Technology Performance Report: Duke Energy Notrees Wind Storage Demonstration Project

2013 Interim Report

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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 more reliable conventional generation. 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.

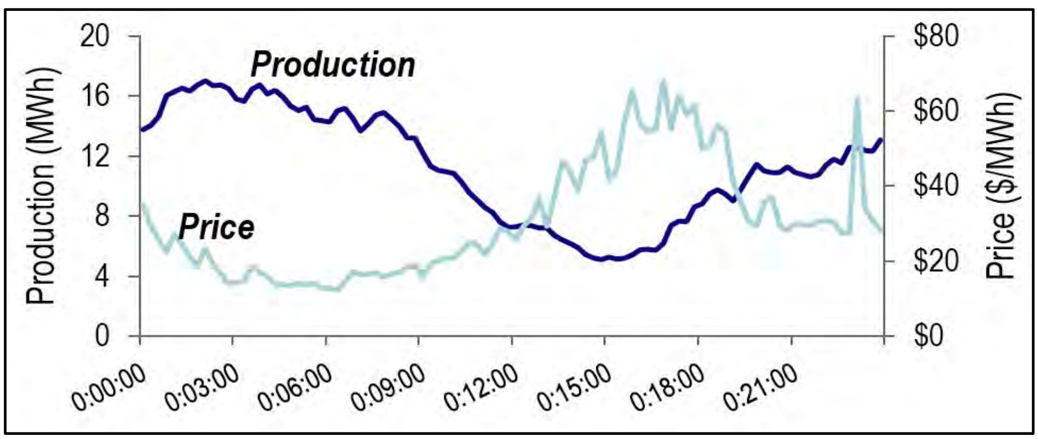

Figure 1-1
Wind Power Production vs. Price of Electricity over a Typical Day

The Notrees Wind Storage Demonstration Project is installing an advanced battery energy storage system (BESS) with a capacity of 36 MW/24 MWh to optimally dispatch energy production from the wind farm. This optimization will help energy storage operators capture energy arbitrage, improve grid stability, and demonstrate renewable firming value. Additional carbon dioxide (CO_2) reduction benefits are anticipated, 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 is 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 is 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 will entail an investment of more than $43 million in allowable costs from 2011 to 2014. It consists of two phases, each of which encompasses several tasks, whose status at this writing (November 2013) is described below. 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. The pilot program was completed successfully in February 2014. ERCOT established market rules for the permanent FRRS program in March 2014. The Notrees battery is currently participating in the FRRS market on a regular basis. Details regarding the system's FRRS performance are provided in Chapters 4 and 5.

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 a 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 through the use of 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.

1.2 Project Team

The Notrees Wind Storage Demonstration Project is being 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 will provide operational expertise during the project's design, installation, commissioning, and operation.

EPRI is supporting 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 is Xtreme Power, whose role consists of manufacturing the BESS along with engineering, procurement and construction. Xtreme Power is backed by investors SAIL Venture Partners, Bessemer Venture Partners, The Dow Chemical Company, Fluor Corp., BP Alternative Energy, Dominion Resources, POSCO ICT, SkyLake & Co., and Spring Ventures, LLC.

Transmission services are 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:

- Jason Allen, Vice President, Renewables Operations: Overall operational lead of Duke Energy's wind assets.
- David Mohler, VP, Emerging Technologies: Leads Duke Energy's research and development.

- Robert Jones, 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.
- Jeff Gates, Managing Director, Commercial Transmission: Leads Duke Energy technology research into energy storage, including initiating and supporting pilot and demonstration projects to enable adoption of these technologies.

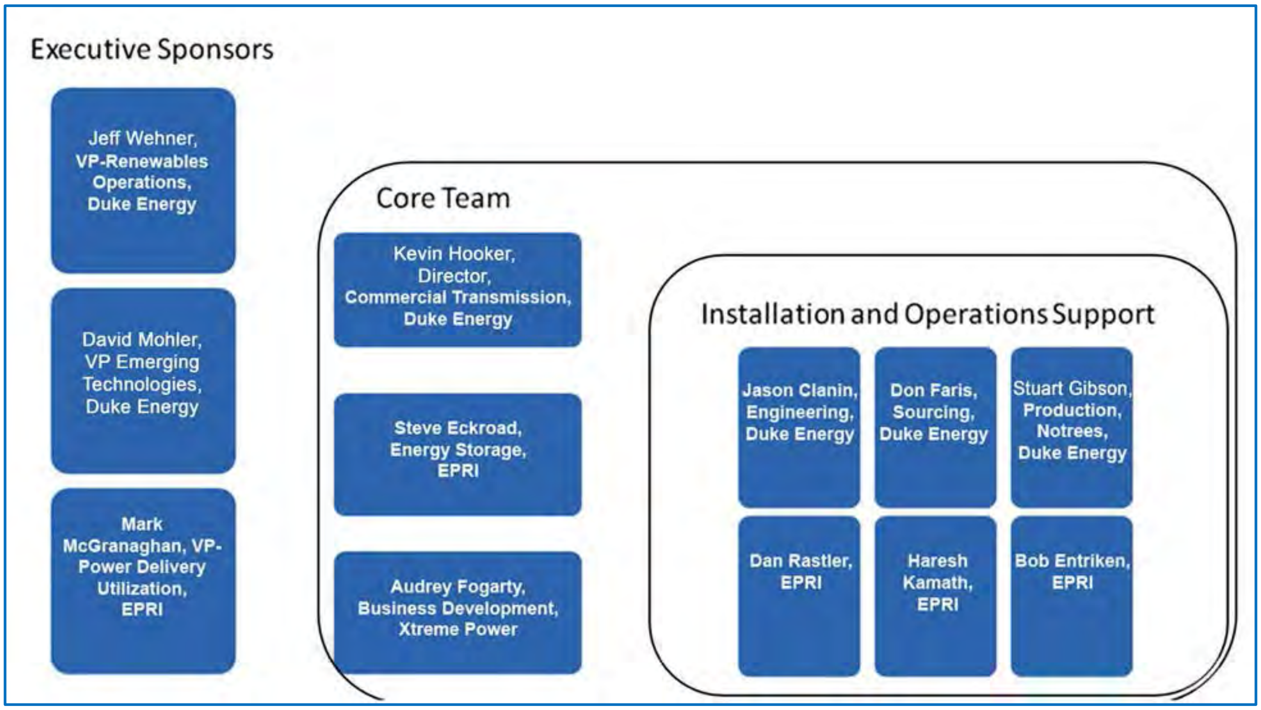

Figure 1-2
Organizational Structure of the Executive Sponsors, Core Team, and Installation and Operations Support

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 calls for gathering 24 months of data, which, if the system operates as planned, will be completed in February 2015. A Final Technical Report (FTR) will be issued in late 2015.

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.

2

ENERGY STORAGE TECHNOLOGIES AND SYSTEMS

2.1 Xtreme Power Company Overview

Xtreme Power, Inc. was founded in 2004 and is headquartered in Kyle, Texas. It is 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 characterizes itself as a system supplier/developer that provides 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.

Beyond the wind power integration/distribution support functionality, Xtreme Power is targeting its DPR product to serve multiple transmission and distribution applications, including solar integration, microgrid, and smart-grid applications. Xtreme Power does not sell individual batteries for test or application; all energy storage equipment is 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

Xtreme Power also has similar energy storage projects deployed or planned for other wind power systems as well as solar power systems.

2.2 Xtreme Power PowerCell™

Xtreme Power's battery technology is 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.

