaborated upon below.

Performance Requirements

The Notrees Data Processing System must be capable of computing and reporting the agreed Build and Impact Metrics agreed as documented in the MBRP. It must also be flexible for validating all of its calculations and for exploring curious aspects of the overall BESS behavior.

Reporting should meet the schedule agreed to in the MBRP. These requirements are elaborated upon below.

Design Constraints

There are as yet no constraints on the design of the Notrees Data Processing System, except for the facts of having limited time and limited resources. The prototype system should produce reports on a quarterly basis, with consolidated reports for DOE and a consolidated final report at the project completion.

3.6 System Description

The software tools developed for this project will operate as stand-alone programs on an individual machine. However, the data collected at the Notrees BESS will be stored in a PI Historian Permanent Database (PD) and a Market Database (MD) operated by Duke Energy. In order for the data to be analyzed, it first needs to be transferred to EPRI. Depending on the means provided by Duke to retrieve the data, the software may incorporate functionality that performs automated retrieval from Duke’s data center. Figure 3-2 is a diagram showing the flow of data.

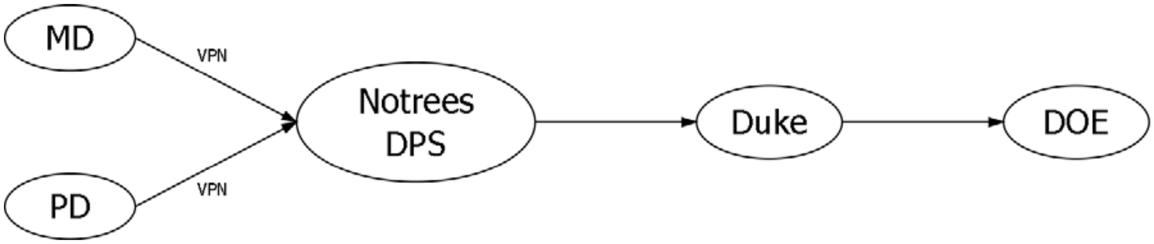


Figure 3-2
Data Flow between System Interfaces

Market Database

Duke Energy operates the Market Database (MD) in their *nMarket* database. The Market Database will be the source for all market data used to compute and analyze the Build and Impact Metrics.

Permanent Database

The Permanent Database (PD) is a PI Historian located in Charlotte and provides permanent, long-term SCADA data storage. The permanent database will be the source for all SCADA data used to compute and analyze the Build and Impact Metrics.

Notrees Data Processing System

This section describes the new Data Processing System for the Notrees data. It consists of several components, each performing a different function, which are executed in series.

1. Data Acquisition—Retrieve the data from Duke databases.
2. Data Verification—Ensure that the data is correct and mark incorrect data.
3. Data Correction—Use heuristics to replace incorrect or missing data.
4. Data Reporting—Process the data for user review and analysis.

For Data Verification, certain redundancies are used to determine data accuracy and. In addition, data may sometimes data can be missing. Such inaccuracies and missing data will be flagged and analysis will be limited during such periods of time.

The ERCOT settlement and the internal settlement between Xtreme Power and Duke Energy will be used to compute the net charging and discharging of the BESS. There is sufficient metering and other schedule information to determine the periods during which the BESS is acting as a generator or a load.

Data Acquisition

Data will be acquired in the format and frequency described below in the *Component Interfaces* section. The data files may be compressed for reduced transmission bandwidth and storage requirements. Each file name will satisfy a versioning format for the purposes of identifying its contents and version number.

Data Verification

If necessary, the data will be uncompressed. Once the data is uncompressed, the data contents must be verified as the MD and PD variables described in the “MD to PDS” and the “PD to DPS” sections below. Each MD and PD variable will need to have a timestamp for the purposes of identifying its unique meaning for calculation and analytical purposes. Acceptable timestamp formats are described in the *Component Interfaces* section below.

Data Correction

Once the data has been verified, there are several steps in the data correction process. Given that the MD and PD variables have the appropriately formatted timestamp, the timestamps need to be checked for duplicate entries. Duplicates will need to be removed and the rate of row entry duplication will be computed. The next step in data correction will be to evaluate the MD and PD variables for acceptable reporting limits. MD or PD variables values that are outside of the acceptable reporting limits will be flagged for review. These flagged values will either be set to null or assigned a new value based on a filling algorithm.

Data Reporting

Reporting provides at a minimum the information necessary for the Build and Impacts Metrics Reporting. This information can be supplemented with information about the data processing and any analysis of interesting system behavior. Following is a description of each Build and Impact metric.

In subsequent updates of this report, these sections will be further developed to give the exact calculations of each metric.

Annual Storage Dispatch

The Duke Energy Notrees Substation data will be used to compute the net charging and discharging of the BESS using the “NOTREES BATT REVMTR MW-EMS” channel. There is sufficient metering and other schedule information to determine the periods during which the BESS is acting as a generator or a load.

$$Ec = \sum P \times \Delta t, P < 0$$

$$Ed = \sum P \times \Delta t\,, P > 0$$

$$E = Ec - Ed$$

This storage dispatch has resolution $\Delta t = 60s$.

Average Energy Storage Efficiency

The storage efficiency can be determined by accounting for the net energy entering and leaving the BESS over a long period of time. This value can be calculated using the results of the Annual Storage Dispatch calculation described previously.

$$\text{AESE} = \frac{Ed}{Ec} \times 100\%$$

The storage efficiency will be calculated at monthly intervals.

Peak Generation and Mix

The hourly and yearly ERCOT peak generation is obtained from annual market reports (ERCOT Generation Mix Report), which also contain monthly generation mix summary data. Fifteen-minute resolution generation mix data is also available in the ERCOT Real-Time Generation Mix data.

Annual Generation Cost

The annual generation cost can be determined from the Duke Notrees Battery Reports during periods when the BESS is operating as a generator. Column V in the reports represents the battery generation revenue, which is recorded at 15-minute intervals.

$$\mathrm{Cc} = \sum \mathrm{LMP} \times \mathrm{P} \times \Delta\mathrm{t}, \mathrm{P} > 0$$

Ancillary Services Price

To calculate the ancillary service prices for the ERCOT system, the total amount of Fast-Responding Regulation Service (FRRS) revenue for the year (both for Reg-Up and Reg-down separately) was divided by the total MW amount awarded for both types of regulation service. The FRRS revenue was obtained from ERCOT’s final report on the FRRS pilot, while the award amounts were provided separately by ERCOT. The resulting figures are thus unweighted average prices.

Ancillary service prices at the BESS were calculated by summing the product of price and award amount for each hour the battery participated in FRRS, and dividing this amount by the total MW amount awarded, yielding a weighted average price. This calculation was repeated for both Reg-Up and Reg-Down service.

Since the BESS was the majority participant in the FRRS pilot (there was only one other participant, who committed to provide up to 1 MW Reg-Up and Reg-Down, compared to the Notrees BESS providing up to 32 MW Reg-Up and 30 MW Reg-Down), the ERCOT statistics apply considerably.

Congestion

The system-level congestion amount (MWh) and cost were found in the 2013 ERCOT State of the Market Report. For the amount, the West Texas region was used, since that is where the Notrees battery is located. The cost figure is an ERCOT-wide total.

Congestion costs may be determined by locating periods of time when the wind plant is producing power and real-time energy prices in the BESS area show a difference from those nearby. Under these conditions, the price difference and the net wind-storage schedule could help place a monetary value on congestion costs in the region near the BESS. Since the BESS is small relative to wind energy production in the region, this value may be very small or difficult to measure on an impact versus baseline basis.

Valuation process:

1) Look for most valuable CRR

2) Determine the Battery Congestion Capacity from LMP differences between Notrees and the other hub. The capacity that can sustain power over the longest congestion period is the Battery Congestion Capacity.
3) Price the Battery Congestion Capacity at the CRR level.

Emissions

Emissions factors for the ERCOT system were obtained from ERCOT's 2013 Renewable Content Calculator. These factors were then multiplied by the total amount of energy generated during the year to obtain the amount of CO_2, SO_2, NOx, and particulate matter released from power generation facilities in the ERCOT system.

For the BESS, it was assumed that the battery was being charged with energy generated by gas turbines. Emissions factors were calculated using EIA generation by fuel type and emissions data for Texas for 2012. These factors were then multiplied by the net energy consumed by the battery during the year.

CO_2 Emissions: Curtailments of the wind farm compared to the battery operation can help indicate when the battery is supporting wind power production when it would otherwise be curtailed. A comparison of conditions during the impact period with those during the baseline period could help determine the quantity of additional wind energy being enabled by the BESS. This quantity would displace emissions from a proxy thermal unit on a per-MWh basis to compute the carbon dioxide reduction.

Pollutant Emissions (SO_x, NO_x, PM-2.5): Just as for the carbon dioxide emissions, other pollutant emissions could be estimated from the wind plant curtailment reductions on a per-MWh basis, when compared to a proxy thermal plant's emissions.

This project will provide project-level emissions impact information regarding annual storage dispatch and average energy storage efficiency. The peak generation and mix will be provided for the project level and the system level. The system level reporting depends on successful collaboration with ERCOT to obtain such information. Likewise, annual generation costs will be provided and system level reporting depends on the depth of collaboration with ERCOT.

Ancillary Services pricing can be provided for the Notrees location and for a system average, depending on the ERCOT market price availability and their reporting in ERCOT's annual State-of-the-Market report.

Environmental reporting of CO_2 and other emissions will be reported, depending on the ability of the project to obtain peak generation mix and especially the marginal resource type from ERCOT.

Data Analysis

Initial processing of the data via the DPS will yield aggregated results in the form of tables and visualizations that will require interpretation and explanation. More than likely, the results themselves will present further avenues of enquiry. Unusual or unexpected results will be investigated so as to ascertain their causes and implications. The analysis proposed here will explain *why* a particular result either makes sense or appears abnormal. This process may involve adjusting or revising initial assumptions to better understand the underlying processes being observed.

The insights obtained from this analysis will be documented in the quarterly and final reports. They will present a valuable learning opportunity for Duke and DOE, and could provide a basis for further research in the future.

Duke Reporting Function

Subject matter expert will review reports, provide feedback, approve reports for transmittal to DOE, and transmit reports to DOE.

DOE Reporting Function

Subject matter expert will review DOE reports, provide feedback, and approve DOE reports on behalf of DOE.

System Interfaces

A data acquisition system installed at the Duke Energy Notrees BESS site captured a variety of different measurements from the system that could then be analyzed to quantify the performance and economic benefits of the Notrees BESS. Preprocessing and analysis of the data needed to be performed on a regular basis in an automated fashion, which is the function of the software described in this section.

Component Interfaces

This subsection describes the interfaces between components depicted in Figure 3-2.

MD to DPS Interface

The MD to DPS interface is shown in Figure 3-2. The MD includes the following variables:

- Real-time electricity price
- Ancillary services prices
- Demand response revenue (load shifting only)
- Congestion charges (load shifting only)
- BESS settlements
- ERCOT generation mix
- ERCOT peak load

PD to DPS Interface

The PD to DPS interface is shown in Figure 3-2. The PD includes the following variables:

- Real power (kW) from the Dynamic Power Resource (DPR)
- Reactive power (kVar) from the DPR
- Apparent power (KVA) from the DPR

- Power factor
- Total DC voltage – between storage PowerCells and electronics
- PowerCell column pack DC voltage – between storage PowerCells and electronics
- Max PowerCell column pack DC voltage – between storage PowerCells and electronics
- Min PowerCell column pack DC voltage – between storage PowerCells and electronics
- DC Current – between storage PowerCells and electronics
- Temperature readings for the DPR
- Inverter status
- SOC

The PD may also include the following variables:

- Estimates of overall system efficiency (AC-to-DC, DC-to-AC)
- Response times
- Component degradation and lifetimes
- Operation and maintenance requirements
- Environmental, health, and safety factors

DPS to Duke Interface

The output of the DPS will be a collection of reporting metrics. These metrics will be available for Duke to access electronically or as physical hard copies and to distribute to the necessary staff. This connection is diagrammed in Figure 3-2.

Duke to DOE Interface

The reporting metrics from the DPS will be available for Duke to distribute electronically or as physical hard copies to DOE. This connection is diagrammed in Figure 3-2.

User Interfaces

The programs developed for this work took the form of script files that can be launched via a command line interface, or from within the interpreter (e.g., R, Matlab, or Python) required by the scripting language. Output was in a format readily imported into spreadsheets for further analysis and graphical reporting.

Hardware Interfaces

All programs developed for this work were capable of running on a personal computer.

Software Interfaces

Software was developed to import data into the MD and PD databases. This software was written in the Python scripting language, though the R scripting language may have been used for some tasks. Given the relatively small amount of data involved, Microsoft Access was be used to store the data. Stored SQL queries were be added to the database to automate and simplify the process of computing the required performance metrics. Either Duke Energy or EPRI with Duke Energy support developed the queries.

The software developed for the DPS was compatible with the Microsoft Windows 7 platform. Depending on the language used to develop the software, the appropriate language interpreter package may have needed to be installed on the user's machine.

Communication Interfaces

Data files were transmitted over a secure TCP/IP connection using a standard protocol such as FTP or HTTP, or a secure implementation thereof (e.g., SFTP or HTTPS, respectively).

Memory Constraints

The software developed for this work had to be capable of running on a Windows 7 personal computer having no more than 4 gigabytes of RAM.

Operations

The operation of the preprocessing and analysis programs was intended to be reasonably straightforward such that a user can execute them quickly and easily. Aside from specifying parameters of the input data file (like the given ERCOT month, week, or day), no configuration changes should need to be made from one data set to the next. The software should be simple for the user to install.

3.7 Notrees DPS Design

This section describes the design for the Notrees Data Processing System.

Notrees DPS User Characteristics

DPS users are engineers familiar with running command line programs. Users were expected to have experience working with and managing moderately sized data sets. The primary users are personnel from EPRI and Duke Energy.

Notrees DPS Business Process

The DPS business process is a repeated process for producing a periodic update report, a single quarterly DOE report, a single annual DOE report, or a final report. The high-level steps follow the flow of Figure 3-2, with sub-tasks following the DPS process. The DPS process may be reworked according to the needs of the analysis.

Users

MD_Engineer – able to program the MD and produce MD files for input to the DPS.

PD_Engineer – able to program the PD and produce PD files for input to the DPS.

DPS_Data_Processer – able to conduct data processing steps (1 to 3) of the DPS.

DPS_Analyst – able to conduct the data analysis step (4) of the DPS.

DPS_Reviewer – able to review all DPS steps and provide guidance for analysis, and prepare DOE reports.

Duke_Reviewer – able to review all DPS steps, provide guidance for analysis, and help prepare DOE reports.

DOE_Reviewer – able to review and approve DOE reports.

Notrees DPS Constraints, Assumptions, and Dependencies

There were no specific constraints, assumptions, or dependencies.

Notrees DPS Database Requirement

This section describes the structure of the file system used to store all input and output data of the DPS and all DOE reports submitted to Duke Energy.

Notrees DPS System Attributes

This section describes the reliability, availability, security, maintainability, and portability of the Notrees DPS system.

Reliability

The DPS was able to operate on a monthly basis.

Availability

The DPS was available during normal business hours. Fall over systems were available in the case of primary system failure. Fall over required at most one working day.

Security

All users were expected to take appropriate precautions to secure the transmitted data files against unauthorized use.

Maintainability

At the conclusion of the project, EPRI will provide source code for queries used to process and analyze the Notrees data to Duke Energy as part of the report.

Portability

This specification assumed that all preprocessing and analysis activities will take place on computer systems utilizing the Microsoft Windows 7 platform. No provision was made for porting the programs created for this work to any other operating system or platform.

3.8 Data Inventory

An inventory of the data available for the Notrees DPS is provided in Appendix B.

4

TECHNOLOGY PERFORMANCE RESULTS

4.1 Activity in 2012

The following subsection describes activities related to commissioning, starting, and testing the BESS, which occurred in the fourth quarter of 2012. Activity in 2013 follows in Section 4.2, and activity in 2014 follows in Section 4.3.

Commissioning of the Notrees Energy Storage Facility followed a comprehensive Startup Testing & Commissioning Plan to ensure that all DPR modules and ancillary equipment were properly installed and undamaged. The startup testing included visual, mechanical, and electrical checks to verify the equipment condition, and identify any deficiencies that needed correction before commission testing of each DPM began. Commissioning concluded with complete functional and operational tests to ensure that the system's electric output characteristics and operations were as expected. Xtreme Power also conducted a Commissioning Plan, Testing, and Documentation process, which included all of the following inspections, checks, and tests:

Conditions Preceding Testing Procedure

Integrated Module Testing was successfully completed on all 24 Dynamic Power Modules of the battery system.

The owner's remote terminal units (RTUs) were tested. The interface between the owner's RTU and the contractor's SCADA system was fully tested and functional prior to the System Performance Testing.

Commissioning Testing was performed on all 24 Dynamic Power Modules as well as all other DPR components and the system as a whole.

Test Setup and Instrumentation

The performance tests were conducted at the project site upon installation of the DPR. All tests were conducted in a grid-interactive or grid-tied configuration. The test series was programmed into the real-time controller (SCADA) as an automated test. The SCADA system commanded the inverter/charger to follow a pre-described profile and follow an automatic generation control (AGC) signal from the utility as described in the test procedures.

Data Transmission Tests

Data Transmission Testing verified that the data transmission pathway between the owner's SCADA and the contractor's SCADA equipment functioned appropriately. These tests confirmed the data transmission for the following criteria:

- Curtailment Setpoint
- Curtailment Flag
- Frequency Reg. Flag
- Total MW

- Total MVAR
- System State of Charge (SOC).

DPR Performance Testing

Performance Testing was conducted per the DNP3 data points list and as agreed upon by the contractor and the owner. The performance of the DNP system was confirmed with simulation completed in earlier tests described above. Additional precautions were taken during this phase of the process since control of the DPR system was tested from a remote interface such as the owner's Project Control Room. This testing included but was not limited to mode of operation, reset of faults, and data exchange between the DNP system and the owner.