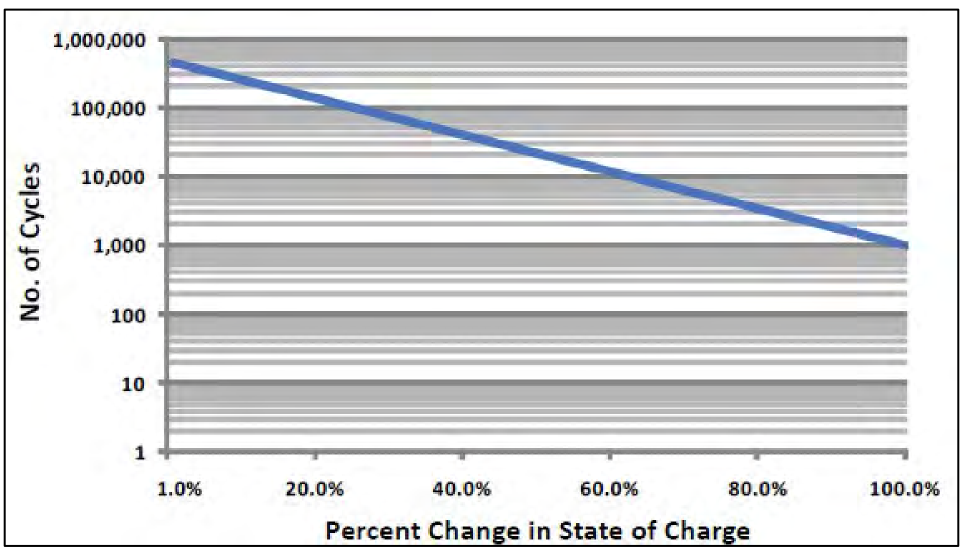

Figure 2-3
Xtreme Power's PowerCell Warranty Curve

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.

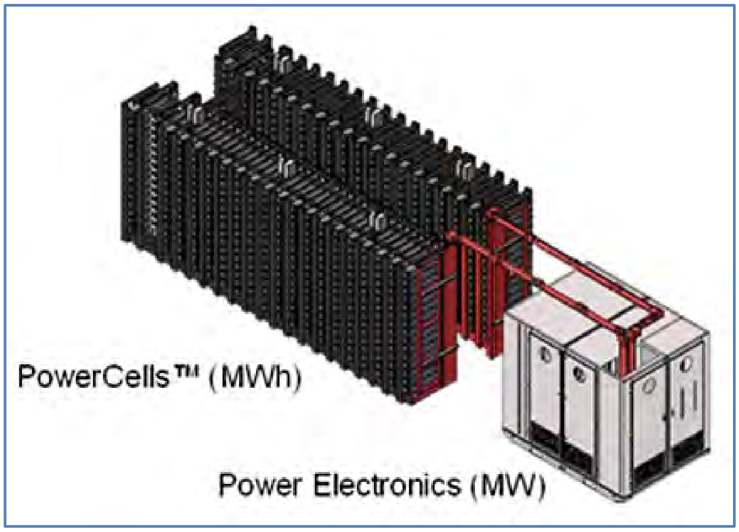

Figure 2-4
Components of a PowerCell Module: A paired PowerCell Pack and PCS

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.

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).

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[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.

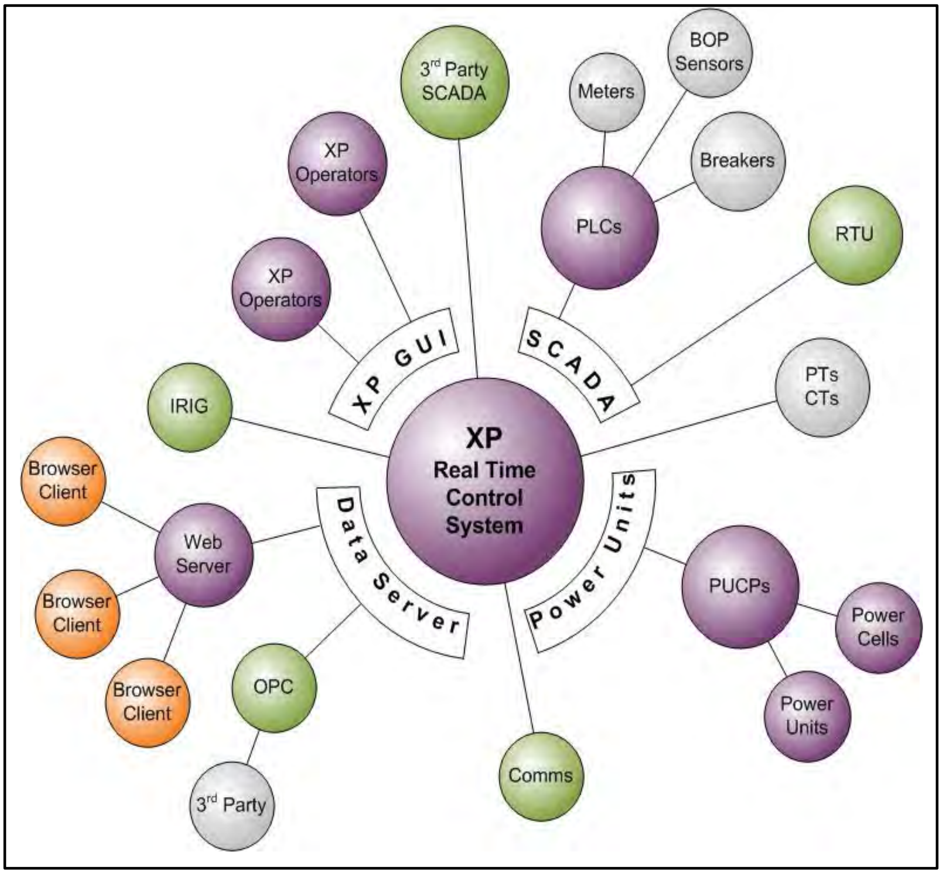

Figure 2-6
Conceptual Diagram of Real-Time Control System

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 set point (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 Set Point: 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. Also, 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 set-points 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 has been 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 2-9 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.

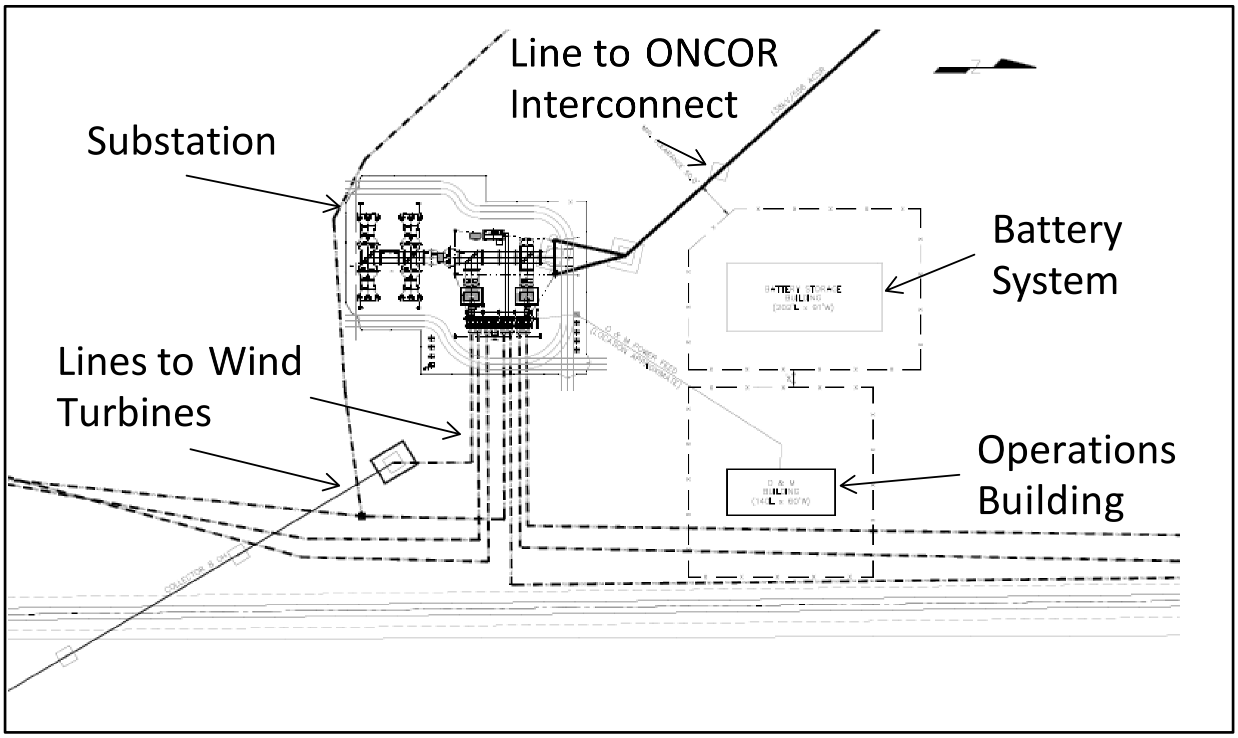

Figure 2-7
Location of Dynamic Power Resource in Relation to Substation and Operations Building