Other tests completed include:

DPR System Ramp Real Power Tests: All 24 1.5-MVA/1.0-MWh modules were commanded to ramp simultaneously to 1500 kW at a 1.5-MW/minute ramp rate for both power-in and power-out together in parallel.

DPR System Ramp Reactive Power Tests: All 24 1.5-MVA/1.0-MWh modules were commended to ramp simultaneously to 1500 kVAR at 1.5 MVAR/minute ramp rate for both power-in and power-out together in parallel.

DPR System Energy Delivery Test: The entire system delivered 14.4 MWh of energy to the owner's collection system over a 3-hour period (i.e., the battery will be discharged at 4.8 MW for 3 hours). Energy delivered for alternate power levels of 4 MW, 12 MW and 24 MW was also measured, but not used for acceptance criteria.

Regulation Interface Tests

Regulation Interface Testing required a regulation setpoint signal to be sent through the RTU interface, then the DPR contractor's corresponding action was initiated immediately. The following tests were performed with frequency control and ramp rate control disabled:

- Raise Regulation Setpoint Test
- Lower Regulation Setpoint Test
- Regulation Enable/Disable.

Up and Down Reserve Capability Test

The DPR system was required to start at "zero" output, ramp up to 36.0 MW, maintain output at 36.0 MW for a number of minutes mutually agreed upon by the contractor and owner, and then linearly ramp down the system's output from 36.0 MW to 0.0 MW over a prescribed period of time.

Efficiency Test

The DPR system was charged from 20% to 80% SOC, and discharged from 80% to 20% SOC, to monitor the efficiency of the charging and discharging of the DPR. The auxiliary/parasitic power consumption was monitored and included in the calculation of the efficiency.

72-Hour Reliability Test

The goal of the Reliability Test was to 1) demonstrate that the project can perform continuously and reliably over a range of operating modes under actual operating conditions, and 2) demonstrate that the project interoperates continuously and reliably with the Notrees Wind Project over a range of operating modes under actual operating conditions.

4.2 Activity in 2013

The Notrees Wind Storage Demonstration Project completed commercial operation testing in February 2013.

Duke Energy and Xtreme Power gathered and archived operating data throughout 2013. In late 2013, EPRI and Duke agreed on the necessary data-reporting format and reporting frequency for transmitting information from the Notrees Data Acquisition System (DAS) to EPRI's Data Processing System (DPS), as described in Sections 3.5 through 3.8. EPRI began receiving data in early 2014, with analysis to follow.

Fast-Responding Regulation Service Pilot Project

The Notrees demonstration's primary activity in 2013 was participating in ERCOT's Fast-Responding Regulation Service (FRRS) pilot project.

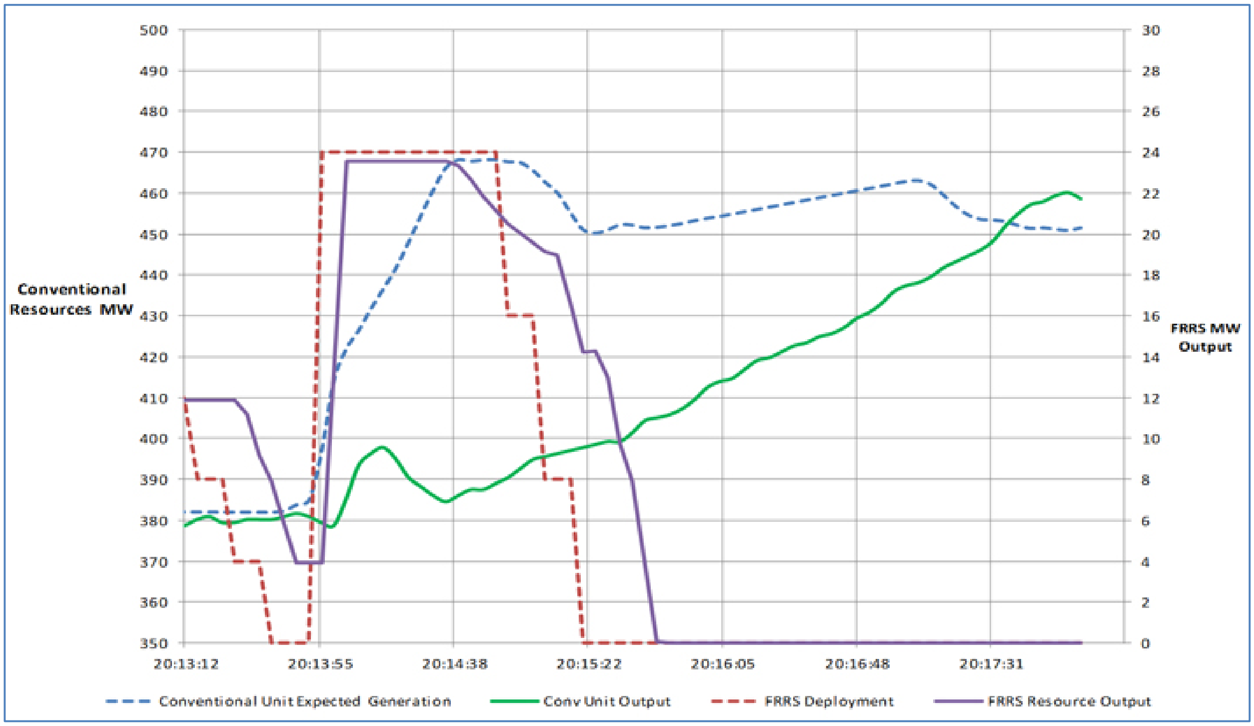
As authorized by Public Utility Commission of Texas (PUCT) Substantive Rule 25.361(k), in November 2012 ERCOT established a pilot project to test FRRS. The PUCT directed that FRRS be tested as a separate ancillary service that requires full or calculated partial deployment of a resource's obligated capacity within 60 cycles of a substantial deviation in system frequency or receipt of an ERCOT deployment signal. Among other goals, the pilot seeks to verify whether qualified resources can reliably deploy as required and to determine the operational value of such a service. If the pilot proves successful, ERCOT will propose a Nodal Protocol Revision Request (NPRR) to implement FRRS.

The stated purpose of the pilot project, as approved by the PUCT and amended at the July 16, 2013 meeting of the ERCOT Board of Directors, was to:

- Determine whether FRRS can improve ERCOT's ability to arrest frequency decay during unit trips;
- Determine the optimal means of deploying FRRS by testing various deployment methodologies;
- Determine whether FRRS can reduce the need for Regulation Service and thereby reduce total Ancillary Service costs;
- Assess the operational benefits and challenges of deploying FRRS;
- 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.

To participate in FRRS, a qualified scheduling entity (QSE) must have the capability to receive a dispatch instruction from ERCOT through a separate ICCP signal. A resource must have the capability to independently detect and record system frequency with an accuracy of at least 1 mHz and a resolution of no less than 32 samples per second. The resource must also be able to measure and record MW output with a resolution of no less than 32 samples per second. In addition, resources must be separately qualified to provide FRRS-Up (increase in output or reduction in consumption provided during certain defined low frequency conditions) and/or FRRS-Down (reduction in output or increase in consumption provided during certain high frequency conditions), but are not required to seek qualification for both services.

In announcing the FRRS project, ERCOT said it believes that a faster-responding regulation service has the potential to increase the reliability of the ERCOT system at a lower total cost to load when compared with solely relying on conventional regulation service. For example, Figure 4-1 contrasts the response of conventional resources and fast-responding regulation services to a low-frequency event. Note the much quicker response of the FRRS resource.



Source: ERCOT (2013) [1].

Figure 4-1
Response from Conventional Resources (Source: ERCOT)

Notrees Participation in FRRS

The Notrees facility began providing FRRS service to ERCOT through a one-year pilot program on February 25, 2013. The project committed to providing 32 MW of FRRS-Up capacity and 30 MW of FRRS-Down capacity. An additional 1 MW FRRS-Up and FRRS-Down provided by other resources began participating on March 16, 2013.

In its pilot program, ERCOT conducted a weekly commitment of FRRS capacity, separately committing a maximum of 65 MW for FRRS-Up capacity and 35 MW for FRRS-Down capacity for each hour in the upcoming week. Although ERCOT established a method for allocating those totals among several competing participants, in practice the Notrees Wind Storage Demonstration facility was the only participant for its first few weeks, providing 32 MW of FRRS-Up and 30 MW of FRRS-Down. An additional 1 MW of FRRS-Up and FRRS-Down from other resources began participating on March 16, 2013. The FRRS pilot project continued into early 2014.

Results of the Notrees facility's participation in the FRRS pilot project are summarized in Chapter 6.

4.3 Activity in 2014

The Notrees demonstration's primary activity in 2014 was participating in ERCOT's Fast-Responding Regulation Service (FRRS) pilot project until the end of February 2014, when the FRRS pilot project ended. At that point, operations transitioned to participation in the ERCOT Regulation ancillary services market for the remainder of 2014.

The Notrees BESS was an active participant in the ERCOT Regulation Up market throughout 2014. It did not participate in the Regulation Down market. A discussion of that strategic decision, as well as a summary of the project's operational results, is provided in Chapter 6.

4.4 Future Activity

The Notrees demonstration concluded in December 2014. Subsequent primary activity continues to be participating in ERCOT's Regulation ancillary services market.

Duke Energy's future plans and activities, include options to continue providing Regulation services, transition to other services, and conduct further testing and impact assessment.

5

GRID IMPACTS AND BENEFITS

This chapter describes in general terms the potential grid impacts and benefits that the Notrees Wind Storage Demonstration might provide over the course of its operating lifetime. Not all of these characteristics were incorporated into the test plan; rather, they provided guidance regarding project and system metrics that could be derived from collected data.

Chapter 6 summarizes some of the actual results of fast-responding frequency regulation services provide by the BESS through ERCOT, while Chapter 7 addresses plans for future activities that may yield grid impacts and benefits.

5.1 Project and System Metrics

Duke Energy identified the impact metrics as either project or system metrics throughout the planning and reporting process. Duke Energy reported project metrics for impacts observed specific to the area that project assets, functionality, or programs were implemented. For example, frequency regulation services provided from the battery system were metered at the point of interconnection. Duke Energy reported system metrics for impacts observed on the entire transmission or distribution system based on estimates of the ERCOT system impacts attributable because of the battery system's participation in ERCOT. For example, estimates of avoided carbon emissions within ERCOT were calculated based on estimated system-wide carbon emissions at times when the battery system provided generation to the grid.

The following Impact Metrics correspond to those indicated in the Metrics and Benefits Reporting Plan (MBRP). The reference document[2] defines each metric in detail, while the following descriptions consist of short definitions and an elaboration on how the DAS and analytical methods could compute the metrics in practice.

Annual Storage Dispatch (Project Only)

The ERCOT settlement and the internal settlement between Xtreme Power and Duke Energy were used to compute the net charging and discharging of the BESS. There was sufficient metering and other schedule information to determine the periods during which the BESS acted as a generator or a load.

Average Energy Storage Efficiency (Project Only)

The storage efficiency was determined by accounting for the net energy entering and leaving the BESS over a long period. This value came from the metering of the BESS and from settlement information.

---

[2] *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*, Report SAND2010-0815, February 2010
http://www.smartgrid.gov/sites/default/files/resources/energy_storage.pdf

Peak Generation and Mix (Project and System)

The ERCOT peak generation and mix were determined from ERCOT's regular market reports.

Annual Generation Cost (Project and System)

The annual generation cost was determined from the settlement during periods when the BESS is operating as a generator.

Ancillary Services Price (Project and System)

The ancillary services prices were determined from ERCOT market information. The system level prices are reported in regular ERCOT reports.

Congestion (Project Only)

Congestion was determined from the Real Time Energy prices nearby the BESS site.

Congestion Cost (Project Only)

Congestion costs were determined by locating periods of time when the wind plant produced power and real-time energy prices in the BESS area showed a difference from those nearby. Under these conditions, the price difference and the net wind-storage schedule help place a monetary value on congestion costs in the region near the BESS. Since the BESS is small relative to wind energy production in the region, this value may be very small or difficult to measure on an impact versus baseline basis.

CO_2 Emissions (Project and System)

Curtailments of the wind farm compared to the battery operation helped indicate when the battery supported wind power production when it would otherwise be curtailed. Comparison of conditions during the impact period with those during the baseline period helped determine the quantity of additional wind energy being enabled by the BESS. This quantity displaces emissions from a proxy thermal unit on a per-MWh basis to compute the carbon dioxide reduction.

The 2015 ERCOT report *2014 Demand and Energy Report* contains the generation mix for reporting CO2 emissions, which is found in Table 5: Electric Power Industry Generation by Primary Energy Source, 1990-2012. The overall values of CO_2 emissions are found in Table 7: Electric Power Industry Emissions Estimates, 1990 through 2012.

Pollutant Emissions (Project and System)

Just as for the carbon dioxide emissions, other pollutant emissions were estimated from the wind plant curtailment reductions on a per-MWh basis, when compared to a proxy thermal plant's emissions.

This project provided project-level emissions impact information regarding annual storage dispatch and average energy storage efficiency. The peak generation and mix were provided for the project level and the system level. The system level reporting depended on collaboration with ERCOT to obtain such information. Likewise, annual generation costs were provided, and system level reporting depended on the depth of collaboration with ERCOT.

Ancillary Services pricing was provided for the Notrees location and for a system average, depending on the ERCOT market price availability and ERCOT's reporting in its annual State-of-the-Market report.

Environmental reporting of CO_2 and other emissions were reported, depending on the ability of the project to obtain peak generation mix and especially the marginal resource type from ERCOT.

5.2 Impacts and Benefits of FRRS Participation

As described in Section 4.2, the Notrees Wind Storage Demonstration facility began participating in ERCOT's FRRS pilot program in February 2013. In general, the facility performed very well in the FRRS program, responding quickly and reliably as required. In a June 2013 preliminary report, ERCOT concluded that:

- The introduction of FRRS improves ERCOT's ability to arrest frequency decay during unit trips.
- FRRS pilot resource generally followed ERCOT FRRS deployments and responded automatically using local frequency detecting techniques.
- When deployed, FRRS reduces the rate of change of frequency and regulation deployed to conventional resources.
- ERCOT observed lower quantities offered for FRRS-Down and an overall lower performance for FRRS-Down.

Data produced by the project's participation in FRRS are summarized in Section 6.3 as part of the report's findings and conclusions.

6

MAJOR FINDINGS AND CONCLUSIONS

This chapter documents the installation and operation of the Notrees Wind Storage Demonstration project, including its construction in 2012, its first year of commercial operation and participation in ERCOT's FRRS pilot program, subsequent participation in the Regulation service market, and overall system performance through 2014

6.1 Construction

The concrete foundation of the project building was poured in March 2012. The structure in the background of Figures 6-1 and 6-2 is the Operations Building.

Figure 6-1
Preparations for pouring concrete (view northwest to southeast)

Figure 6-2
Concrete work in progress (view southwest to east)

In April 2012, work proceeded on framing the project building and installing switchgear around its perimeter.

Figure 6-3
Building construction at left, switchgear enclosure at right (view northwest to south)

Figure 6-4
Construction in progress

By late April 2012, building framing was complete and construction began on exterior walls.

Figure 6-5
Walls along the east side of the building, with concrete forms for transformer pads in foreground and switchgear at center right (view south to north).

Figure 6-6
Preparations for pouring concrete on the opposite (west) slide of the building (view northwest to south)

In early May 2012, approximately a week after the previous photos were taken, most of the project building's walls were in place and being insulated. Concrete work continued around the building's perimeter.

Figure 6-7
East side of building, with concrete pads for transformers in place (view southeast to north)

Figure 6-8
East side and unfinished north end of project building (view northeast to south)

6.2 Integrated Module Testing

By October 2012, building construction was completed and all battery/PCS units were in place. Integrated Module Testing occurred in October and November.

Figure 6-9
Completed building exterior

Figure 6-10
Typical transformer (left) with cooling units (right) outside the building

Figure 6-11
PowerCell Modules are arranged in two parallel rows that run the length of the building (one row in foreground, the other row visible at left background).

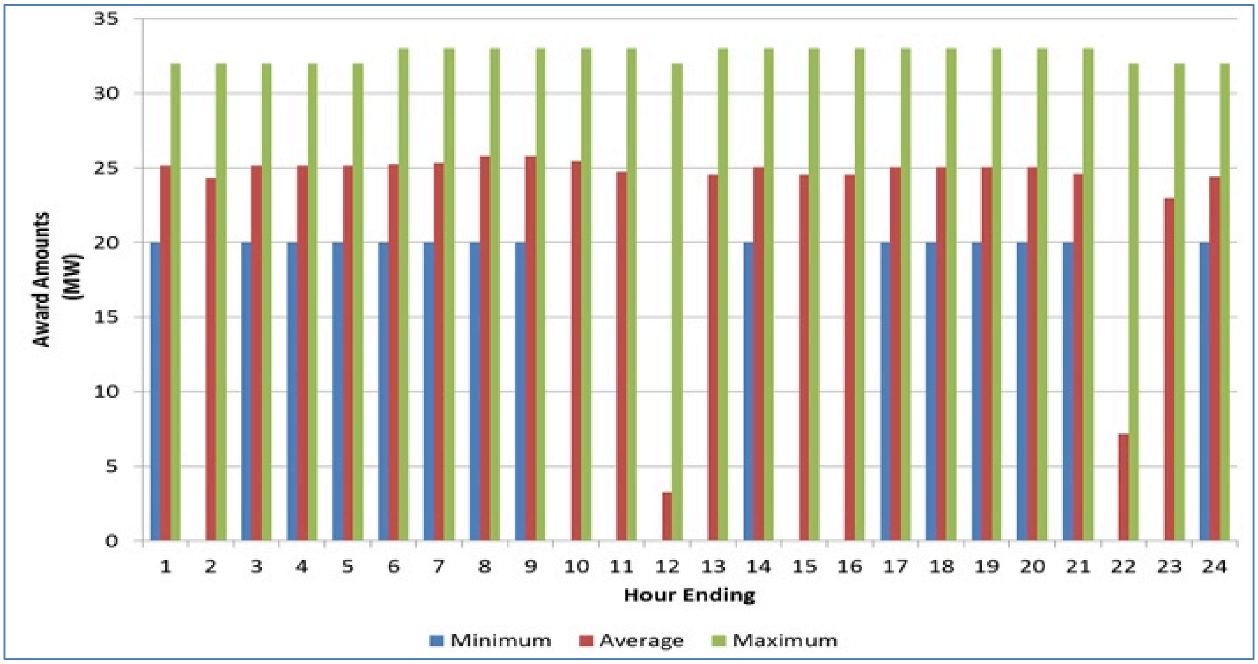
Figure 6-12
Two of the PowerCell Module PCS units (batteries at right)

6.3 Fast-Responding Regulation Service (FRRS)

The Notrees Wind Storage Demonstration Project began providing FRRS service to ERCOT through a one-year pilot program on February 25, 2013. The project provides 32 MW of FRRS-Up capacity and 30 MW of FRRS-Down capacity. An additional 1 MW FRRS-Up and FRRS-Down provided by other resources began participating on March 16, 2013.

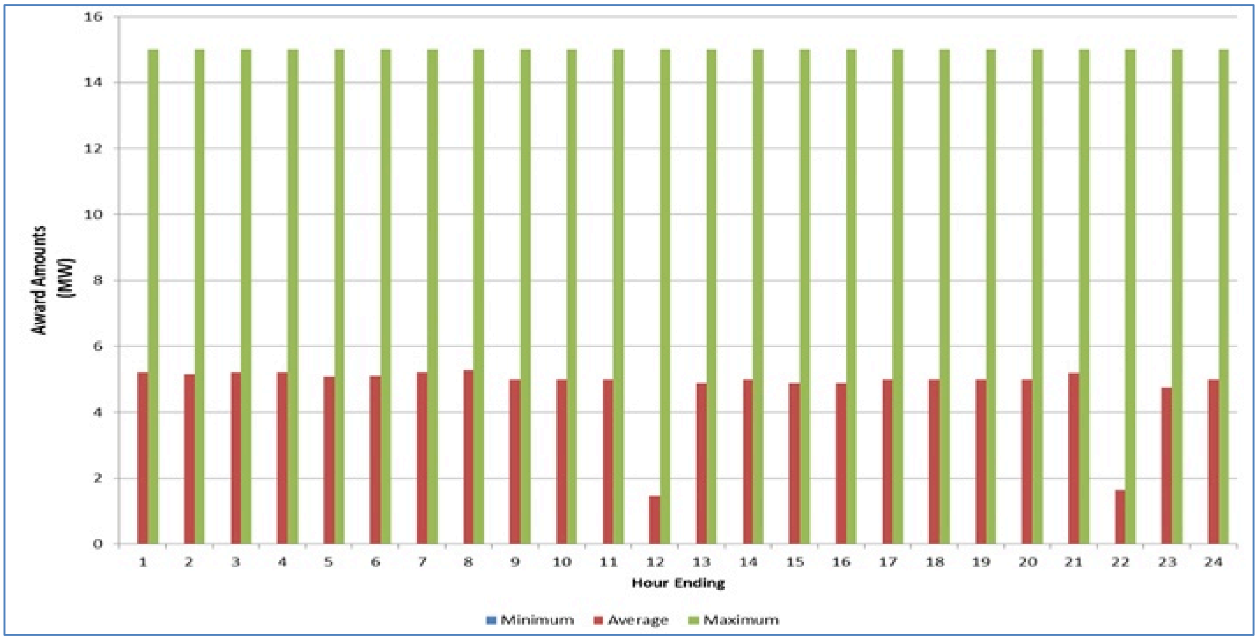
The figures below summarize selected FRRS performance results. Note that these figures do not distinguish between FRRS-Up and FRRS-Down services provided by the Notrees BESS and the other resources. However, since the Notrees project provided the vast majority of available capacity, these results are a fair representation of its performance.

Figures 6-13 and 6-14 show the aggregate amounts of FRRS-Up and FRRS-Down awarded for the first nine weeks of the pilot program. Each figure indicates the minimum and maximum amounts of capacity ordered as well as the average.



Source: ERCOT [1]

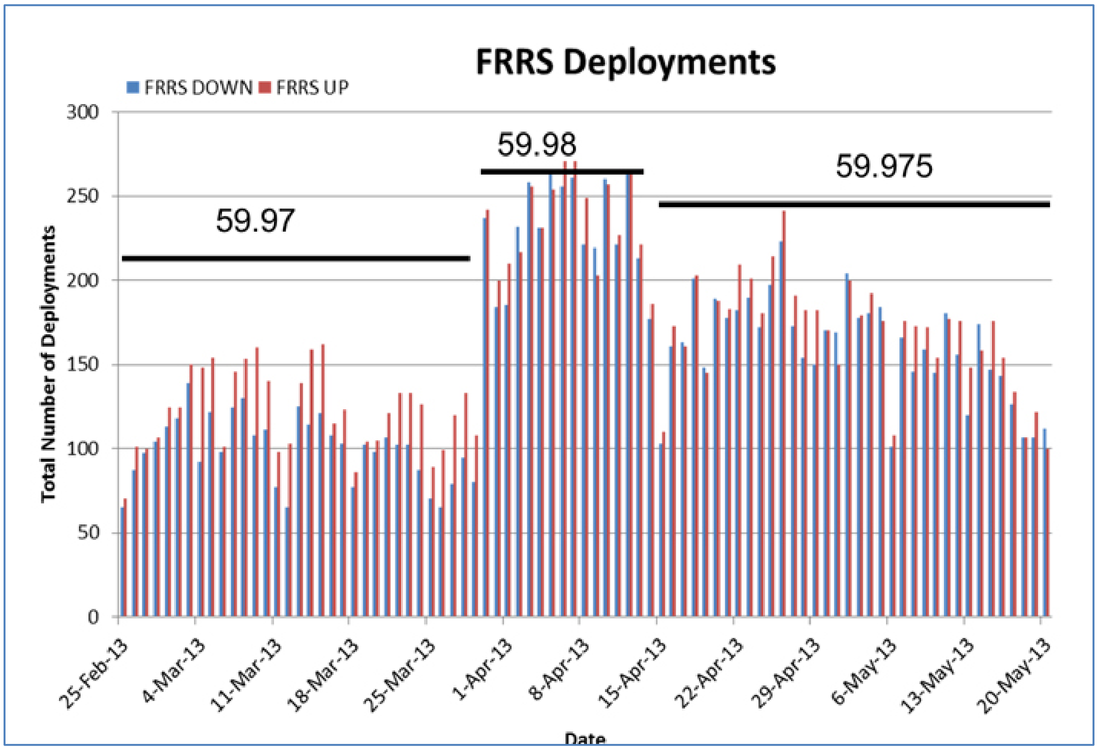
Figure 6-13
Aggregate FRRS-Up Award Amounts for First 13 Weeks



Source: ERCOT [1]

Figure 6-14
Aggregate FRRS-Down Award Amounts for First 13 Weeks

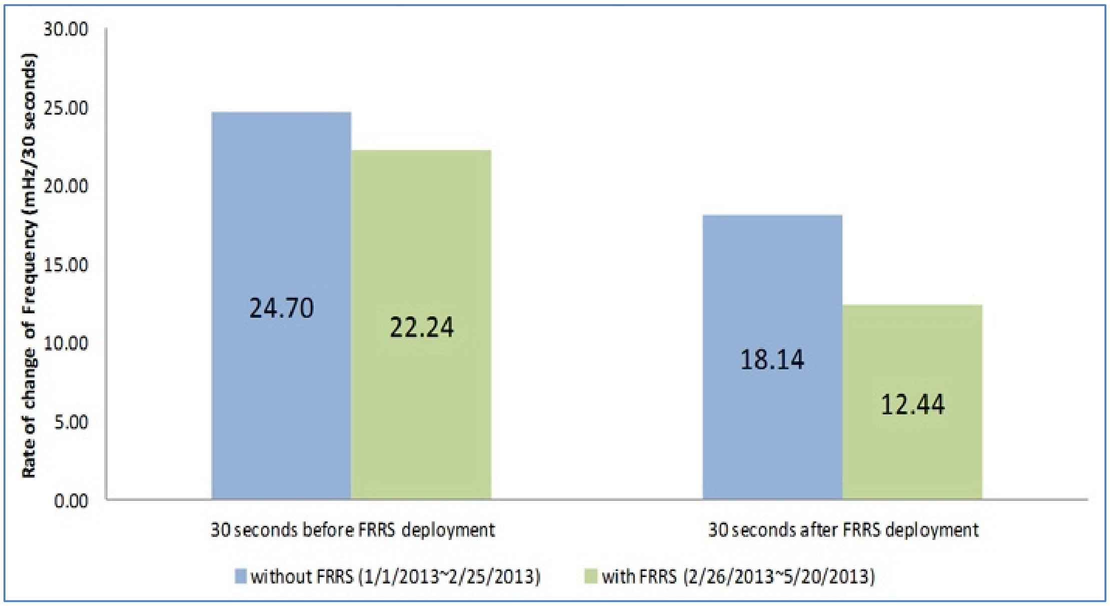
Figure 6-15 shows FRRS deployments, both up (in red) and down (in blue), from February 25 through May 20, 2013. The spans marked 59.97, 59.98, and 59.975 indicate which dates those particular low trigger frequency parameters were in effect.



Source: ERCOT [1]

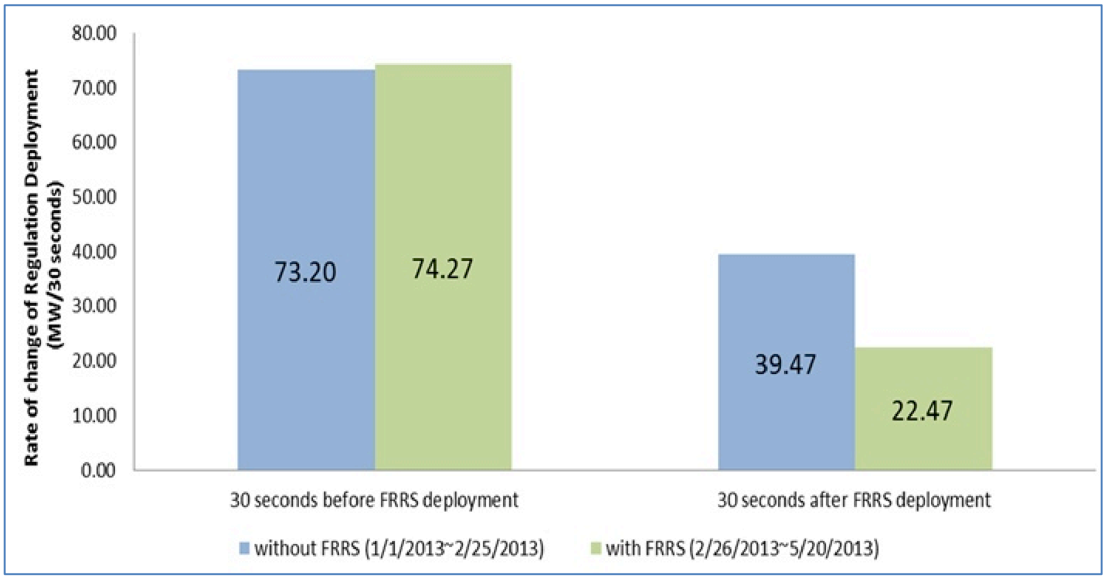
Figure 6-15
Number of FRRS Deployments, February–May 2013

Figure 6-16 illustrates the rate of change of frequency, and Figure 6-17 shows the rate of change of regulation deployment, with and without FRRS for selected ranges of dates.



Source: ERCOT [1]

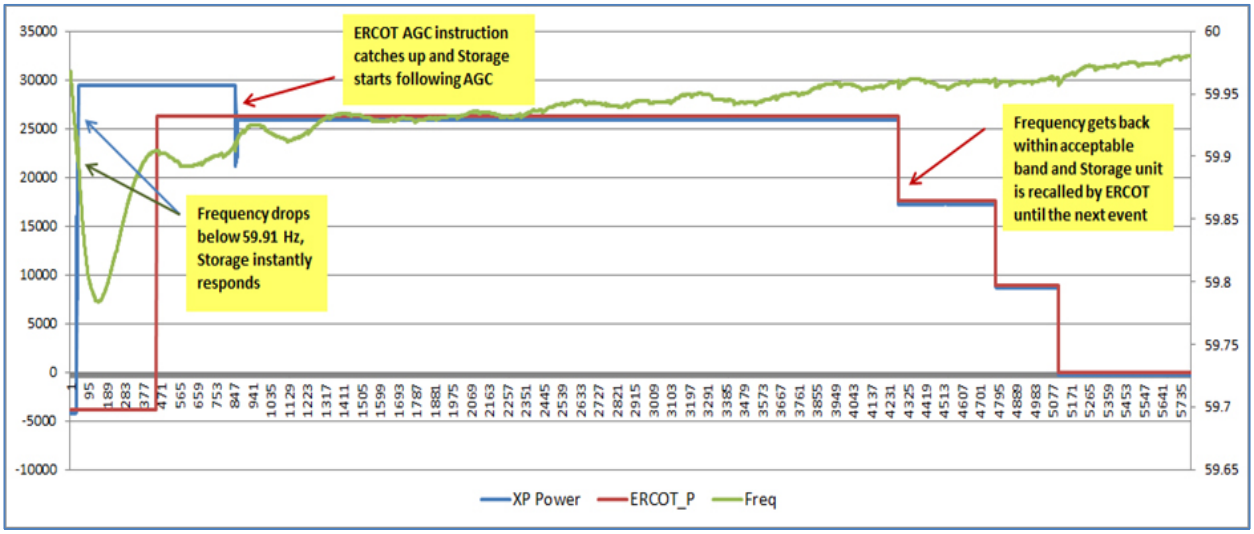
Figure 6-16
Rate of Change of Frequency (mHz/30 seconds)



Source: ERCOT [1]

Figure 6-17
Rate of Change of Regulation Deployment (MW/30 seconds)

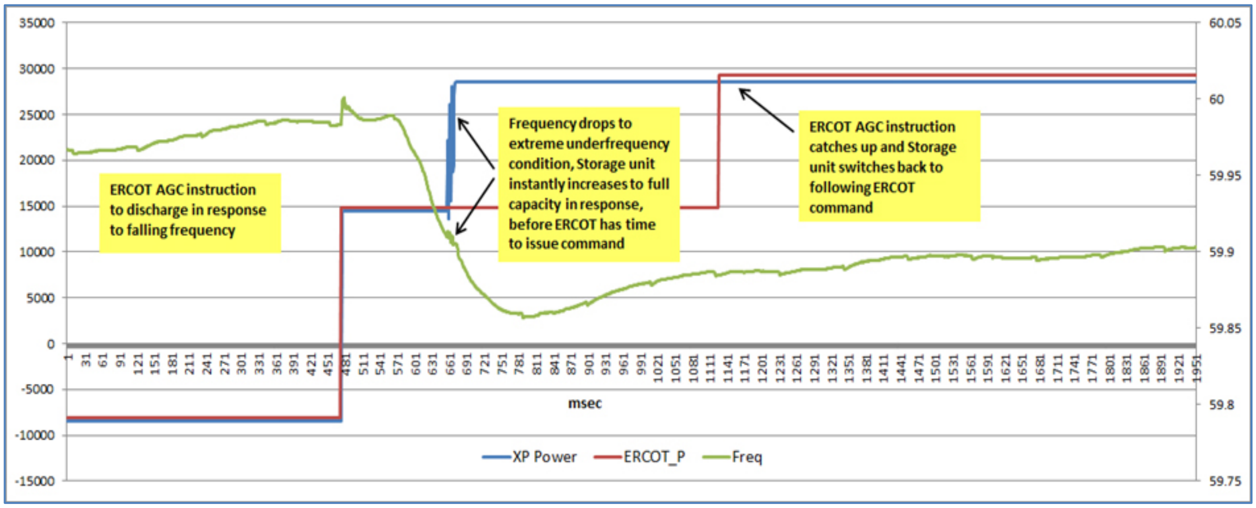
Figures 6-18 and 6-19 illustrate how the Notrees BESS can respond immediately to address frequency deviations (shown in green in the figure), and give Automated Generation Control (AGC) crucial time to correct the problem.



Source: Duke Energy [2]

Figure 6-18
Illustration of BESS Arresting Extreme Frequency Deviation

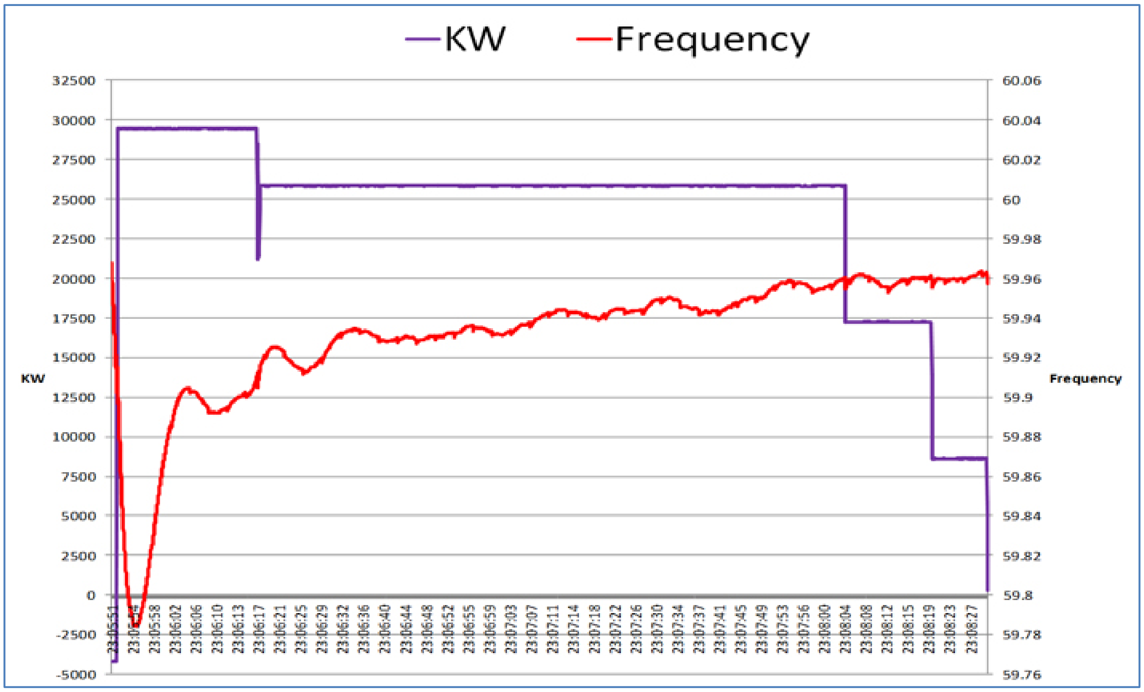
The left axis indicates the energy scale in kW for the XP Power (blue) and ERCOT AGC signal (red), and the right axis indicates the frequency in Hz for the ERCOT system (green). Shortly after Time Point 1, the XP Power goes to maximum output of almost 30,000 kW (30 MW) and remains at that level until the ERCOT AGC instructions “catch up” after about two cycles (~8 seconds).