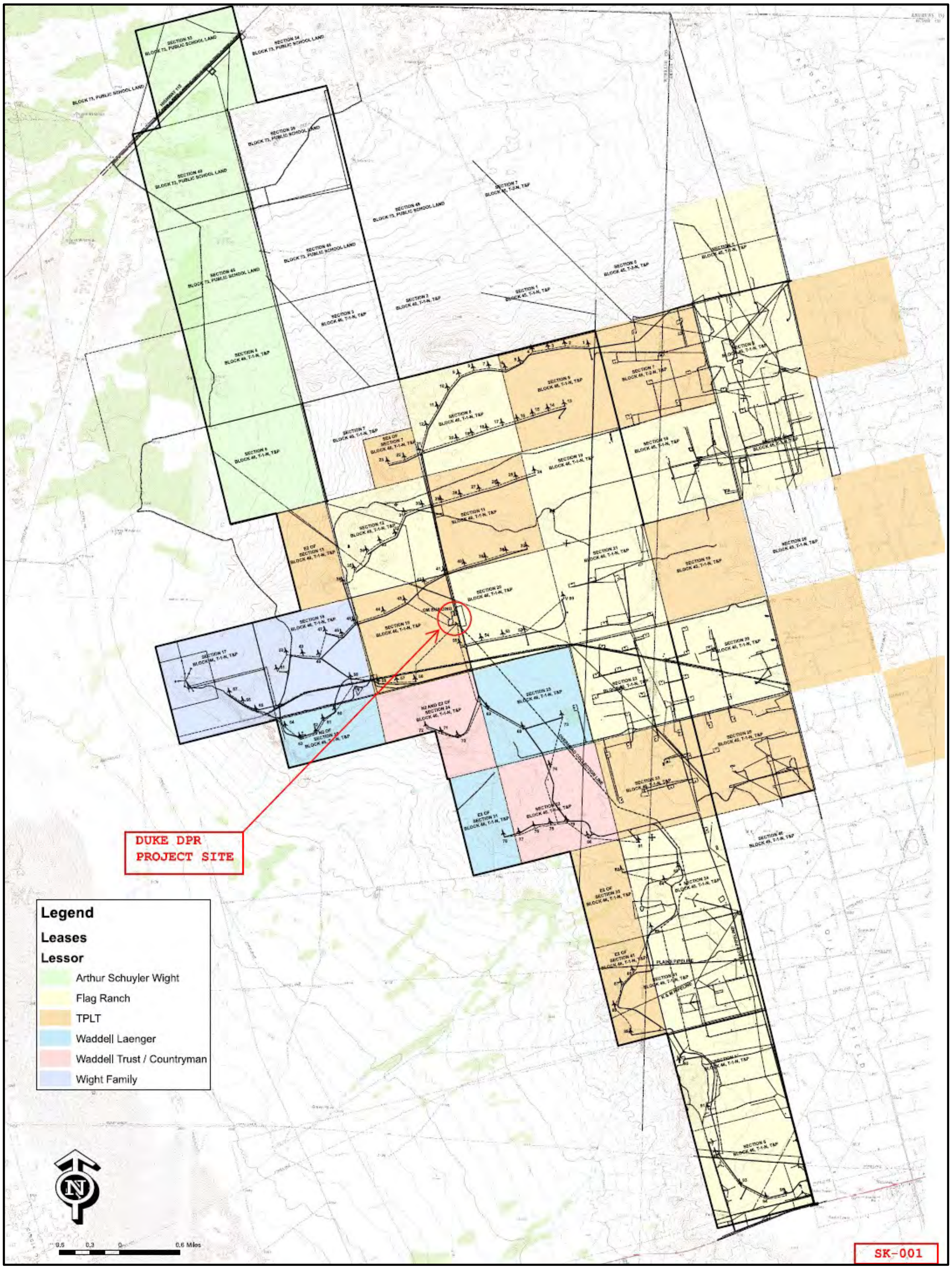

Figure 2-8
Location of DPR Facility on Project Site

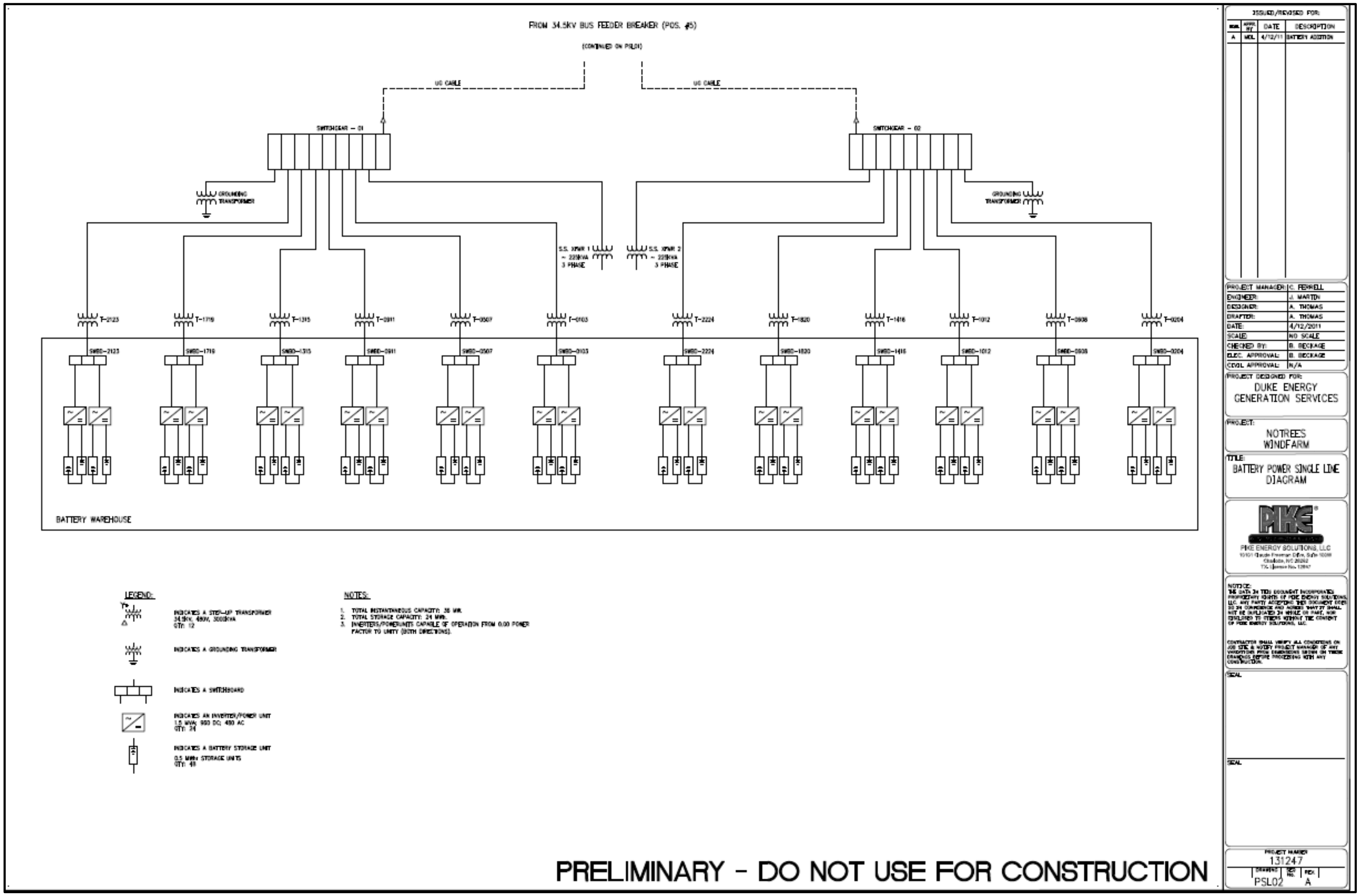

Figure 2-9
One-Line Diagram for DPR Energy Storage Facility

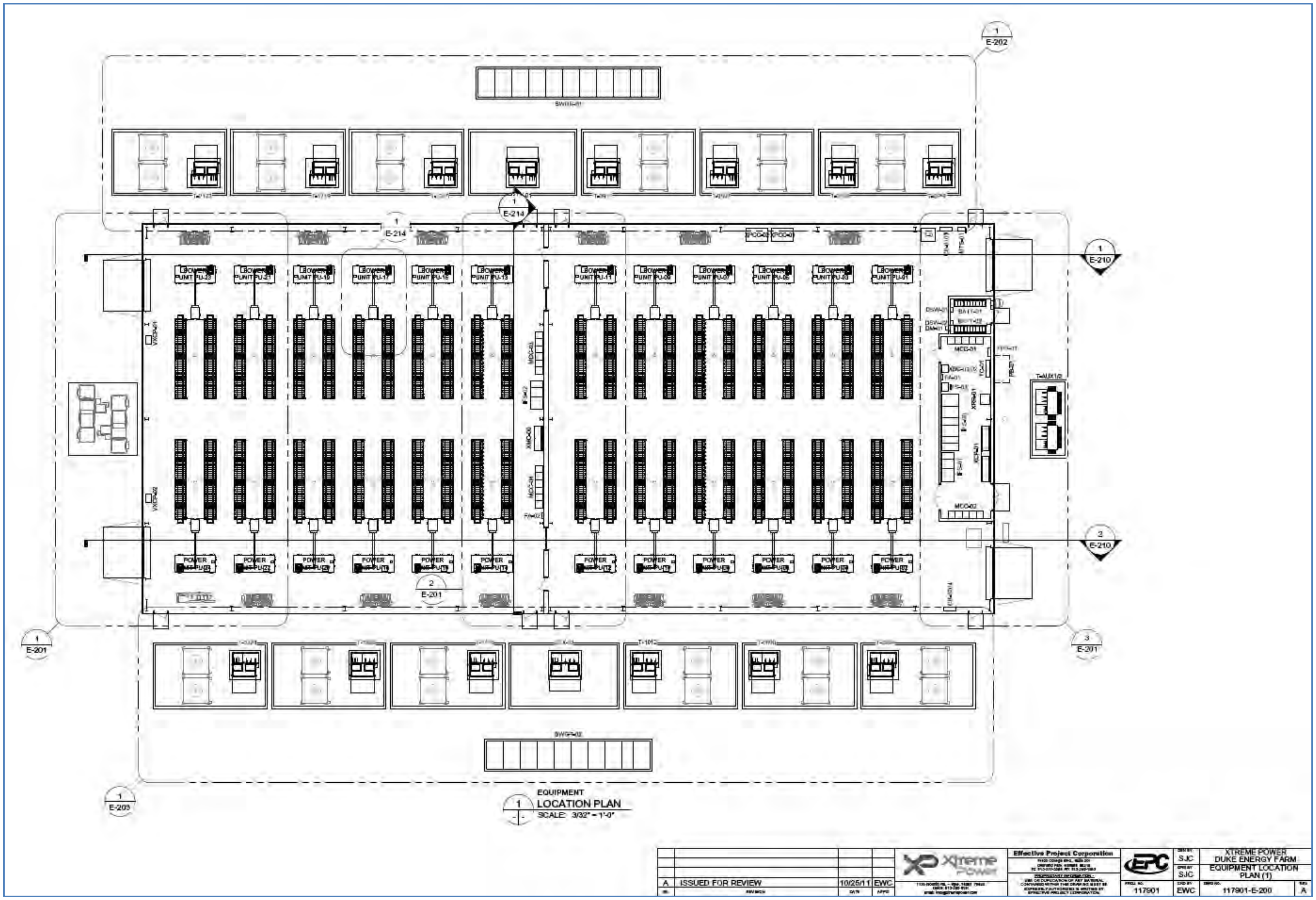

Figure 2-10
Equipment Location Plan within the Project Building

3
ANALYSIS METHODOLOGIES AND OBJECTIVES

3.1 Analysis Objectives

Energy storage can maximize the value of wind energy through multiple value streams. This project is designed to enable the following applications:

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. The time shifting capabilities of the battery were demonstrated as part of the system functional testing completed in November 2012.

Area Regulation: A portion or all of the energy storage capacity can be committed to provide regulation service to the ERCOT system. This service will first be offered to demonstrate proof-of-concept and may later become part of the regular dispatch strategy. The Notrees Battery project demonstrated the ability to follow an Automatic Generation Control (AGC) signal as part of part of the ERCOT certification process completed in December 2012.

Electric Supply Reserve Capacity: A portion or all of the energy storage capacity can be committed to provide various forms of operating reserve. As in regulation service, this strategy will be demonstrated for proof-of-concept and may become a regular part of the scheduling. The Notrees Battery Project demonstrated the ability to act as Reserve Capacity and be called on by the system operator when needed as part of the ERCOT certification process completed in December 2012.

Voltage Support: Energy storage can also be dispatched to provide local voltage support as a special feature of the inverters. The BESS may provide reactive power for voltage regulation to help maintain voltage at a specified level, depending on ERCOT allowances. Voltage regulation can be provided via a Power Factor Set Point or a Voltage Set Point control, which can either be static or dynamic. Voltage regulation is performed relative to the voltage or power factor as measured at the point of common coupling (PCC). The voltage support and regulation features of the Notrees Battery were demonstrated as part of the functional testing completed in November 2012.

Transmission Congestion Relief: As with the Time Shifting application, the BESS can charge when exports are limited by system congestion. This practice will relieve congestion, allowing more renewable-based energy to be moved to ERCOT customers. The transmission congestion relief function is demonstrated by the Notrees Battery on a regular and ongoing basis. Charging is typically performed when prices are lower which coincides with times in which there is an excess of renewables and specifically wind renewables available on the local transmission system.

Renewable Energy Time Shift: Similarly, energy storage can be used to maximize renewable energy production in the Notrees Wind Farm. 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. While this application has been theoretically proven as part of the overall time shifting functions performed by the battery throughout its performance life, there have also been specific occasions throughout the production life of the battery where the wind farm had turbine outages at the same time when the battery was supplying power to the grid.

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. This application was demonstrated by a simulation conducted in March 2012 using a single 1.5 MW inverter and the simulated output of a 1.5 MW wind resource. The battery was demonstrated to control the ramp rate of the combined output to less than 100 kw/min.

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. This application was demonstrated as part of the ERCOT certification process completed in December 2012. This function is a regular part of the Notrees Battery's continuing operation in the FRRS market supporting frequency regulation within ERCOT.

More general benefits include 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.

In addition to these benefits, the Notrees Battery Demonstration Project created a number of jobs both on a temporary basis during construction phase and on an ongoing basis to provide operation and maintenance support of the project. During the 2011 and 2012 construction phase of the battery there were between 10-50 construction personnel on site over the 24 month construction of the project. In addition to this there were several personnel involved in the manufacture of the batteries, inverters, switchgear and balance of plant materials used on site. As part of the ongoing operation and maintenance of the plant during 2013, there were 8 Full Time Equivalents (FTE's) employed by Xtreme Power and 6 FTE's employed by Duke Energy in supporting the project.

3.2 Methods for Determining Technical Performance

The Notrees Wind Storage Demonstration Project anticipates collecting 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. It is currently proposed that the battery system will be included in the joint wind farm offering and settlement, but will be metered separately.

Pending ERCOT approval, this system will document baseline information for the Notrees location.

At the time of writing this report (November 2013), no baseline data has been collected due to the need to finalize the BESS settlement. 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 that will be collected and analyzed during operation of the BESS at the Notrees Wind Farm includes the following (data marked with an asterisk (*) will be 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 are currently operating a data acquisition system (DAS) to monitor the Notrees Wind Farm. Additional systems for collecting and analyzing data from the baseline system and the new BESS are in the design phase (see Section 3.5). This supplemental functionality is being 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 will be 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

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 shall 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 will be dependent on actual grid conditions, ramp rate control, and frequency regulation, as well as AGC commands.

Regulation Down

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 shall be capable of moving from neither absorbing nor producing power to its maximum Down Reserve power level in less than 50 msec.

AGC or Set Point Response

The DPR will respond to the AGC set point under all system frequency conditions, in accordance with ERCOT interconnection rules. AGC signal will be a set point signal.

Frequency Regulation

The DPR shall 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 will 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 will cause an immediate and opposite change in the DPR output. Controls will keep 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).

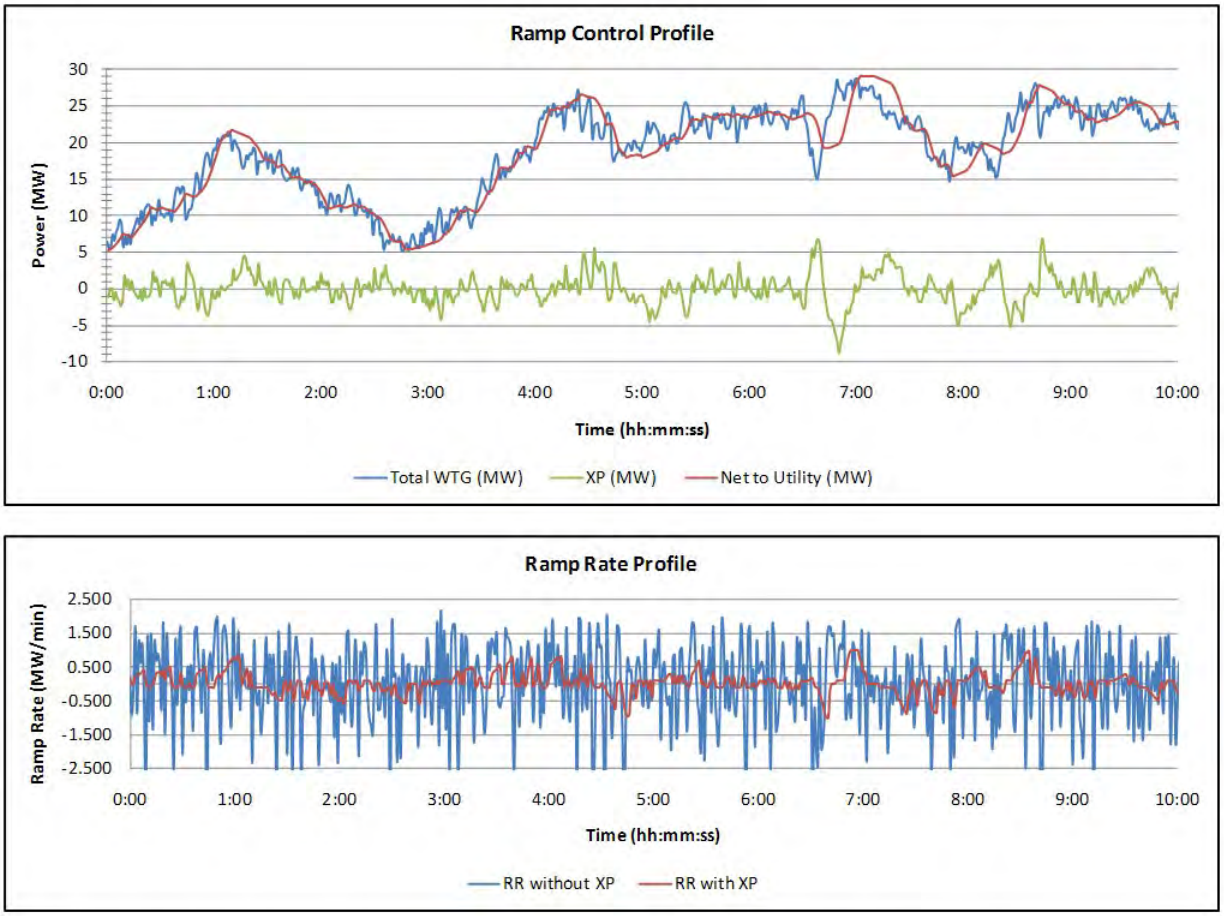

Figure 3-1
Examples of Ramp Rate Control Provided by Xtreme Power DPR, based on Actual Operating Data

Curtailment Capture

The DPR system will 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. The exact nature of the coordinated control between the BESS and the wind farm is not determined at the time of this writing (November 2013).

3.4 Metering and Communication with ERCOT

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

Under the proposed arrangements for grid metering, real-time operation and performance of the DPR on the ERCOT grid will be telemetered and monitored by ERCOT at the ERCOT-Polled-Settlement meter installed at the wind farm point of interconnection. This configuration was finalized as part of a settlement enetered into by ERCOT, Oncor, Duke Energy and Xtreme Power in February 2014 [Note: The ERCOT Board approved FRRS in Nov 2012 .] Additional metering will be 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 will manage the real-time communication of DPR telemetry and operations to ERCOT in conjunction with the real-time communication currently 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 will be 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.

The Data Processing System (DPS) software developed by EPRI will receive 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 will review and analyze the data reports. The data analysis will comprise the main part of the regular reporting.

The following subsections describe the overall system requirements, 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. The Final Technical Report will elaborate on these requirements.

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. The Final Technical Report will elaborate on these requirements.

Design Constraints

There are 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.

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.