Source: Xtreme Power (2013). [25]

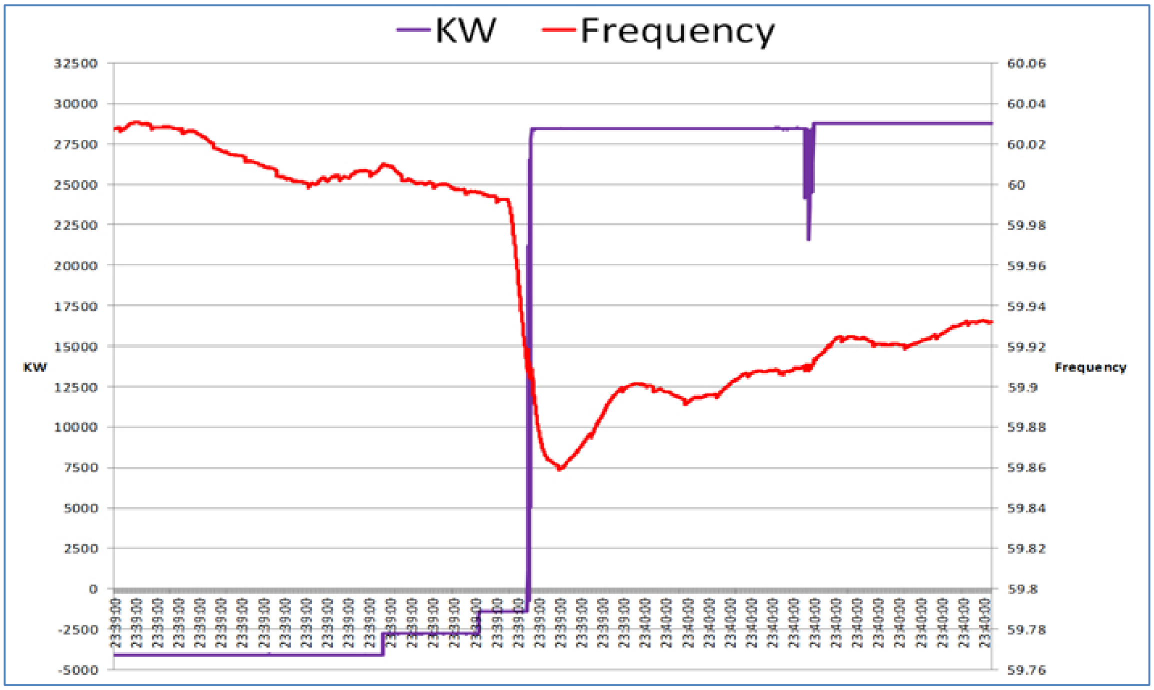
Figure 6-19
Illustration of BESS Arresting Extreme Frequency Deviation

The figures below all show actual events during the ERCOT FRRS pilot program when FRRS resources responded to low or high frequency triggers. Under the program, a FRRS resource must meet two performance criteria: it must deploy within 60 cycles of a dispatch instruction or triggering frequency; and it must provide 95% to 110% of the obligated capacity during the entire duration of the deployment.



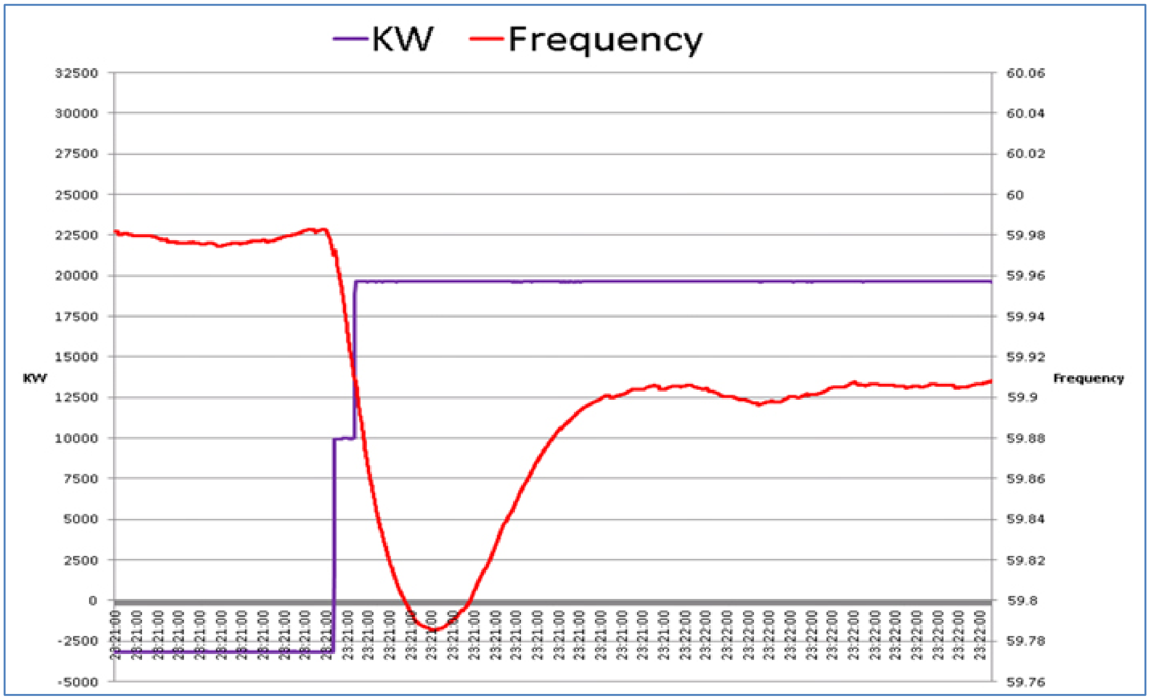
Source: ERCOT (2013) [26]

Figure 6-20
Event on March 7, 2013 (with high-resolution data)



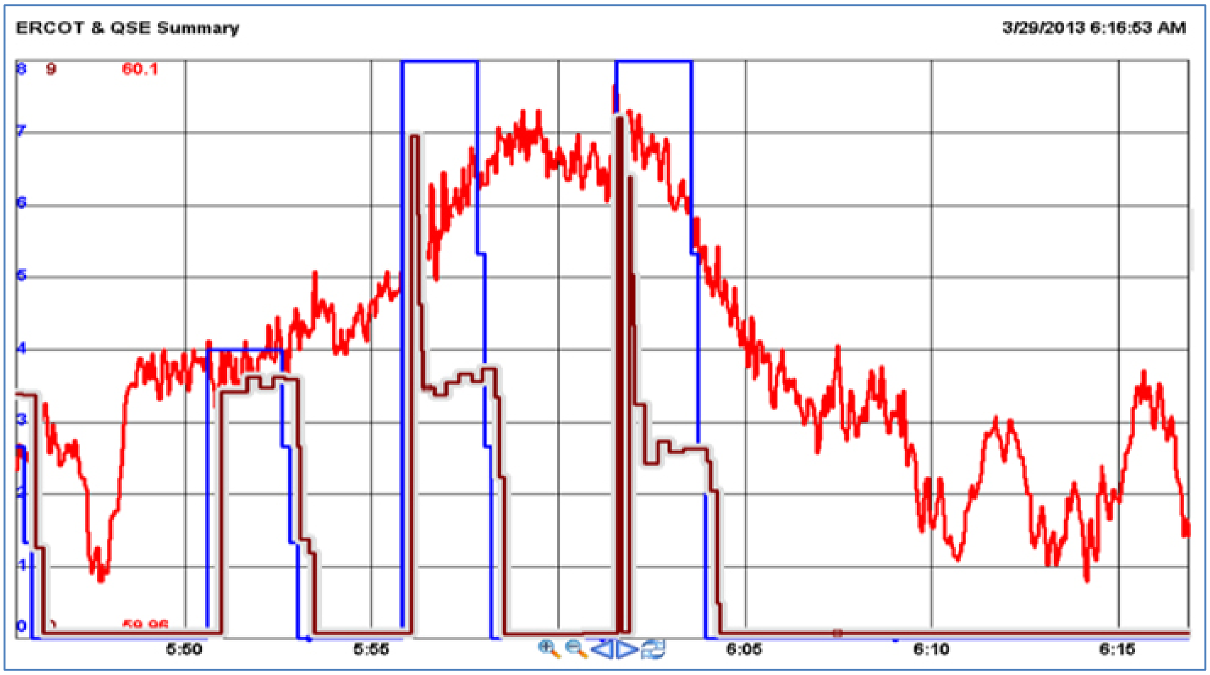
Source: ERCOT (2013) [26]

Figure 6-21
Event on March 15, 2013 (with high-resolution data)



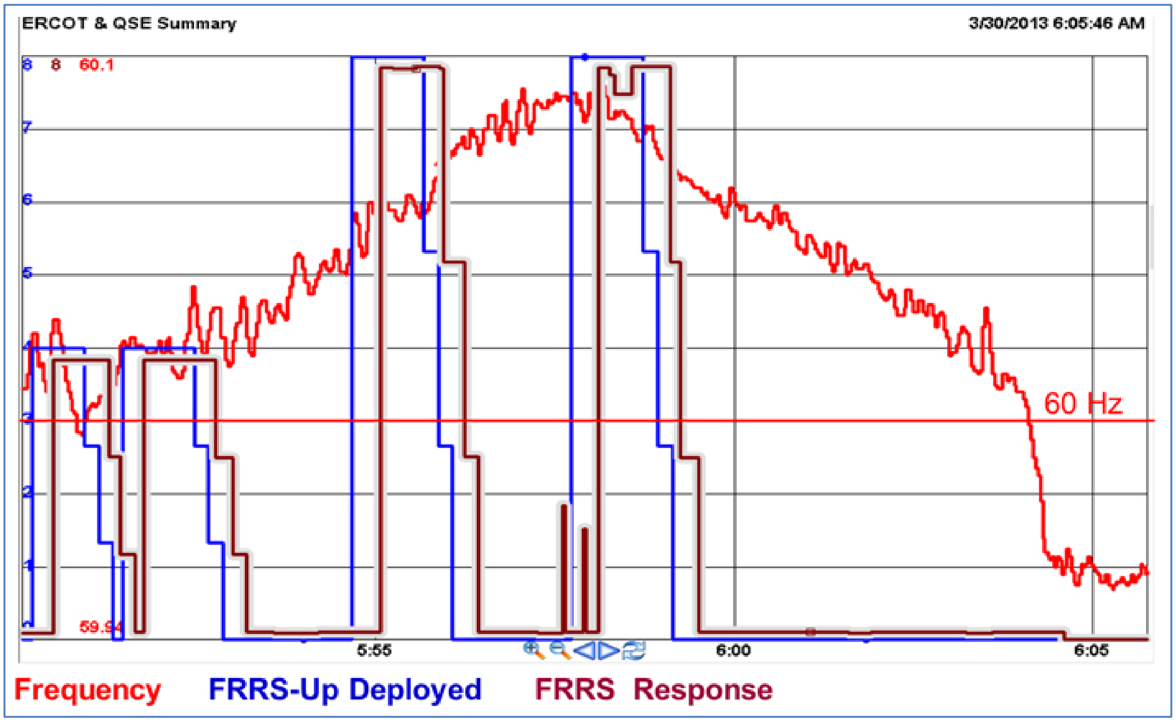
Source: ERCOT (2013) [26]

Figure 6-22
Event on April 9, 2013 (with high-resolution data)



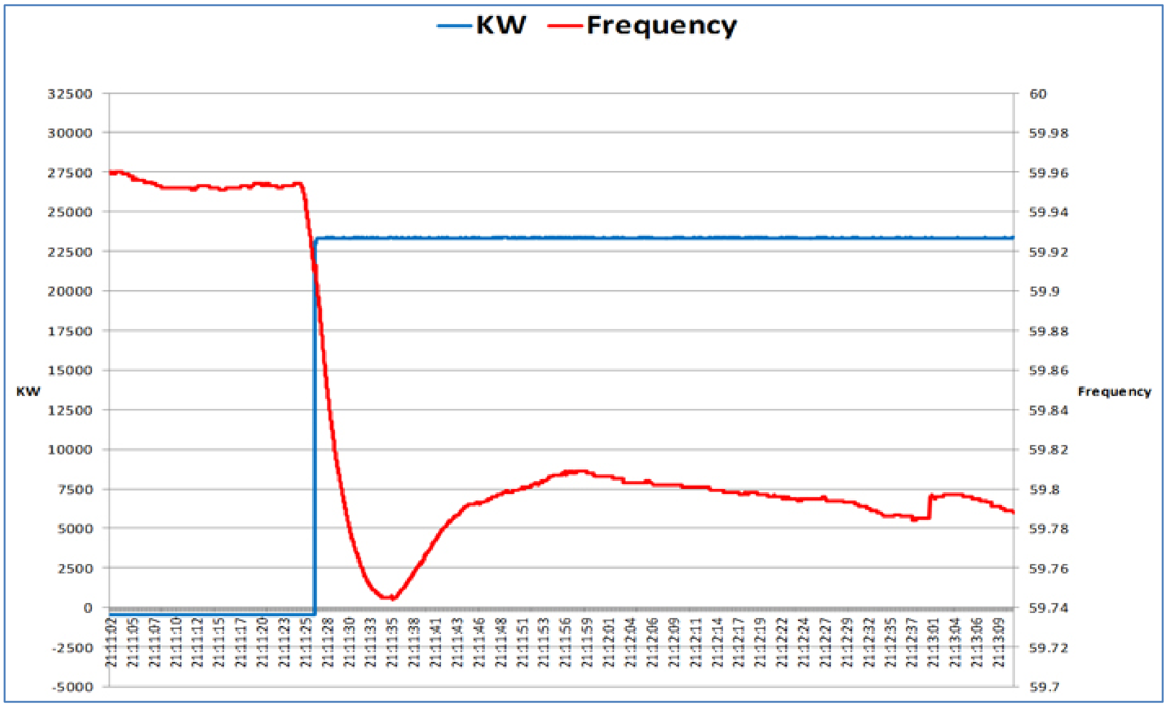
Source: ERCOT (2013) [26]

Figure 6-23
High-Frequency Event on March 29, 2013



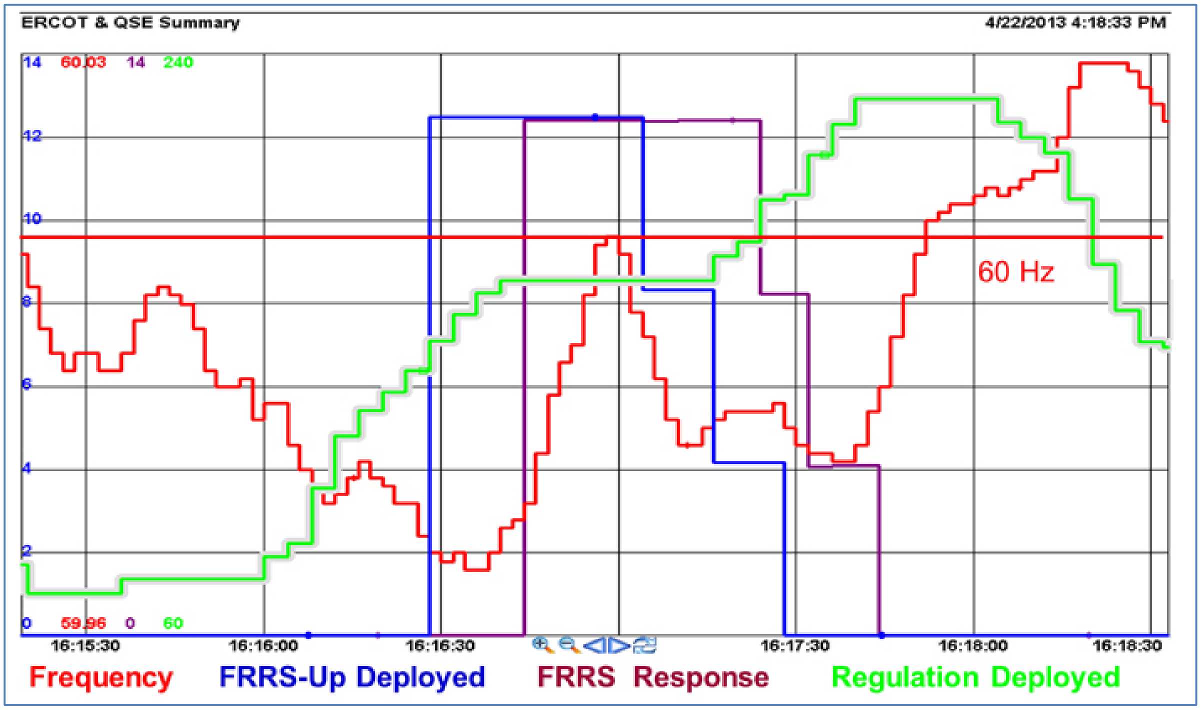
Source: ERCOT [26]