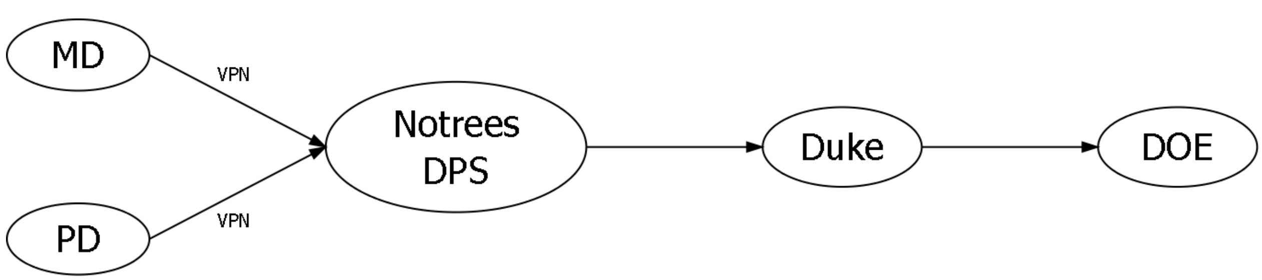

Figure 3-2
Data Flow between System Interfaces

Market Database

Duke Energy operates the Market Database 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 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. In addition, data may sometimes 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.

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 come from the metering of the BESS and from settlement information.

Peak Generation and Mix

The ERCOT peak generation and mix can be determined from their regular market reports.

Annual Generation Cost

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

Ancillary Services Price

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

Congestion

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

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.

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.

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.

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 Set Point
- 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 set-point signal to be sent through the RTU interface, and the DPR contractor's corresponding action was initiated without delay. The following tests were performed with frequency control and ramp rate control disabled:

- Raise Regulation Set Point Test
- Lower Regulation Set Point 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 have been gathering and archiving operating data throughout the year. As of late 2013, EPRI and Duke have 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 Section 3.5. EPRI expects to begin receiving data in early 2014, with analysis to follow.

Fast-Responding Regulation Service Pilot Project

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

As authorized by Public Utility Commission of Texas Substantive Rule 25.361(k), in November 2012 ERCOT established a pilot project to test FRRS. The PUC 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. The stated purpose of the pilot project, as approved by the PUC and amended at the July 16, 2013 meeting of the ERCOT Board of Directors, is 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. [Note: ERCOT is not subject to FERC jurisdiction. However, in creating the FRRS program ERCOT used Order 755 as an example. FERC Order 784, which expands 755 to include batteries, flywheels, etc., was promulgated July 18, 2013. Thus, Order 784 was not in existence when ERCOT created the FRRS program and was consequently not in view as a possible example.]

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 as 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.

Figure 4-1
Response from Conventional Resources (Source: ERCOT[2])

[2] 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

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 conducts 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. To date, those are the only resources participating in the FRRS pilot project.

The one-year pilot project is scheduled to run until February 2014. If the pilot proves successful, ERCOT will propose a Nodal Protocol Revision Request (NPRR) to implement FRRS.

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

4.3 Planned Activity in 2014

The current FRRS Pilot Program is scheduled to complete in February 2014. It is anticipated that because of the success of the Notrees Battery Project in responding to the frequency signal provided by ERCOT (greater than 95% performance to frequency regulation signal provided), FRRS will be made into a permanent market by ERCOT. If this expected result comes to pass, the Notrees battery will continue to participate in the market on a day ahead or same day basis depending on the ultimate market rules. This application currently looks like the best long term fit for the battery. In addition, it is anticipated that Duke Energy will continue to lobby ERCOT to provide a market structure which appropriately rewards the fast responding nature and the high performance level of the battery in providing frequency stability in the region.

In addition, Duke and Xtreme are continuing to upgrade the operation and maintenance practices for the batteries, and we anticipate continuing this in 2014. Some areas which we are working on include: optimizing the timing and application of balancing charges, determining battery cell end of life, and optimizing revenue based upon specific market rules provided by ERCOT.

5

GRID IMPACTS AND BENEFITS

This chapter describes in general terms the potential grid impacts and benefits that the Notrees Wind Storage Demonstration may provide over the course of its operating lifetime. Not all of these characteristics will necessarily be incorporated into the test plan; rather, they provide 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 in 2013, while Chapter 7 addresses plans for future activities that may yield grid impacts and benefits. Results of BESS operation after November 2013 will be reported in the 2014 interim TPR and the 2015 final TPR.

5.1 Project and System Metrics

Duke Energy will identify the impact metrics as either project or system metrics throughout the plan and reporting process. Duke Energy will report project metrics for impacts observed specific to the area project assets, functionality, or programs are implemented. For example, frequency regulation services provided from the battery system will be metered at the point of interconnection. Duke Energy will report system metrics for impacts observed on the entire transmission or distribution system based on estimates of the ERCOT system impacts attributable as a result of the battery system participation in ERCOT. For example, estimates of avoided carbon emissions within ERCOT may be calculated based on estimated system-wide carbon emissions at times when the battery system is providing generation to the grid.

The following Impact Metrics correspond to those indicated in the Metrics and Benefits Reporting Plan (MBRP). The reference document[3] defines each metric in detail, while the following descriptions consist of short definitions and an elaboration on how the DAS and analytical methods will compute the metrics in practice.

Annual Storage Dispatch (Project Only)

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.

Average Energy Storage Efficiency (Project Only)

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 come from the metering of the BESS and from settlement information.

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[3] *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 can be determined from their regular market reports.

Annual Generation Cost (Project and System)

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

Ancillary Services Price (Project and System)

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

Congestion (Project Only)

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

Congestion Cost (Project Only)

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.

CO_2 Emissions (Project and System)

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. 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 (Project and System)

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 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 their 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.

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 has 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 process of constructing the Notrees Wind Storage Demonstration Project, which occurred in 2012. It also summarizes the facility's performance in ERCOT's FRRS pilot program, as well as general system performance, in 2013.

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.

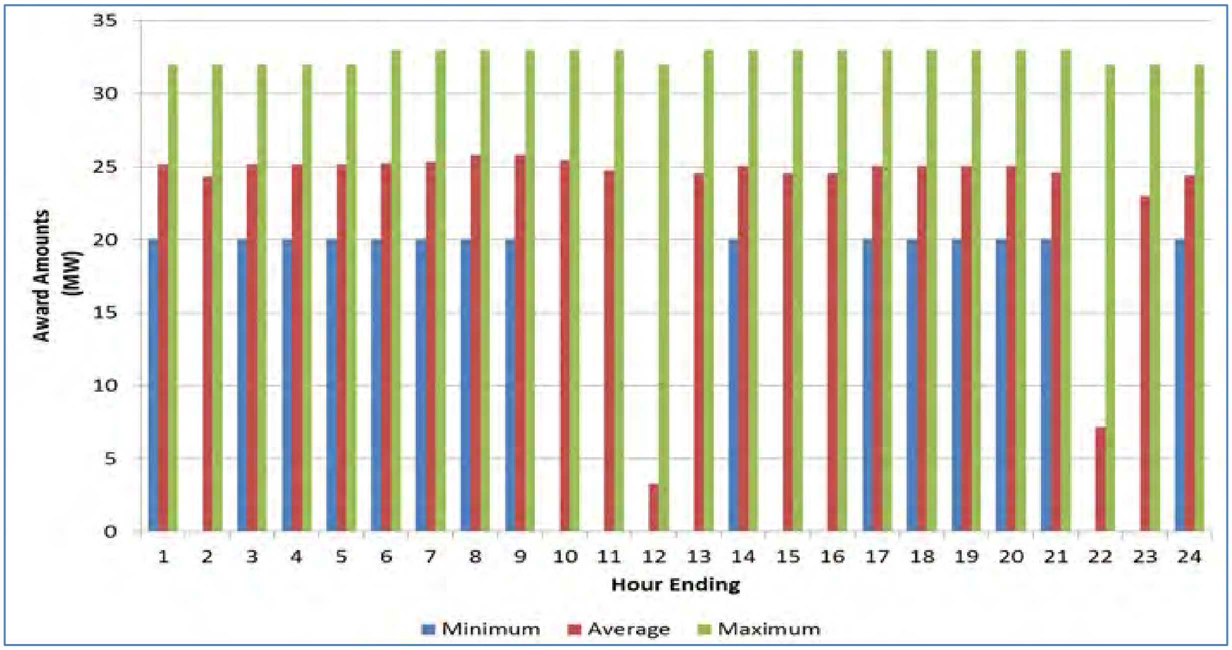

Figure 6-13
Aggregate FRRS-Up Award Amounts for First Nine Weeks (Source: ERCOT)

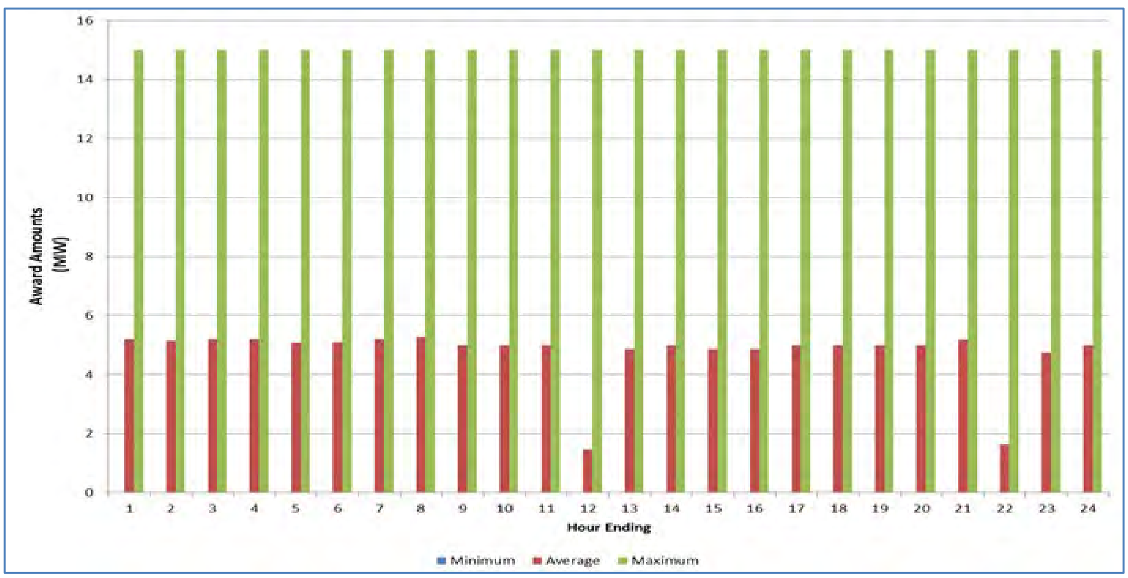

Figure 6-14
Aggregate FRRS-Down Award Amounts for First Nine Weeks (Source: ERCOT)

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.

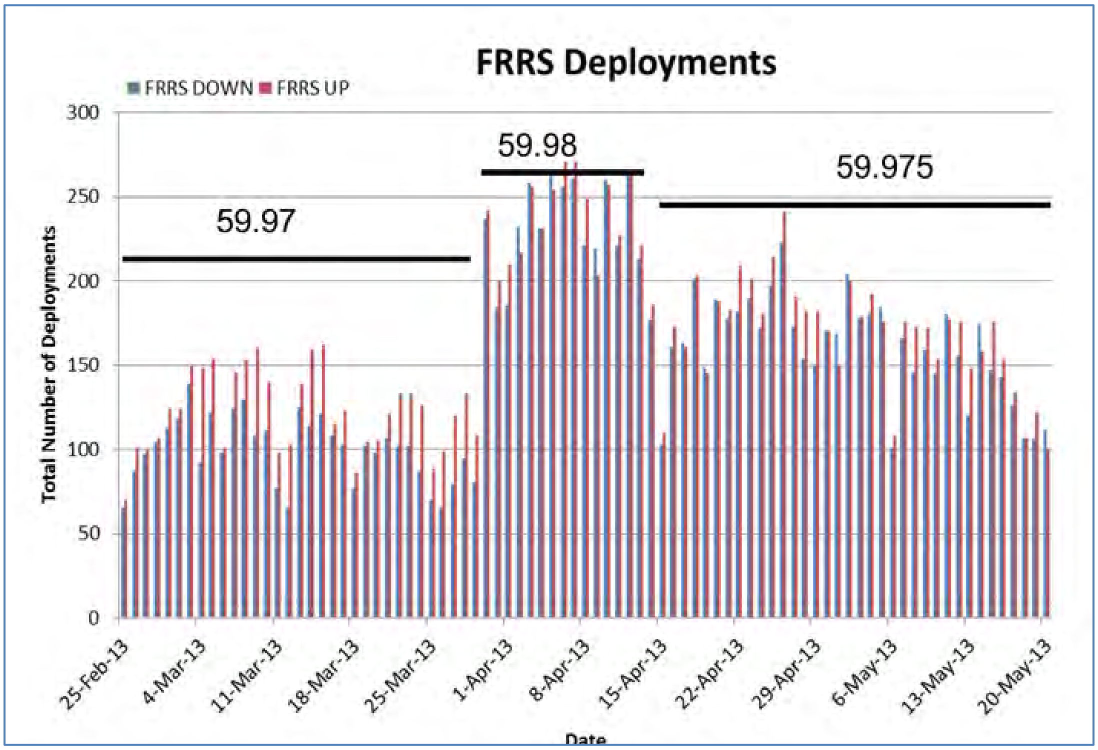

Figure 6-15
Number of FRRS Deployments, February–May 2013 (Source: ERCOT)

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.

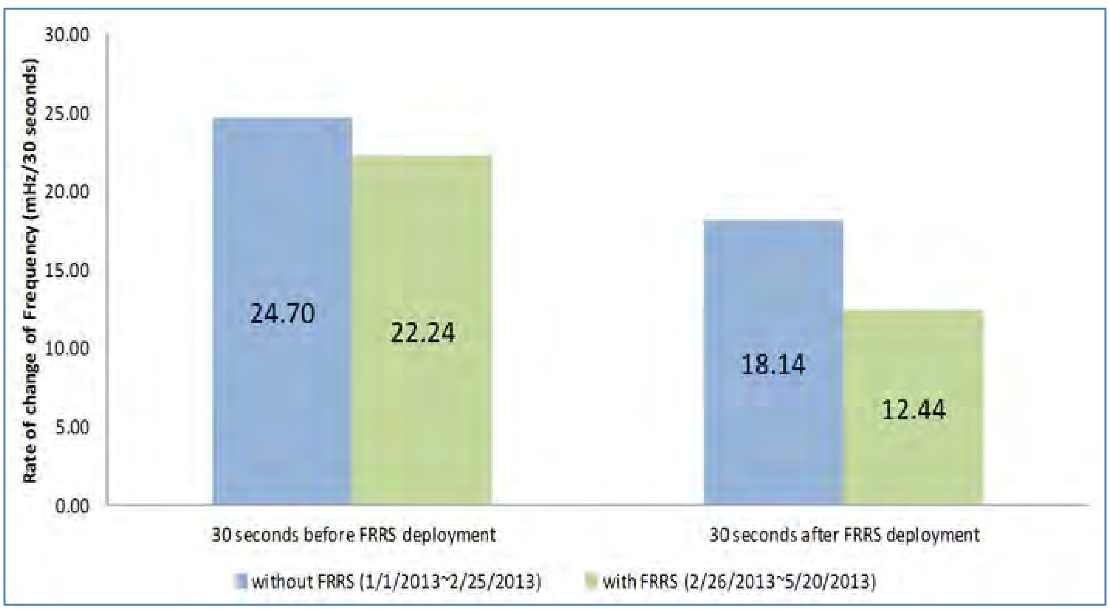

Figure 6-16
Rate of Change of Frequency (mHz/30 seconds) (Source: ERCOT)