Figure 6-24
High-Frequency Event on March 30, 2013



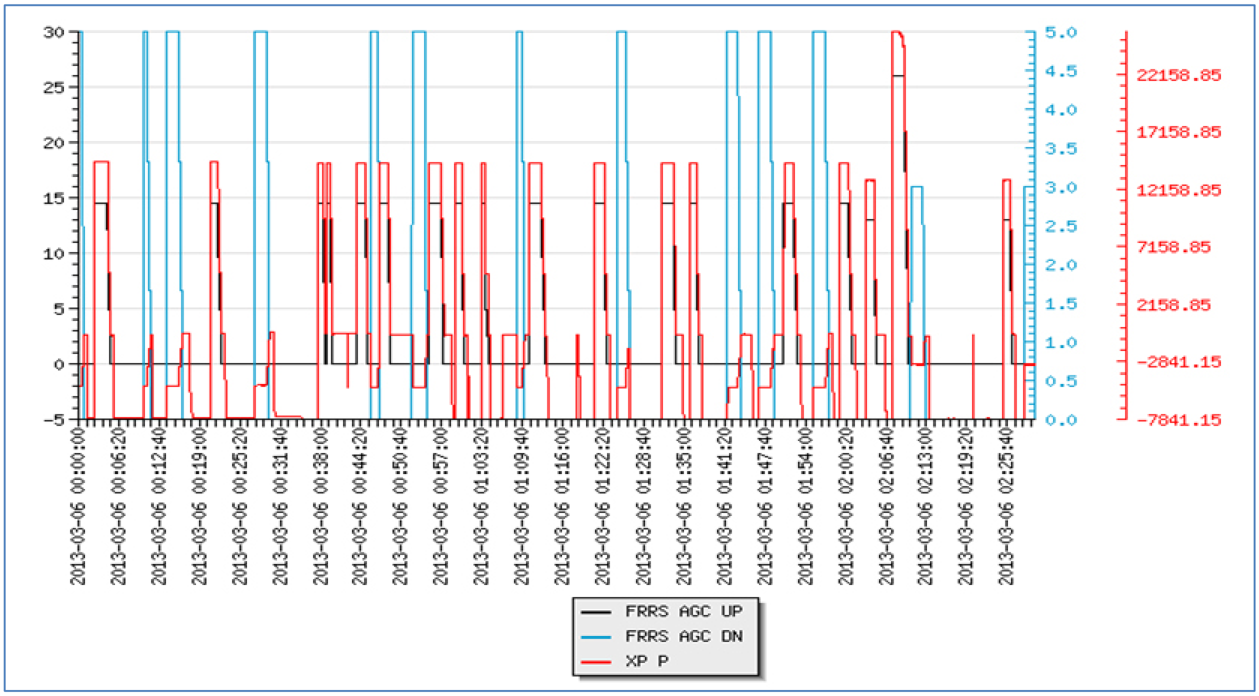
Source: ERCOT [1]

Figure 6-25
Frequency Event on May 22, 2013



Source: ERCOT [1]

Figure 6-26
Effect of FRRS-Up on Frequency and Reg-Up, April 22, 2013



Source: Younicos (formerly Xtreme Power) (2013) [25]

Figure 6-27
Response of BESS (in red) to ERCOT Regulation Signals, March 6, 2013

ERCOT issued its *Final Report on ERCOT Pilot Project for Fast Responding Regulation Service (FRRS)* in presentation format on March 26, 2014. Considering that the Notrees BESS operation provides the vast majority of the service, this ERCOT report is a very good source of understanding for an independent assessment of the Notrees demonstration performance and impacts. There were three resources participating in the pilot project:

- Participant 1 was a nominal 36-MW battery in Winkler/Ector County
- Participant 2 was a nominal 1-MW battery in Harris County
- Participant 3 was a nominal 0.1-MW fleet electric vehicle charging station in Tarrant County

ERCOT determined generally, that:

- The use of FRRS (and the demonstration project by proxy) successfully improved the system’s ability to arrest frequency decay during unit trips. This is a significant benefit for this isolated interconnection.
- Performance in response to Regulation service signals was successful, and the automatic response using local frequency detection was also successful.
- Other conventional resources had reduced burdens for rate of change of output because of the fast response.
- There was a reduced amount of FRRS Down offered during the course of the project.

The reduced amount of FRRS Down was directly a result of the demonstration project reducing its offers into the FRRS Down market. For instance, after of July 2013, there were no more offers. As mentioned above, this was a decision on the part of Duke Energy regarding the best, or optimal, use of available battery capacity.

ERCOT Rate of Change of Frequency

To better appreciate the benefit to the ERCOT system provided by the demonstration project, Table 1—which was included in ERCOT's final report on the FRRS pilot project—reports the Rate of Change of Frequency (RoCoF) with baseline data for January 2013 and the project performance thereafter.

Table 6-1
Average Rate of Change of Frequency during FRRS Pilot

Time Period	Average MW Deployed	Average RoCoF prior to FRRS-Up Deployment (mHz/30 seconds)	Average RoCoF after FRRS-Up Response (mHz/30 seconds)
January 2013	0.00*	21.79	17.31
Feb 1 to Feb 24	0.00*	27.61	18.96
Feb 25 to Feb 28	12.05	23.44	11.76
Mar-13	14.40	23.38	12.03
Apr-13	11.57	19.57	13.40
May-13	12.45	18.36	12.61
Jun-13	14.15	15.66	9.66
Jul-13	14.57	14.24	9.66
Aug-13	13.08	13.52	8.76
Sep-13	11.08	16.85	9.34
Oct-13	14.42	17.95	11.07
Nov-13	14.38	19.40	11.60
Dec-13	11.07	16.09	10.53
Jan-14	10.20	17.12	9.92
Feb-14	10.26	16.56	10.23
*FRRS not deployed before pilot began on February 25, 2013			

Source ERCOT (2014). [3]

Note that the RoCoF improves even when no FRRS-Up is deployed, as in January 2013 and early February 2013, because of the automated Regulation Up response from other units. These values should be compared with the more favorable values throughout the remainder of the year, wherein the RoCoF is reduced by as much as half its baseline value.

Prior to deployment of FRRS, the Rate of Change of Regulation Up (RoCoRU) was two to three times faster according to Table 6-2, also from the ERCOT FRRS final report. This is an indication of the reduced burden on conventional thermal power generating units, which may translate into reduced mechanical stresses and reduced maintenance costs.

Table 6-2
Average Rate of Change of Regulation Up during FRRS Pilot

Time Period	Average MW Deployed	Average RoCoRU prior to FRRS-Up Deployment (mHz / 30 seconds)	Average RoCoRU after FRRS-Up Response (mHz / 30 seconds)
January 2013	0.00*	69.25	36.91
Feb 1 to Feb 24	0.00*	77.15	42.03
Feb 25 to Feb 28	12.05	80.35	18.61
Mar-13	14.40	80.12	21.32
Apr-13	11.57	64.70	25.24
May-13	12.45	62.32	32.17
Jun-13	14.15	59.10	32.35
Jul-13	14.57	58.41	27.77
Aug-13	13.08	55.29	28.05
Sep-13	11.08	64.20	31.51
Oct-13	14.42	64.68	28.46
Nov-13	14.38	61.09	27.15
Dec-13	11.07	61.05	27.31
Jan-14	10.20	51.34	27.42
Feb-14	10.26	50.30	27.85
*FRRS not deployed before pilot began on February 25, 2013			

Source ERCOT (2014). [3]

The impact that FRRS (and later provision of Regulation Up) has had upon improving the overall reliability of the ERCOT system has been the most important use and benefit provided to date by the Notrees BESS during the course of this demonstration project; gaining over $2.5 million in revenue from Regulation service is the main evidence of the value of the BESS. There is no other monetary evidence of value.

6.4 Project and System Impacts

This section presents the project and system impact values identified in the MBRP. The project values are associated with the Notrees BESS, specifically. The system values are associated with the ERCOT balancing area unless otherwise noted. Some system values are reported for the West Texas area or for Texas as a whole, due the availability of data applicable to this case.

Because the Notrees BESS project is not related to heating months (October-March) and cooling months (April-September) impacts are reported on an annual basis.

Some differences between reported values for the Annual Storage Dispatch (Energy Delivered) found in this report and the DOE Quarterly Reports may be attributed to different metering, house load accounting, or later adjustments. The differences between these values are about 5% to 8%. The values found in this report are the latest, best versions available.

2012 Baseline Metrics

Table 6-3 contains 2012 baseline system values. The values for the BESS project in 2012 are all zero. The system values are provided for comparison to those in tables that represent later years.

Peak Generation in ERCOT is reported from the 15-minute interval average data in order to identify the larger value, when compared to the hourly average values. No values for Ancillary Services (FRRS) are reported, because the program was not operating during that period. Congestion in West Texas was not identified as an issue in the 2012 *State of the Markets Report* [5]. As a result, this value is labeled as "N/A" for 2012.

In summary, there is somewhat limited information to use as a baseline in 2012 for the Notrees BESS demonstration project.

Table 6-3
Baseline Metrics for the ERCOT System in 2012

IMPACT METRICS: Storage Systems				
Metric	**Value**	**Project**	**System**	**Notes**
Annual Storage Dispatch (Energy Received)	MWh	0	N/A	
Annual Storage Dispatch (Energy Delivered)	MWh	0	N/A	
Annual Storage Dispatch (Net Energy Received)	MWh	0	324,859,701	[4]
Average Energy Storage Efficiency	%	0	N/A	
Peak Generation (Testing)	MW	0	N/A	[4] on 15-min
Peak Generation (Operations)	MW	0	66,583	
Generation Mix	%			[4] Annual averages
• Natural Gas		N/A	44.6%	
• Coal		N/A	33.8%	
• Nuclear		N/A	11.8%	
• Wind		N/A	9.2%	
• Water		N/A	0.1%	
• Net DC/BLT		N/A	0.2%	
• Other		N/A	0.3%	
Annual Generation Cost (Energy Received)	$	0	N/A	
Annual Generation Cost (Energy Delivered)	$	0	N/A	
Annual Generation Cost (Net Energy Cost)	$	0	9.507 billion	[4], [5], 324,859,701 MWh [D&E] * $28.33/MWh [SOM]
Hourly Generation Cost	$/MWh	0	N/A	
Ancillary Services Cost (FRRS)	$	0	N/A	
Ancillary Services Price (FRRS)	$/MW-h	0	N/A	FRRS did not exist in 2012.
Congestion	MWh	0	N/A	West Texas
Congestion Cost	$	0	480,000,000	[5]
CO_2 Emissions	tons	0	212,462,678	[4], [15]

IMPACT METRICS: Storage Systems				
Metric	**Value**	**Project**	**System**	**Notes**
Pollutant Emissions (SOx)	tons	0	300,007	[4], [15]
Pollutant Emissions (NOx)	tons	0	113,359	[4], [15]
Pollutant Emissions (PM-2.5)	tons	0	18,760	[4], [15]

2013 Impact Metrics

Table 6-4 contains 2013 storage system impact values, which may be compared to the 2012 baseline values in Table 6-3.

Table 6-4
Impact Metrics for the Notrees BESS Project and the ERCOT System in 2013

IMPACT METRICS: Storage Systems				
Metric	**Value**	**Project**	**System**	**Notes**
Annual Storage Dispatch (Energy Received)	MWh	14,433.5	N/A	[6]
Annual Storage Dispatch (Energy Delivered)	MWh	9,790.8	N/A	[6]
Annual Storage Dispatch (Net Energy Received)	MWh	4,642.7	331,624,102	[6], [8]
Average Energy Storage Efficiency	%	67.8	N/A	[6]
Peak Generation (Testing)	MW	32.9	N/A	[7], [8]
Peak Generation (Operations)	MW	31.9	67,328	
Peak Load (Testing)	MW	30.6	N/A	[7], [8]
Peak Load (Operations)	MW	15.3	N/A	
Generation Mix	%			[8], Annual averages
• Natural Gas		N/A	40.5%	
• Coal		N/A	37.2%	
• Nuclear		N/A	11.6%	
• Wind		N/A	9.9%	
• Water		N/A	0.1%	
• Net DC/BLT		N/A	0.5%	
• Other		N/A	0.3%	
Annual Generation Cost (Energy Received)	$	487,009	N/A	[9]
Annual Generation Cost (Energy Delivered)	$	-353,004	11.491 billion	[8], [9], [10] 331,624,102 MWh [D&E] * 33.71 $/MWh [SOM]
Annual Generation Cost (Net Energy Cost)	$	134,005	N/A	[9]
Hourly Generation Cost	$/MWh	28.86	33.71	= Net Energy Cost / Net Energy Received
Ancillary Services Cost (FRRS-Up)	$	-1,303,297	1,310,019	[3], [9]
Ancillary Services Cost	$	-30,130	27,190	[9]

IMPACT METRICS: Storage Systems				
Metric	**Value**	**Project**	**System**	**Notes**
(FRRS-Down)				
Ancillary Services Price (FRRS-Up)	$/MW-h	9.14	8.57	[11], [12], Project is MW-weighted, System is unweighted.
Ancillary Services Price (FRRS-Down)	$/MW-h	6.02	4.89	[11], [12], Project is MW-weighted, System is unweighted.
Congestion	MWh	0	93,200,000	[10], West Texas Zone
Congestion Cost	$	0	466,000,000	[10], all ERCOT
CO_2 Emissions	tons	2,556.27	216,886,689	[13], [14], [15]
Pollutant Emissions (SOx)	tons	0.02	306,254	13], [14], [15]
Pollutant Emissions (NOx)	tons	2.14	115,720	13], [14], [15]
Pollutant Emissions (PM-2.5)	tons	0.13	19,151	13], [14], [15]

Notable differences between the system impact values from 2012 (baseline) and 2013 are:

- Net Energy Received increased 7 TWh, from 325 TWh to 332 TWh
- The ERCOT system peak rose 745 MW, from 66,583 MW to 67,328 MW.
- The percentage of electrical energy produced by natural gas decreased from 44.6% to 40.5%.
- The percentage of electrical energy produced by coal rose from 33.8% to 37.2%.
- West Texas congestion was not noted in 2012, but became the most notable source of system congestion in 2013, according to the market monitor.
- Overall system congestion costs decreased from $488 million to $466 million.
- CO_2 emissions increased about 5 Mtons, from 212 Mtons to 217 Mtons, which is consistent with increased energy received, increased coal use and decreased natural gas use.
- Pollutant Emissions (SO_X, NO_X, PM-2.5) are slightly (2%) higher, which is again consistent with energy and CO_2 increases.

The only system impact related to the Notrees BESS is the decrease in West Texas congestion. The *2013 State of the Market Report for the ERCOT Wholesale Electricity Markets* [10] says, “Given increases in local loads and the increase in fuel prices, it is noteworthy that transmission congestion decreased in 2013. This reduction was due in large part to transmission improvements that decreased the congestion levels in the West zone.”

While Notrees BESS likely had little to do with this impact, should such storage be located more strategically, where congestion relief is more practical, it could have a significant benefit. Total ERCOT congestion rent for the year 2012 totaled $516 million, of which West Texas accounted for 53.4% and thus $275 million. In 2013, the ERCOT congestion rent totaled $466 million, of which West Texas accounted for 40.7% and thus $190 million. This sum is quite significant when compared with the overall cost of construction of the demonstration project.

Due to the use of the Notrees BESS project for FRRS during its first year of operation, its impact on the ERCOT system has mostly been in terms of reliability benefits that are monetized through the $1.3 million in FRRS Up and Down revenue documented in the Project column of Table 6-4. Further evidence of the reliability benefits was presented earlier in descriptions of the reductions in the Rate of Change of Frequency and the Rate of Change of Regulation Up. These benefits are not directly monetized, and likely provide broad public benefits to other producers and consumers in the ERCOT market.

2014 Impact Metrics

Table 6-5 contains 2014 storage system impact values, which may be compared to the 2012 baseline values in Table 6-3 to gain some sense of the overall impact of the Notrees BESS on the ERCOT system.

Table 6-5
Impact Metrics for the Notrees BESS Project and the ERCOT System in 2014

IMPACT METRICS: Storage Systems				
Metric	**Value**	**Project**	**System**	**Notes**
Annual Storage Dispatch (Energy Received)	MWh	10,429	N/A	[20]
Annual Storage Dispatch (Energy Delivered)	MWh	6,291	N/A	[20]
Annual Storage Dispatch (Net Energy Received)	MWh	4,138	340,033,353	[18], [20]
Average Energy Storage Efficiency	%	60.3	N/A	[17]
Peak Generation (Operations)	MW	22.7	66,580	[17], [18]
Peak Load (Operations)	MW	7.5	N/A	[17]
Generation Mix	%			[18] annual averages
Natural Gas		N/A	41.1	
Coal		N/A	36.0	
Nuclear		N/A	11.6	
Wind		N/A	10.6	
Water		N/A	0.1	
Net DC/BLT		N/A	0.4	
Other		N/A	0.3	
Annual Generation Cost (Energy Received)	$	538,910	N/A	[19], [20]
Annual Generation Cost (Energy Delivered)	$	-368,950	13.818 billion	[18], [20], [21] 340,033,353 MWh [D&E] * 40.64 $/MWh [SOG]
Annual Generation Cost (Net Energy Cost)	$	169,160	N/A	[20]
Hourly Generation Cost	$/MWh	41.07	40.64	[21]
Ancillary Services Cost (Reg-Up)	$	-1,787,428	57,184,103	[3], [20], [27] rounding error $13,259
Ancillary Services Cost (Reg-Down)	$	0.00	40,118,171	[27]
Ancillary Services Price (Reg-Up)	$/MW-h	13.12	14.88	[20], [24] Project is MW-weighted, System is unweighted.
Ancillary Services Price (Reg-Down)	$/MW-h	N/A	10.90	[24] Project is MW-weighted, System is unweighted.
Congestion	MWh	0	~200,000,000	[24], West Texas Zone

IMPACT METRICS: Storage Systems				
Metric	**Value**	**Project**	**System**	**Notes**
Congestion Cost	$	0	708,000,000	[24], all ERCOT
CO_2 Emissions	tons	2,475.50	210,126,824	[18], [22]
Pollutant Emissions (SOx)	tons	0.02	267,963	[18], [22]
Pollutant Emissions (NOx)	tons	2.07	99,748	[18], [22]
Pollutant Emissions (PM-2.5)	tons	0.12	18,259	[18], [22]

Table 6-5 can also be compared to the 2013 impact values in Table 6-4 to realize the changes in the Notrees BESS and overall ERCOT system performance between the first and second years of operation.

During 2014, the BESS provided only Regulation Up (Reg-Up) services.

While the generation mix and project emissions are almost unchanged from 2013 (year-one operations) to 2014, notable changes in the impact metric values are:

- Project Energy Received decreased 4.0 GWh, from 14.4 GWh to 10.4 GWh, and Project Energy Delivered decreased 3.6 GWh, from 9.8 GWh to 6.2 GWh. However, the Project Net Energy Received changed only 10% from 4.6 GWh to 4.2 GWh.
- There was no BESS testing in 2014, so the values are not applicable (N/A).
- The ERCOT system peak decreased slightly, from 67.3 GW to 66.6 GW.
- The Project Peak Generation decreased 9.2 MW, from 31.9 MW to 22.7 MW, which indicates a 29% decrease in the maximum power output.
- The Project Peak Load decreased 7.8 MW, from 15.3 MW to 7.5 MW, which indicates a 51% reduction in the maximum charging rate.
- The Project Annual Generation Cost (Energy Received) changed slightly from $487,009 to 538,910. This reflects the cost of charging the BESS when recovering from a Reg-Up call.
- The Project Annual Generation Cost (Energy Delivered) changed from -$353,004 to -$368,910. This reflects positive revenues from discharging, while providing Regulation Up.
- Project Net Energy Cost is increased $35,155 from $134,005 to $169,160.
- The Project Hourly Generation Cost rose significantly from $28.86/MWh to $41.07/MWh, and the System Hourly Generation Cost rose less so from $33.71/MWh to $40.64/MWh. The 2014 Project and System values are notably similar.
- Project Ancillary Services Cost (Reg-Up) decreased $484,000 from -$1.303 million to -$1.787 million, reflecting a significant increase in project revenue from this service.
- Project Ancillary Services Cost (Reg-Down) is gone in 2014 ($0.0); the BESS did not participate in the ERCOT Regulation Down Ancillary Services market in 2014.
- Project Net Revenue (computed from energy and ancillary services costs) is up $418,846 from $1,199,422 to $1,618,268. This is a 35% increase.
- Project Ancillary Services Price (FRRS-Up in 2014 to Reg-Up in 2015) increased 44% from $9.14/MW-h to $13.12/MW-h.
- West Texas congestion was significant in 2013, and more than doubled in 2014, according to the market monitor. The $200,000 value is estimated from Figure 38 of [24].

- Overall system congestion costs increased significantly from $466,000,000 to $708,000,000, due mostly to increases in the South Texas and Houston zones.

The *2014 State of the Market Report for the ERCOT Wholesale Electricity Markets* focuses on congestion increases in South Texas and Houston zones and does not mention the West Texas zone, even though it doubled in value.

One system impact related to the Notrees BESS may be its lack of participation in the Regulation Down market. As a result, there may have been less capacity participating in that market in 2014 and the system price increased from $4.89/MW-h to $10.90/MW-h.

Due to the use of the Notrees BESS project solely for Regulation Up during its second year of operation, its impact on the ERCOT system was mostly in terms of reliability benefits that were monetized through the $1.787 million in Regulation Up revenue documented in the Project column of Table 6-5.

After the ERCOT FRRS pilot project terminated at the end of February 2014, the BESS switched to participation in only the Regulation Up market. The maximum Reg-Up capacity is significantly reduced in 2014, when compared to earlier years and its designed capacity; its peak generation and load were halved. The system prices for Up and Down service in 2014 were more than double the 2013 values and counter this reduction in the BESS operation. The main reason for reduced operations is that successive Regulation Down calls are difficult for the Notrees BESS to perform, and have the potential to exclude participation in Regulation Up, which has a higher price on average. It is important to optimize battery life and net financial performance.

The average price for Reg-Up service increased by 44%, which may be an indication of increasing demand for ancillary services. According to Table 2 of the 2014 SOM report [24], the number of hours and MW deficiencies of Reg-Up in 2014 were almost the same as in 2013. The report says, “Ancillary services prices are highly correlated with day-ahead energy prices and, by extension, with real-time energy prices.” Additionally, because the average natural gas price rose from $3.70/MMBTU in 2013 to $4.32/MMBTU in 2014, and the average West Texas Real-Time Electricity Price also rose from $37.99/MWh to $43.58/MWh over the same period, the increase in the Reg-Up price may reflect an amplified version of this fundamental. In particular, the average Reg-Up price was over $55/MW-h in February 2014 and over $35/MW-h in March 2014, according to the market monitor. These months are outliers in 2014, with the remaining months having Reg-Up price averages of about $15/MW-h or less.

It is not known whether the ERCOT frequency response is significantly changed as a result of the reduced BESS participation in the Regulation Up market, because there is no public information available on this subject at this time, unlike the reporting on the FRRS project in 2013.

Project Net Revenue is up 35%, and may be mostly attributable to the 44% increase in the Reg-Up price.

The Project Hourly Generation Cost rose 42% in 2014, mainly because energy costs also rose. The Project value of $41.07/MWh is very close to the System value of $40.64/MWh, which means that the BESS is likely being operated on a continuous basis and not likely being operated to seize transient market opportunities, such as real-time electricity price spikes.

Technical Community Outreach

Since 2010, Duke Energy and EPRI have conducted over 10 individual outreach efforts in the form of webcasts, conference presentations, articles, and research reports [28]–[37]. Further, the EPRI Energy Storage research program conducts quarterly web cast updates to EPRI members, and has covered the Notrees BESS since the project's inception. In the future, Duke Energy and EPRI plan to publish an excerpted form of this Final Report.

Interoperability and Cyber Security Plans

From a financial perspective it was more advantageous for the battery to participate in ERCOT's capacity market, therefore interoperability was not pursued. Participants in the capacity market can be called upon to produce at any instance; because of this instantaneous demand profile, the project was not able to deploy charging schemes around low market pricing for wind energy.

The Notrees BESS is connected through the Duke Energy IT network. The cyber security protocols in place are consistent with the Duke Energy generation fleet, which is responsible for protecting nuclear assets along with many other fuel-sourced assets.

Lessons Learned

This section describes lessons learned during the three-year course of the Duke Notrees BESS project.

Contracting and construction characterized the first year, 2012. At the same time, Duke, through an ERCOT stakeholder committee, supported the creation of a special pilot project for Fast Responding Regulation Service (FRRS) that eventually helped to demonstrate the major technical capabilities of the BESS. Duke, Oncor, and ERCOT also spent significant effort devising an acceptable metering and settlement system for the BESS, which is coupled deep (12 miles) behind the ERCOT market meter in an Oncor substation. This market meter measures both the BESS performance and the energy production of the existing wind farm. Further complications regard the treatment of BESS house loads relative to the other existing house loads and their rate design.

The second year, 2013, was dominated by the February start of the FRRS pilot project, which was originally scheduled for six months, but eventually lasted for one year. The BESS not only responded quickly and accurately to the ERCOT regulation signal, but it was called routinely over 100 times a day, as depicted in one ERCOT presentation chart. In mid-2013, the BESS ceased participation in the Regulation Down market because it was not economical.

The third and final year of the project, 2014, the FRRS project concluded at the end of February, and the BESS continued to participate in the ERCOT Regulation Up market, with availability as a fast-responding resource.

Technical Capabilities

The Notrees BESS was acceptance tested in the field (i.e., at Notrees) to provide a maximum power level of 36 MW, and to provide 14.4 MWh energy over a 3-hour period (i.e., at a power level of 4.8 MW). The duration of the charging and discharging intervals was longer than operations at full capacity. For the Regulation market, the BESS qualified with ERCOT for 32 MW Regulation Up service and 30 MW Regulation Down service.

As of the present date (October 2015), the BESS does not operate at full capacity, but at around 15 MW discharge rate (Regulation Up), and a somewhat lower charging rate (only for recharging). It participates only in the Regulation Up market, which is more profitable.

Wind/Storage Integration

The BESS likely provided wind/storage integration benefits indirectly by following the ERCOT Regulation signal. In periods of high or low wind energy production, the Regulation signal is likely to instruct the BESS (and other Regulation resources) to quickly charge (reduce output) or discharge (increase output), respectively.

Providing Ancillary Services

The BESS provides millions of dollars of value the ERCOT market per year, as defined by its ancillary services revenue. This revenue comes at a cost of energy cost, which seems to occur often during peak periods in order to maintain availability.

Off-Peak Energy Storage

While the Notrees BESS could be operated to provide off-peak storage service, this function did not provide sufficient economic incentive for this project at this time. For instance, the Notrees BESS is not like a Compressed Air Energy Storage (CAES) facility, which has a large amount of storage to cycle over one day. Instead, its smaller size makes it most useful services those that operate over periods of time of one hour or less.

Economic Viability

The arrangement with the BESS vendor (Xtreme Power, at the time of project initiation) was intended to assure economic viability of the project for Duke Energy. However, Xtreme Power was not able to provide this assurance in the short term, and was eventually forced to declare bankruptcy (the assets were eventually transferred to Younicos).

Regulation Up commitments are for a full hour, and there are penalties (deratings) associated with an inability to perform all calls during that period. This is a significant risk for the Notrees BESS given its energy storage capacity of less than one hour at full power. As a result, the battery was derated under hourly commitments in such a way to ensure full compliance.

The BESS did not participate in Regulation Down services during the last half of 2014 because of tactical issues associated with maintaining high availability for the complementary Regulation Up service. Regulation Down service also provided much less revenue than Regulation Up.

Operations and maintenance costs (O&M) have not been reported. If reported, they are typically in terms of site-level costs as a percentage of the overall labor and house load at the Notrees office.

The total cost of the Notrees BESS was $47.6 million. Its Net Revenue during 2013 and 2014 was $2.817 million = $1.199 million + $1.617 million. It can be expected to pay back the Duke Energy investment of $21.8 million in less than 10 years, which for a first-of-a-kind system of this scale is good financial performance in the utility industry.

Contributions to the State of the Art

The Notrees BESS contributed to new learnings in the use of FRRS in the ERCOT system. ERCOT conducted extensive planning study analysis and experimental analysis to determine the following points:

- Control settings for FRRS, such as the deadband setting
- Use of relatively small amounts of FRRS (tens of MW) to avoid large amounts of Load as a Resource calls (hundreds of MW).

6.5 Conclusions

- The BESS performed well as part of the ERCOT FRRS pilot study and provided significant reliability benefits to the overall ERCOT system, as evidenced by more than $1.1 million in revenue from that service.
- The BESS remained operationally profitable through the 24-month study period with Net Revenues of $2.8 million, demonstrating potential to cover Duke Energy’s $21.8 million cost share within 20 years of operation, assuming a 3% interest rate.
- The operating capacity of the BESS was significantly reduced over its two-year operating period. In 2013, its peak generation was 31.6 MW and peak load was 15.3 MW, while in 2014 the corresponding values were 22.7 MW and 7.5 MW.
- While its controls and operations were fully integrated with the adjacent wind turbine generation plant, the BESS did not realize explicit synergies.
- Coincidence between local congestion (represented by local real-time price differences) and overall system reliability needs (potentially via the Regulation service scheduling) may have led to indirect wind-storage synergies, but these would have occurred via the ERCOT operations and market mechanisms.

This demonstration project has shown that construction and operation of utility-scale battery energy storage systems is possible. Two years of experience proved the value of the BESS as a reliability resource to the ERCOT system and the need for a more advanced battery technology. Perhaps the most important value of the Notrees BESS is its flexibility to adapt to its rapidly changing physical and business climate. Days in West Texas can be exceedingly cold and hot, and likewise the system operating conditions. Electricity prices range from low negative values to thousands of dollars per MWh.

These results support consideration of the development and operations of utility-scale BESS. The reference design of all systems—plant, batteries, inverters, transformers, interconnection, controls, data acquisition and storage, and finance—are laid out in full in the body of this report. Operational performance metrics serve as benchmarks for future systems and the further operations of this BESS.

7
FUTURE PLANS

7.1 Project Phases and Milestones

As noted, the Notrees Wind Storage Demonstration Project consisted of two phases:

- Phase 1: Project Definition, NEPA Compliance and Economic Analysis. Identify an energy storage solution capable of meeting technical and economic hurdles identified for the project.
- Phase 2: Project Implementation. Complete installation according to the final design and schedule, and gather integration lessons learned. Successfully commission and operate the system to achieve identified benefits by utilizing dispatch designs. Confirm the value of energy storage in supporting wind generation.

The end of each phase was considered a milestone. Executive approval to enter the next phase was considered successful completion of that milestone. Table 7-1 summarizes the measures of success and target completion dates for each milestone.

Table 7-1
Milestone Log

Milestone	Measure of Success	Target
End of Phase 1	Bid proposals meet economic and technical requirements identified in market valuation and RFP. Receive approval from the DOE Project Office to continue with the final design and construction. Successfully complete the development of the design for integrating storage into the current wind farm SCADA system and dispatch designs reconfirming economic valuation results.	June 30, 2011 (Completed June 22, 2011)
End of Phase 2	Successfully meet installation completion schedule. Successfully complete the storage impact study by gathering and analyzing 24 months of data.	December 31, 2014

Phase 1 was completed on June 22, 2011. Phase 2 was completed on December 31, 2014. Tables 7-2 and 7-3 provide more details about the specific tasks that comprised each phase. While the project is now complete, the Notrees BESS continues as an ongoing resource in the ERCOT balancing area.

Table 7-2
Phase 1 Tasks

Task	Lead Responsible
Define project objectives and develop the initial project plan to meet objectives, including site and resource needs.	Core Team
Develop economic analysis of value created by energy storage when combined with wind generation assets (specifically the value of adding Energy Storage to a 152.6-MW wind farm in west ERCOT region).	Jason Allen/Jeff Gates
Internally develop the valuation for the current market structure model for the zonal and transmission constrained market existing in ERCOT.	Jeff Gates
Externally develop the valuation for the future post-CREZ (Competitive Renewable Energy Zone) nodal market.	Jeff Gates
Identify the optimal size and operational capabilities of the storage unit using these economic analyses.	Core Team
Develop the technical specification document aligned with the size and functions identified.	Core Team
NEPA Compliance: Request categorical exclusion under NEPA regulations.	Duke Environmental Health & Safety Team
Issue two staged RFI/RFPs to identify solution providers.	Don Faris
Bid evaluation, negotiation, and recommendation.	Core Team
Update the Project Management Plan (PMP): Revise the PMP immediately after project award to reflect changes in schedule, resources, key technical drivers, and technical approach.	Core Team
Reconfirm NEPA compliance of the proposed site design with DOE Project Office support. No additional NEPA analyses if the DOE determines that the proposed project qualifies for a Categorical Exclusion. If the DOE determines that an Environmental Assessment (EA) or Environmental Impact Statement (EIS) is required, Duke Energy will work with the DOE to complete the NEPA process.	Core Team
Award contract.	Don Faris
Complete SCADA integration design and reconfirm market valuation through dispatch designs.	Jason Allen
Gather baseline wind farm production and dispatch data for 12 months.	Jason Allen
Design storage unit integration with existing SCADA system at wind farm to enable dispatch.	Jason Clanin/Xtreme Power
Develop dispatch scenarios for optimal use of storage system in zonal and nodal markets, including control system algorithms to efficiently operate the battery system for various conditions that are anticipated.	Core Team

Table 7-3
Phase 2 Tasks

Task	Due
Finalize contract with Xtreme Power	July, 1, 2011
Prepare site	October, 1, 2011
Deliver energy storage equipment to site	February, 15, 2012
Complete installation	December,14, 2012
Begin commercial operation	December, 2012
Continue to monitor and analyze impact. Data analysis, cost and benefit analysis. Reporting.	Ongoing

As described above, the Notrees Wind Storage Demonstration facility began providing Fast-Responding Regulation Services to ERCOT in February 2013. Although originally scheduled to last a few months, the pilot project was subsequently extended to last one year, until February 2014. At that time, project stakeholders evaluated the system's performance and results, and decided not to continue the FRRS pilot program. Instead, it was decided that the use of FRRS would become part of the existing Regulation service.

7.2 Reporting

Project results and lessons learned will be disseminated in several different ways, including quarterly meetings of project participants, reports filed as listed in the Requirements Checklist, and annual attendance at the DOE Storage Conference. Management of the smart grid portfolio requires a level of tracking of project metrics and other data that will help Duke Energy and DOE manage the project based on specific performance criteria. Project data must also be readily available for review in various forms to entities other than the participating stakeholders.

EPRI has assisted with the documentation of the project. In addition to this final 2015 TPR, EPRI prepared interim reports in 2013 and 2014. EPRI also provided operations results and benefits assessments.

7.3 Further Technology and Market Development Activities

Duke Energy would be very interested in working with DOE on future cutting-edge energy storage technology applications.

8 REFERENCES

[1] ERCOT (2013). *Preliminary Report on ERCOT Pilot Project for Fast Responding Regulation Service (FRRS)*: June 12th, 2013
http://www.ercot.com/content/mktrules/pilots/frrs/Preliminary_Report_on_Fast_Responding_Regulation_Service_Pil.ppt

[2] Duke Energy (2014). Storage Week 2014, Presentation by Jeff Gates.
'Jeff gates - Storage Week Presentation 021214 v2.pptx'

[3] ERCOT (2014). *Final Assessment for Fast-Responding Regulation Service Pilot Project*, March 25, 2014
http://www.ercot.com/content/meetings/tac/keydocs/2014/0327/11._Final_Assessment_for_FRRS_Pilot_Project_as_of_3-25-14_as.doc

[4] ERCOT (2013). 2012 Demand and Energy by Month, 10 January 2013
http://www.ercot.com/content/news/presentations/2012/ERCOT2012D&E.xls

[5] Potomac Economics (2013). *2012 State of the Market Report for the ERCOT Wholesale Electricity Markets*, June 2013
https://www.potomaceconomics.com/uploads/ercot_reports/2012_ERCOT_SOM_REPORT.pdf

[6] EPRI (2014) Spreadsheet computation of storage dispatch and efficiency
'Annual Storage Dispatch & Efficiency v1.xlsx'

[7] Duke (2014). 2013 Notrees BESS time series data
Notrees Data for Zak Q4 2013.xlsx
Notrees Data for Zak Q3 2013.xlsx
Notrees Data for Zak Q2 2013.xlsx
Notrees Data for Zak Q1 2013.xlsx

[8] ERCOT (2014). 2013 Demand and Energy Report, 11 February 2014
http://www.ercot.com/content/news/presentations/2014/ERCOT2013D&E.xls

[9] EPRI (2014). Spreadsheet computation of Generation Costs
'Generation Cost v2.xlsx'

[10] Potomac Economics (2014). *2013 State of the Market Report for the ERCOT Wholesale Electricity Markets*, September 2014
https://www.potomaceconomics.com/uploads/ercot_documents/2013_ERCOT_SOM_REPORT.pdf

[11] ERCOT (2014). Publicly available awards for Notrees BESS in ERCOT FRRS Market
'FRRS_Pilot_Final_NoTrees_Awards_022513_ending_123113.xlsx'

[12] ERCOT (2014). Publicly available Ancillary Services prices in ERCOT DAM.
'2013 AS MCPC for Julia-UTC.xlsx'

[13] EIA (2013). *Electric Power Industry Generation by Primary Energy Source, 1990-2012,*
http://www.eia.gov/electricity/state/texas/xls/sept05tx.xls

[14] EIA (2013). 1990 - 2012 *U.S. Electric Power Industry Estimated Emissions by State* (EIA-767, EIA-906, EIA-920, and EIA-923)
http://www.eia.gov/electricity/data/state/emission_annual.xls

[15] ERCOT (2013). *2013 Renewable Content Calculator* http://www.ercot.com/mktinfo/retail/electric/2013_Renewable_Content_Calculator_EFLWorkbook%20v4.xls

[16] EPRI (2014) Spreadsheet computation of storage dispatch and efficiency '2014 Annual Storage Dispatch & Efficiency v1.xlsx'

[17] Duke (2014). 2014 Notrees BESS time series data, 1-minute intervals 'Notrees Data for Zak 2014.csv'

[18] ERCOT (2015). *2014 Demand and Energy Report*, 7 January 2015 http://www.ercot.com/content/news/presentations/2015/ERCOT2014D&E.xls

[19] Duke (2015). 2014 Notrees BESS analytical data, 15-minute intervals 'Notrees_Battery_Report_2014.xls'

[20] Duke (2015). 2014 Notrees BESS settlement data, monthly '2014_NTBA revenue detail v3.pdf'

[21] ERCOT (2015). *Power Forward: ERCOT 2014 State of the Grid Report*, February 2015. http://www.ercot.com/content/news/presentations/2015/2014%20State_of_the_Grid_Web_21015.pdf

[22] ERCOT (2015). *2014 Renewable Content Calculator*, April 2015. http://www.ercot.com/mktinfo/retail/electric/2014_Renewable_Content_Calculator_EFLWorkbook_v0.xls

[23] ERCOT (2015). Publicly available 2014 Ancillary Services Prices for DAM, '2014 AS MCPC.xlsx' http://www.ercot.com/mktinfo/prices/index.html

[24] Potomac Economics (2014). *2014 State of the Market Report for the ERCOT Wholesale Electricity Markets*, July 2014 https://www.potomaceconomics.com/uploads/ercot_documents/2014_ERCOT_State_of_the_Market_Report.pdf

[25] Xtreme Power (2013). *Duke Notrees: World's Largest Battery Energy Storage with Wind*. Presentation 'XP_Duke_Slides_AF 032813.pptx'

[26] Duke Energy (2013). *Fast Responding Regulation Service Pilot.* Presentation to the ERCOT Performance, Disturbance, Compliance Working Group (PDCWG) http://www.ercot.com/content/mktrules/pilots/frrs/Fast_Responding_Regulation_Service_Pilot_Presentation_PDCWG_.ppt

[27] ERCOT (2015). Private communication of publicly available 2014 Regulation market cleared quantities and market clearing prices.

[28] Duke Energy (2010). "Notrees Wind Storage Project Description," *???*, November 3, 2010.

[29] Duke Energy (2011). "Smart Grid Demonstration Program Notrees Wind Storage Project," Project Kickoff Meeting, April 12, 2011.

[30] EPRI (2012). *Duke Energy Notrees Wind Storage Demonstration Project: 2012 Interim Report.* EPRI, Palo Alto, CA: 2012. 1024289, http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001024289

[31] EPRI (2013). *Duke Energy Notrees Wind Storage Demonstration Project: 2013 Interim Report*. EPRI, Palo Alto, CA: 2013. 3002001177, https://membercenter.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002001177

[32] Duke Energy (2014). "Duke Notrees Wind + Storage Demonstration May 2014 Project Update," *EPRI Energy Storage Program*, May 13, 2014.

[33] Duke Energy (2014). "Duke Notrees Wind + Storage Demonstration May 2014 Project Update," *EPRI Energy Storage Program*, May 31, 2014.

[34] EPRI (2014). Duke Energy Notrees Wind Storage Demonstration Project: 2014 Interim Report, EPRI, Palo Alto, CA: 2014. 3002003667.

[35] Duke Energy (2014). "Duke Notrees Battery Energy Storage System," *Storage Week 2014*, February 12, 2014.

[36] EPRI (2015). Duke Energy Notrees Wind Storage Demonstration Project: 2014 Interim Report, EPRI, Palo Alto, CA: 2014. 3002006083.

[37] Public Utilities Reports (2014). "Storage Steps Up," Power Profit Fortnightly, Public Utilities Reports, Feb. 26, 2014.
http://powerprofit.fortnightly.com

A APPENDIX: EMS DATA REQUIREMENTS

The tables below list the required measurement channels, units, and reporting rates for data acquired from the Duke Notrees BESS Energy Management System (EMS).

XP Battery Data File Format and Data File Attributes

XP-delivered zipped data files to EPRI via FTP. The unzipped data files are named with the following convention: data_*YYYY-mm-dd*.csv, where each file represents one day's worth of collected data. The earliest data file is data_2013-02-25.csv and the latest data file is data_2013-11-30.csv; there are 279 files in total.

Table A-1
Required Measurement Channels From Xtreme Power

Channel	Header Code	Unit of Measure	Reporting Frequency	Data Type	Valid Values
Timestamp	IRIG_time	NA	2/s	string	YYYY-mm-dd HH:MM:SS
DPR output power	XP_P	kW	2/s	float	[-1.5E03, 1.5E03]*
DPR reactive power	XP_Q	kVar	2/s	float	(-1.5E03, 1.5E03)*
Real-time electricity price	LMP	$	2/s	float	[-1000, 5000]
PowerCell column pack DC voltage between storage PowerCells and electronics	DCV_ Analog_*x*	V	2/s	float	[0, 1250]
DC current between storage PowerCells and electronics	DCI_Analog _*x*	A	2/s	float	[-2812, 2812]
Inverter status	Inv_Status_ *x*	NA	2/s	string	{RunPQ, Ready, WaitGridOk, Fault, Starting, Discharging, WaitSlave, Stopping, Reset, WaitDCIn, Off, Heating, Standby, (blank)}

The Inverter Status channel has several valid values, which are further explained below:

- **RunPQ:** In PQ Mode, the unit operates as an AC current controlled voltage-source inverter. The inverter is synchronized with the phases of the line voltage automatically.

- **Ready:** The inverter is offline and not running with the AC breaker shut.
- **WaitGridOk:** The inverter is offline and the AC breaker is open.
- **Fault:** The inverter is in a faulted state; unit is unable to be started until the fault is reset (cleared).
- **Starting:** The inverter is in the process of starting up or turning on.
- **Discharging:** The inverter is discharging the caps during shut down. During turning off, the inverter continues to gate for a fraction of a second after the AC and DC contactors have been opened. This is to intentionally discharge the caps and avoid residual charge.
- **WaitSlave:** The master module of inverter is waiting for communication from slave modules.
- **Stopping:** The inverter is in the process of stopping or shutting down.
- **Reset:** The inverter is in the process of reset that was performed on it.
- **WaitDCIn:** This indicates that the absence of DC voltage to the inverter; it typically means the DC switch was not closed in.
- **Off:** The inverter is in an off state with all contactors open, breaker open, etc.
- **Heating:** This is not an applicable status as it is a function of the inverter manufacturer software and firmware; is not used in XP systems.
- **Standby:** The inverter breaker is closed in; contactors are closed in but no gating. This mode can be used when inverter needs to be commanded to go into a mode without gating (typically to reduce insulated-gate bipolar transistor (IGBT) switching and conduction losses) and to return to gating when commanded. The response times to go into standby and back can be as slow as a couple of seconds.
- **(blank):** No inverter status was recorded.

Duke Substation Data File Format and Data File Attributes

Duke-delivered data files to EPRI via email. The data files are named with the following convention: Notrees Data for Zak Qx 2013.xlsx, where each file represents one quarter’s worth of collected data. There are currently four data files (x = 1, 2, 3, 4).

Table A-2 lists the required measurement channels, their units, and reporting rates.

Table A-2
Required Measurement Channels From Duke

Channel	Header Code	Unit of Measure	Reporting Interval	Data Type	Valid Values
Timestamp	TIMESTAMP	NA	1 min	string	
Battery power at 34.5-kV bus	NOTREES BATT REVMTR MW-EMS	MW	1 min	float	[-36, 36]
GE Turbines' total power at 34.5-kV bus	NOTREES GE REVMTR MW-EMS	MW	1 min	float	[0, 60]
Notrees total power at 138-kV bus	NOTREES NET MW - EMS	MW	1 min	float	[-36, 186.75]
Vestas Turbines' total power at 34.5-kV bus	NOTREES VESTAS REVMTR MW-EMS	MW	1 min	float	[0, 90.75]
System frequency	NOTREES FREQUENCY HZ - EMS	Hz	1 min	float	[59, 61]
Curtailment signal	NOTREES ERCOT CURTAIL FLAG-EMS	N/A	1 min	boolean	{True, False}

ERCOT Ancillary Services Data File Format and Attributes

The following table describes data from ERCOT that has been used for the analysis.

Table A-3
Required Measurement Channels From ERCOT

Channel	Header Code	Unit of Measure	Reporting Frequency	Data Type
DPR temperature		NA	N/A	float
Regulation service price		$	60 min	float
Demand response revenue		$	N/A	float
Congestion charges		$	1 month	float

B APPENDIX: INVENTORY OF DATA SOURCES

This appendix provides an inventory of the data available for the Notrees Data Processing System.

1. Oncor Substation Power & Energy Data

Source: Scott Abramson (Duke)

Transmission: E-Mail

Date received: 3/4/2014

Subject: RE: Question about interpolation

Data date range: 1/1/2013-12/31/2013

Timezone: Eastern (Presumed)

Filename: OncorMeteringQ{1,2,3,4}.xlsx

Description: One-minute resolution delivered/received energy and power readings from the point-of-interconnection (POI) meter located at the Oncor substation six miles northwest of the Notrees BESS. Each file contains a single quarter's data.

Notes: The MWh Delivered column represents the energy delivered from the grid to the Notrees substation, whereas the MWh Received column represents the energy received from the wind farm/BESS. The energy columns hold their values constant except for when they update at the beginning of each hour, whereas the power readings are updated each minute.

2. ERCOT LMP Point Geographical Locations

Source: ERCOT website (http://www.ercot.com/content/cdr/contours/rtmLmpHgPoints.kml?uniquenessFactor=1394815213108)

Transmission: Web

Date received: 3/14/2014

Data date range: N/A

Timezone: N/A

Filename: RT-LMP Locations.kml

Description: Google Earth KML file containing geographic locations of LMP points in the ERCOT system. These correspond to the names used in other ERCOT-provided files. Clicking on a point within Google Earth will cause an information bubble to appear containing the street address of the LMP point.

3. ERCOT Congestion Revenue Rights (CRR) Auction Results

Source: ERCOT website (http://mis.ercot.com/misapp/GetReports.do?reportTypeId=11201&reportTitle=Monthly%20Auction%20Results&showHTMLView=&mimicKey)

Transmission: Web

Date received: 3/6/2014

Data date range: 4/2013 – 1/2014

Timezone: N/A

Filenames: Common_MarketResults_{YEAR}.{MON}.Monthly.Auction_AUCTION.csv

where YEAR is the four-digit year, and MON is the three-letter month abbreviation.

Description: Contains final CRR auction results on a monthly basis.

Notes:

Each row contains a single CRR auction result (MW, ShadowPrice) for a particular source and sink for the entire month. Sources and sinks are settlement points within the ERCOT system.

4. ERCOT Fast-Responding Regulation Service (FRRS) Awards

Source: Julia Matevosyan (ERCOT)

Transmission: E-mail

Date received: 3/7/2014

Subject: FW: Looking for Notrees FRRS Offers

Data date range: 2/25/2013-12/31/2013

Timezone: Central

Filenames: FRRS_Pilot_Original_NoTrees_Awards_022513_ending_123113.xlsx, FRRS_Pilot_Final_NoTrees_Awards_022513_ending_123113.xlsx

Description: Contains 2013 FRRS Pilot awards for Notrees site only. “Original” contains original awards for the first part of the pilot program, which ended on 6/7/2013. “Final” contains the adjusted awards for the remainder of the pilot based on performance review.

Notes:

Separate spreadsheet tabs for RegUP and RegDN. Each row contains data for a single day of the year. Columns F through AC provide hourly FRRS offers for each day.

5. ERCOT Generation Mix Report

Source: Julia Matevosyan (ERCOT)

Transmission: E-mail

Date received: 2/25/2014

Subject: FW: Public D&E files

Data date range: 1/1/2013-1/31/2014

Timezone: N/A

Filenames: RobbieERCOT2013D&E.xls, RobbieERCOT2013D&E.xls

Description: Contains a variety of demand and energy-related reports, as well as summaries of generation fuel mixes by month.

Notes: Multiple spreadsheet tabs

6. ERCOT Ancillary Services Prices

Source: Julia Matevosyan (ERCOT)

Transmission: E-mail

Date received: 2/26/2014

Subject: FW: Regulation prices for 2013

Data date range: 1/1/2013-12/31/2013

Timezone: UTC

Filename: 2013 AS MCPC for Julia.xlsx

Description: Ancillary services pricing for each hour of 2013.

Format: Delivery Date, Delivery Hour, Delivery Time, AS Type, MCPC

Notes:

AS Type = {NSPIN, REGUP, REGDN, RRS}

MCPC = price

7. ERCOT Real-Time Generation Mix

Source: Julia Matevosyan (ERCOT)

Transmission: E-mail

Date received: 4/14/2014

Subject: Emailing: IntGenByFuel2013.xls

Data date range: 1/1/2013-12/31/2013

Timezone: Central

Filenames: IntGenByFuel2013.xls

Description: Contains generation mix in MWh by fuel type at 15-minute intervals for 2013. Each tab in the spreadsheet contains a month's worth of data.

Sharing: OK to create summary plots/figures, but numerical data cannot be shared.

8. Xtreme Power (XP) Battery Data

Source: Neil Lichtenstiger (XP)

Transmission: FTP

Date received: 12/16/2013

Data date range: 2/25/2013-11/30/2013

Timezone: UTC

Filename: data_*yyyy-mm-dd*.csv

Description: Two-second data recorded from the power modules.

Format: IRIG Time, Overall Power (kW), Overall Reactive Power (kVar), LMP; Inverter Voltage (volts), Current (amps), and Status for 24 inverters.

9. Duke Energy Notrees Substation Data

Source: Jason Clanin (Duke)

Transmission: E-mail

Date received: 1/16/2014

Subject: Notrees Data (Email {1,2,3,4} of 4)

Data date range: 1/1/2013-12/31/2013

Timezone: Eastern

Filename: Notrees Data for Zak Q*x* 2013.xlsx, where x is the quarter of the year.

Description: One-minute data recorded from the Duke substation.

Format: Battery MW at the 34.5 KV bus, MW from the GE Turbines, Net MW, MW from the Vestas Turbines, System Frequency, Curtailment Flag.

Notes:

Although the Oncor substation is located in Central time, the PI server is located in Eastern time.

10. Duke Notrees Battery Report

Source: Kevin Hooker (Duke)

Transmission: E-mail

Date received: 4/15/2014

Subject: RE: Notrees Battery Reporting

Timezone: Eastern Daylight Time (UTC-4)

Filename: Notrees Battery Report {Feb, Mar, April, May, June, July} 2013 True UP.xls, Notrees Battery Report {August, September, October, November, December} 2013 Final.xls

Description: Fifteen-minute interval energy and pricing data from both the Notrees and Oncor substations. This file includes payments made to the battery, wind farm, and transmission system operator.

11. EIA Electric Energy Production for Texas

Source: U.S. Energy Information Administration

URL: http://www.eia.gov/electricity/state/texas/xls/sept05tx.xls

Transmission: Web

Date received: 7/8/2014

Filename: Sept05tx.xls

Description: Yearly totals of electric energy production from 1990-2012 by energy source.

12. EIA Electric Energy Production for Texas

Source: U.S. Energy Information Administration

URL: http://www.eia.gov/electricity/state/texas/xls/sept07tx.xls

Transmission: Web

Date received: 7/8/2014

Filename: Sept07tx.xls

Description: Electric power industry emissions estimates for CO_2, SO_2, and NO_X for Texas, 1990-2012.

C DOE QUARTERLY REPORTS

This appendix contains tables that summarize the contents of the DOE Quarterly Reports.

Table C-1
2014 DOE Quarterly Report Summary

		2012 Q1		2012 Q2		2012 Q3		2012 Q4		2012 Summary	
Distributed Energy Resources	**Units**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**
Distributed generation: number of units	#	0	0	0	0	0	0	0	0	0	0
Distributed generation: installed capacity	kW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distributed generation: total energy delivered	* kWh	0	0	0	0	0	0	0	0	0	0
Energy storage: number of units	#	0	0	0	0	0	0	24	24	24	24
Energy storage: installed capacity	kW	0	0	0	0	0	0	36,000	36,000	36,000	36,000
Energy storage: total energy delivered	* kWh	0	0	0	0	0	0	0	0	0	0
Plug-in electric vehicles charging points: number of units	#	0	0	0	0	0	0	0	0	0	0
Plug-in electric vehicles charging points: installed capacity	kW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plug-in electric vehicles charging points: total energy delivered	* kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
DER/DG interconnection equipment: number of units	#	0	0	0	0	0	0	1	1	1	1

***** *Energy delivered should be reported just for the quarter being reported, not cumulative for the project to-date.*

Distributed Generation Interface Description

Duke Energy Renewables installed a 36-MW battery energy storage system (BESS) developed by Xtreme Power at the Notrees Wind Farm, which it owns and operates in Texas. The wind farm has a total generation capacity of 152.6 MW. The objective of the Notrees Wind Storage Demonstration Project is to validate that energy storage increases the value and practical application of intermittent wind generation and is commercially viable at utility scale. Project applications include time shifting, area regulation, electric supply reserve capacity, voltage support, transmission congestion relief, and renewables capacity firming.

		2012 Q1		2012 Q2		2012 Q3		2012 Q4		2012 Summary	
Distributed Energy Resources' Installed Costs	**Units**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**
DER Interface Control Systems	$	0	0	0	0	0	0	0	0	0	0
Communications Equipment	$	0	0	0	0	0	0	0	0	0	0

DER/DG Interconnection Equipment	$	0	0	0	0	0	0	0	0	0	0
Renewable DER	$	0	0	0	0	0	0	0	0	0	0
Distributed Generation Equipment	$	0	0	0	0	0	0	0	0	0	0
Stationary Electric Storage Equipment	$	0	0	0	0	0	0	218,062.32	257,589.10	0	0
PEVs and Charging Stations	$	0	0	0	0	0	0	0	0	0	0
Other Costs	$	0	0	0	0	0	0	0	0	0	0
Other Cost Description	N/A										

Table C-2
2013 DOE Quarterly Report Summary

		2013 Q1		**2013 Q2**		**2013 Q3**		**2013 Q4**		**2013 Summary**	
Distributed Energy Resources	**Units**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**
Distributed generation: number of units	#	0	0	0	0	0	0	0	0	0	0
Distributed generation: installed capacity	kW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distributed generation: total energy delivered	*kWh	0	0	0	0	0	0	0	0	0	0
Energy storage: number of units	#	24	24	24	24	24	24	24	24	24	24
Energy storage: installed capacity	kW	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
Energy storage: total energy delivered	*kWh	1,472,740	1,472,740	3,076,656	3,076,656	2,496,379	2,496,379	1,916,171	1,916,171	8,961,946	8,961,946
Plug-in electric vehicles charging points: number of units	#	0	0	0	0	0	0	0	0	0	0
Plug-in electric vehicles charging points: installed capacity	kW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plug-in electric vehicles charging points: total energy delivered	*kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
DER/DG interconnection equipment: number of units	#	1	1	1	1	1	1	1	1	1	1

*** Energy delivered should be reported just for the quarter being reported, not cumulative for the project to-date.***

Distributed Generation Interface Description		Duke Energy Renewables installed a 36-MW battery energy storage system (BESS) developed by Xtreme Power at the Notrees Wind Farm, which it owns and operates in Texas. The wind farm has a total generation capacity of 152.6 MW. The objective of the Notrees Wind Storage Demonstration Project is to validate that energy storage increases the value and practical application of intermittent wind generation and is commercially viable at utility scale. Project applications include time shifting, area regulation, electric supply reserve capacity, voltage support, transmission congestion relief, and renewables capacity firming.									
		2013 Q1		**2013 Q2**		**2013 Q3**		**2013 Q4**		**2013 Summary**	
Distributed Energy Resources' Installed Costs	**Units**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**
DER Interface Control Systems	$	0	0	0	0	0	0	0	0	0	0
Communications Equipment	$	0	0	0	0	0	0	0	0	0	0
DER/DG Interconnection Equipment	$	0	0	0	0	0	0	0	0	0	0
Renewable DER	$	0	0	0	0	0	0	0	0	0	0
Distributed Generation Equipment	$	0	0	0	0	0	0	0	0	0	0
Stationary Electric Storage Equipment	$	21,806,232	25,758,910	21,806,232	25,758,910	21,806,232	25,758,910	21,806,232	25,758,910	21,806,232	25,758,910
PEVs and Charging Stations	$	0	0	0	0	0	0	0	0	0	0
Other Costs	$	0	0	0	0	0	0	0	0	0	0
Other Cost Description	N/A										

Table C-3
2014 DOE Quarterly Report Summary

		2014 Q1		**2014 Q2**		**2014 Q3**		**2014 Q4**		**2014 Summary**	
Distributed Energy Resources	**Units**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**	**Proj**	**Sys**
Distributed generation: number of units	#	0	0	0	0	0	0	0	0	0	0
Distributed generation: installed capacity	kW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Distributed generation: total energy delivered	kW*kWh	0	0	0	0	0	0	0	0	0	0
Energy storage: number of units	#	1	1	1	1	1	1	1	1	1	1
Energy storage: installed capacity	kW	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
Energy storage: total energy delivered	kW*kWh	1,619,320	1,619,320	1,742,160	1,742,160	1,430,160	1,430,160	1,517,270	1,517,270	6,308,910	6,308,910
Plug-in electric vehicles charging points: number of units	#	0	0	0	0	0	0	0	0	0	0

Plug-in electric vehicles charging points: installed capacity	kW *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plug-in electric vehicles charging points: total energy delivered	kWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
DER/DG interconnection equipment: number of units	#	1	1	1	1	1	1	1	1	1	1

***** *Energy delivered should be reported just for the quarter being reported, not cumulative for the project to-date.*

Distributed Generation Interface Description

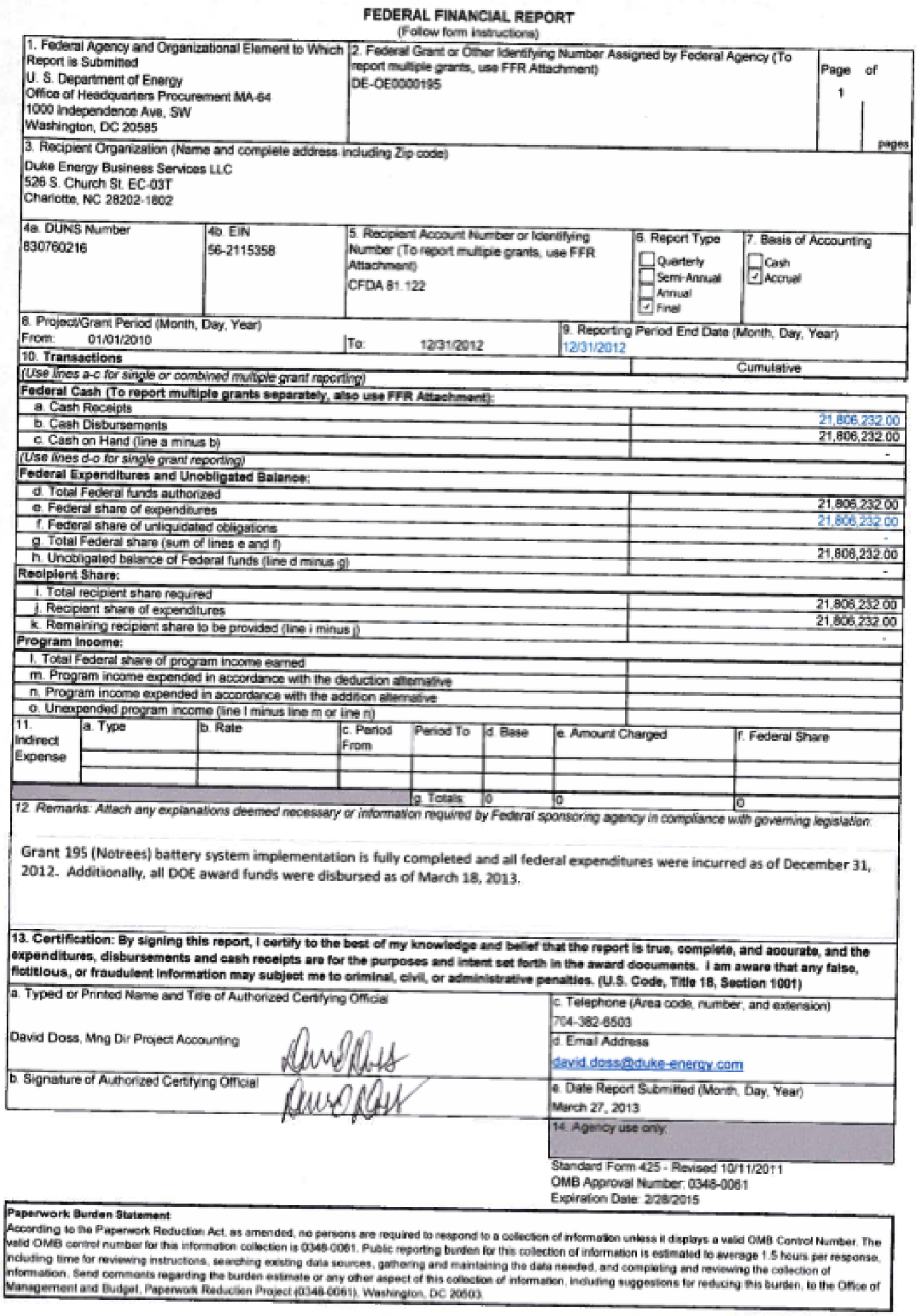
Duke Energy Renewables installed a 36-MW battery energy storage system (BESS) developed by Xtreme Power at the Notrees Wind Farm, which it owns and operates in Texas. The wind farm has a total generation capacity of 152.6 MW. The objective of the Notrees Wind Storage Demonstration Project is to validate that energy storage increases the value and practical application of intermittent wind generation and is commercially viable at utility scale. Project applications include time shifting, area regulation, electric supply reserve capacity, voltage support, transmission congestion relief, and renewables capacity firming.

		Q1		**Q2**		**Q3**		**Q4**		**2014 Summary**	
Distributed Energy Resources' Installed Costs	**Units**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**	**Proj Fund**	**Cost Share**
DER Interface Control Systems	$	0	0	0	0	0	0	0	0	0	0
Communications Equipment	$	0	0	0	0	0	0	0	0	0	0
DER/DG Interconnection Equipment	$	0	0	0	0	0	0	0	0	0	0
Renewable DER	$	0	0	0	0	0	0	0	0	0	0
Distributed Generation Equipment	$	0	0	0	0	0	0	0	0	0	0
Stationary Electric Storage Equipment	$	21,806,232	25,758,910	21,806,232	25,758,910	21,806,232	25,758,910	21,806,232	25,758,910	21,806,232	25,758,910
PEVs and Charging Stations	$	0	0	0	0	0	0	0	0	0	0
Other Costs	$	0	0	0	0	0	0	0	0	0	0

Other Cost Description N/A

D

FORM SF-425 FEDERAL FINANCIAL REPORT



FEDERAL FINANCIAL REPORT

(Follow form instructions)

1. Federal Agency and Organizational Element to Which Report is Submitted U. S. Department of Energy Office of Headquarters Procurement MA-64 1000 Independence Ave, SW Washington, DC 20585	2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment) DE-OE0000195	Page 1 of pages

3. Recipient Organization (Name and complete address including Zip code)

Duke Energy Business Services LLC
526 S. Church St. EC-03T
Charlotte, NC 28202-1802

4a. DUNS Number 830760216	4b. EIN 56-2115358	5. Recipient Account Number or Identifying Number (To report multiple grants, use FFR Attachment) CFDA 81.122	6. Report Type ☐ Quarterly ☐ Semi-Annual ☐ Annual ☑ Final	7. Basis of Accounting ☐ Cash ☑ Accrual

8. Project/Grant Period (Month, Day, Year) From: 01/01/2010 To: 12/31/2012

9. Reporting Period End Date (Month, Day, Year) 12/31/2012

10. Transactions	Cumulative
(Use lines a-c for single or combined multiple grant reporting)	
Federal Cash (To report multiple grants separately, also use FFR Attachment):	
a. Cash Receipts	21,806,232.00
b. Cash Disbursements	21,806,232.00
c. Cash on Hand (line a minus b)	-
(Use lines d-o for single grant reporting)	
Federal Expenditures and Unobligated Balance:	
d. Total Federal funds authorized	21,806,232.00
e. Federal share of expenditures	21,806,232.00
f. Federal share of unliquidated obligations	-
g. Total Federal share (sum of lines e and f)	21,806,232.00
h. Unobligated balance of Federal funds (line d minus g)	-
Recipient Share:	
i. Total recipient share required	21,806,232.00
j. Recipient share of expenditures	21,806,232.00
k. Remaining recipient share to be provided (line i minus j)	-
Program Income:	
l. Total Federal share of program income earned	
m. Program income expended in accordance with the deduction alternative	
n. Program income expended in accordance with the addition alternative	
o. Unexpended program income (line l minus line m or line n)	

11. Indirect Expense	a. Type	b. Rate	c. Period From	Period To	d. Base	e. Amount Charged	f. Federal Share
				g. Totals:	0	0	0

12. *Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:*

Grant 195 (Notrees) battery system implementation is fully completed and all federal expenditures were incurred as of December 31, 2012. Additionally, all DOE award funds were disbursed as of March 18, 2013.

13. Certification: By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and intent set forth in the award documents. I am aware that any false, fictitious, or fraudulent information may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 18, Section 1001)

a. Typed or Printed Name and Title of Authorized Certifying Official: David Doss, Mng Dir Project Accounting

b. Signature of Authorized Certifying Official:

c. Telephone (Area code, number, and extension): 704-382-6503

d. Email Address: david.doss@duke-energy.com

e. Date Report Submitted (Month, Day, Year): March 27, 2013

14. Agency use only:

Standard Form 425 - Revised 10/11/2011
OMB Approval Number: 0348-0061
Expiration Date: 2/28/2015

Paperwork Burden Statement

According to the Paperwork Reduction Act, as amended, no persons are required to respond to a collection of information unless it displays a valid OMB Control Number. The valid OMB control number for this information collection is 0348-0061. Public reporting burden for this collection of information is estimated to average 1.5 hours per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to the Office of Management and Budget, Paperwork Reduction Project (0348-0061), Washington, DC 20503.

E SQL QUERIES

Duke Notrees Substation Data

DataAvailability.sql

```
SELECT Year([Timestamp]) AS Yr,
Month([Timestamp]) AS Mo,
Count(NET_MW)
FROM Duke
GROUP BY Year([Timestamp]), Month([Timestamp]);
```

EnergyDeliveredByBattery.sql

```
SELECT YEAR(TIMESTAMP) AS Yr,
MONTH(TIMESTAMP) AS Mo,
SUM(BATT_MW/60) AS EnergyDelivered
FROM Duke
WHERE BATT_MW > 0
GROUP BY YEAR(TIMESTAMP), MONTH(TIMESTAMP);
```

EnergyReceivedByBattery.sql

```
SELECT YEAR(TIMESTAMP) AS Yr,
MONTH(TIMESTAMP) AS Mo,
SUM(-1*BATT_MW/60) AS EnergyReceived
FROM Duke
WHERE BATT_MW < 0
GROUP BY YEAR(TIMESTAMP), MONTH(TIMESTAMP);
```

PeakGenerationByYear.sql

```
SELECT YEAR(Timestamp) AS Yr,
MAX(BATT_MW) AS PeakGeneration
FROM Duke
GROUP BY YEAR(Timestamp)
```

PeakLoadByYear.sql

```
SELECT YEAR(Timestamp) As Yr,
MIN(BATT_MW) AS PeakLoad
```

```
FROM Duke
GROUP BY Year(Timestamp);
```

ERCOT FRRS Data

AvgPriceByRegType.sql

```
Parameters [RegulationTypeCode] Long;
SELECT AVG(AS_Prices.MCPC) As AvgPrice
FROM AS_Prices
WHERE RegTypeID=[RegulationTypeCode] AND UTCTime>=#2013-01-01# AND
UTCTime < #2014-01-01#;
```

DataAvailability.sql

```
SELECT Year(UTCTime) AS Yr,
MONTH(UTCTime) AS Mo,
COUNT(RegTypeID) AS RecordCount
FROM FRRS_Final_Awards
WHERE RegTypeID=1
GROUP BY YEAR(UTCTime), Month(UTCTime);
```

FRRS_Income_FinalByMonth.sql

```
PARAMETERS [Regulation Type Code] Long;
SELECT Year(AS_Prices.UTCTime) AS Expr1,
Month(AS_Prices.UTCTime) AS Expr2,
Sum(MCPC*MW) AS Income
FROM FRRS_Final_Awards, AS_Prices, RegType
WHERE
(((FRRS_Final_Awards.UTCTime)=AS_Prices.UTCTime) And
((FRRS_Final_Awards.RegTypeID)=AS_Prices.RegTypeID And
(FRRS_Final_Awards.RegTypeID)=[Regulation Type Code]) And
((RegType.ID)=[Regulation Type Code]))
GROUP BY Year(AS_Prices.UTCTime), Month(AS_Prices.UTCTime);
```