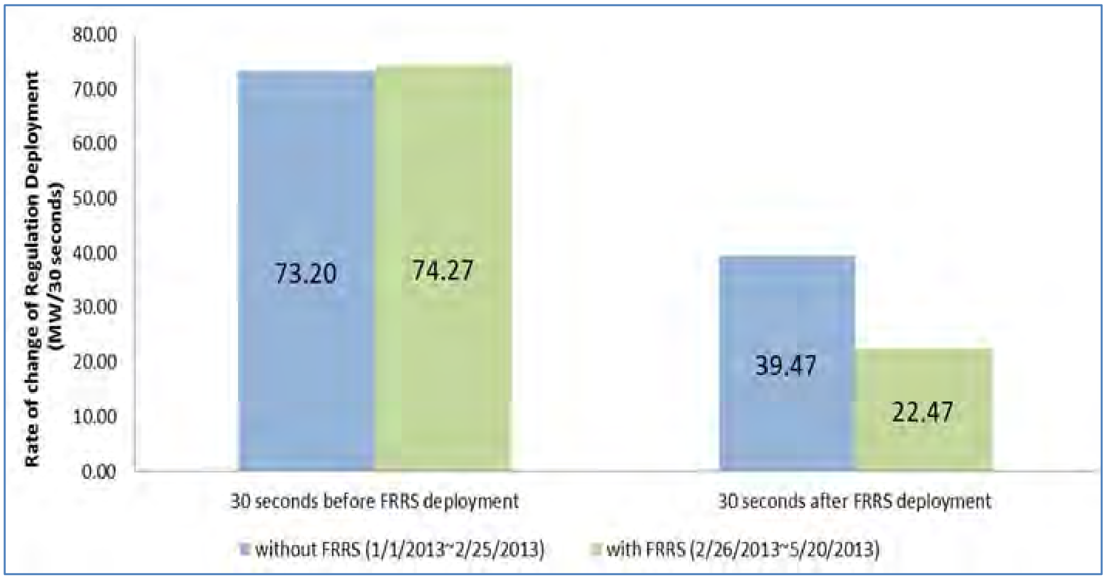

Figure 6-17
Rate of Change of Regulation Deployment (MW/30 seconds) (Source: ERCOT)

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

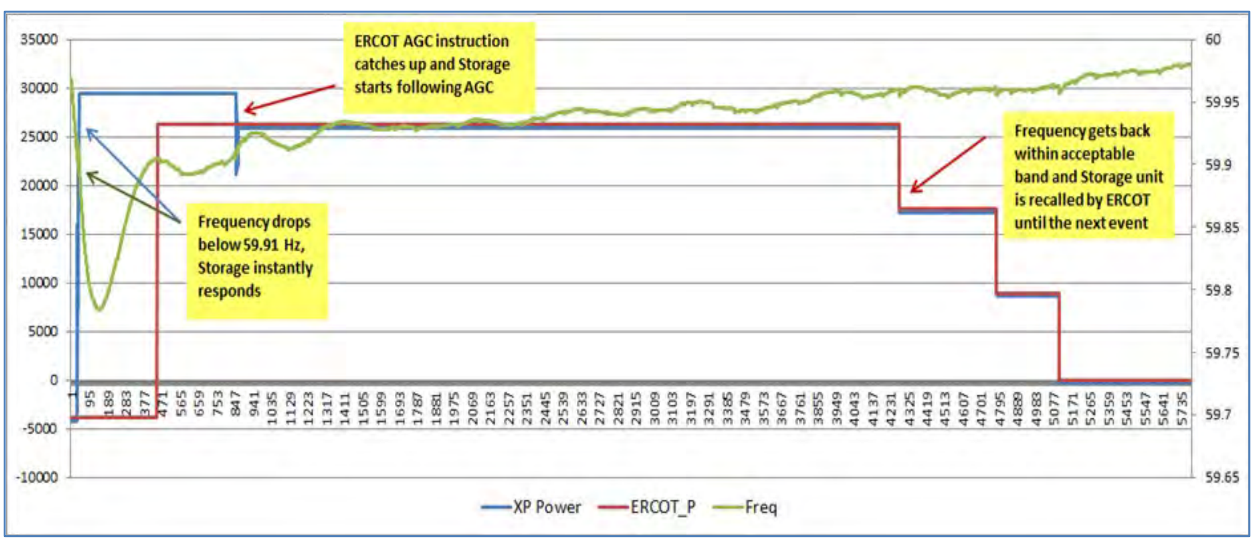

Figure 6-18
Illustration of BESS Arresting Extreme Frequency Deviation (Source: Xtreme Power)

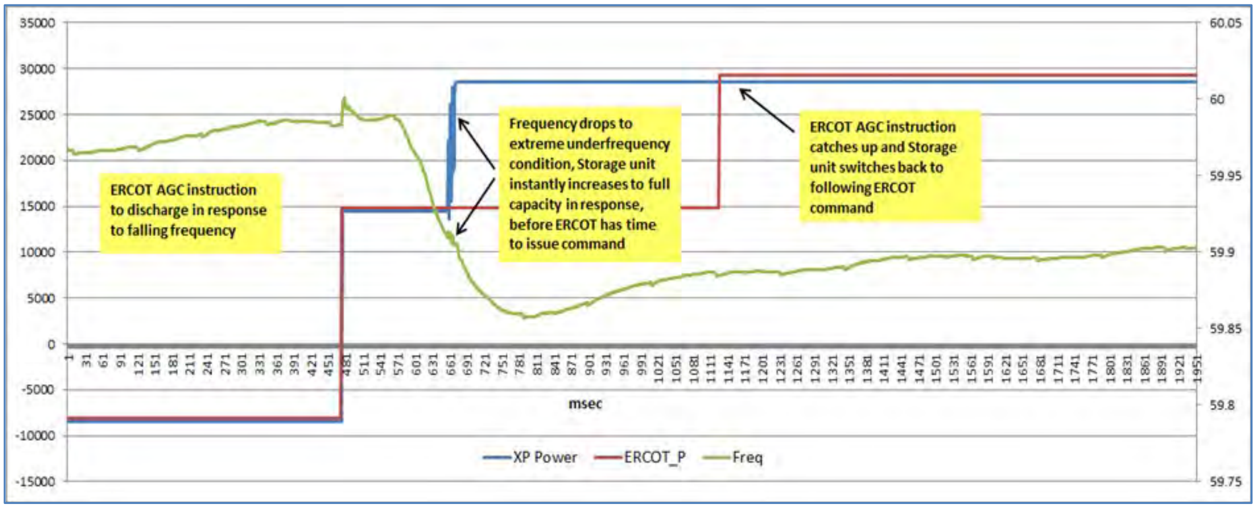

Figure 6-19
Illustration of BESS Arresting Extreme Frequency Deviation (Source: Xtreme Power)

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.

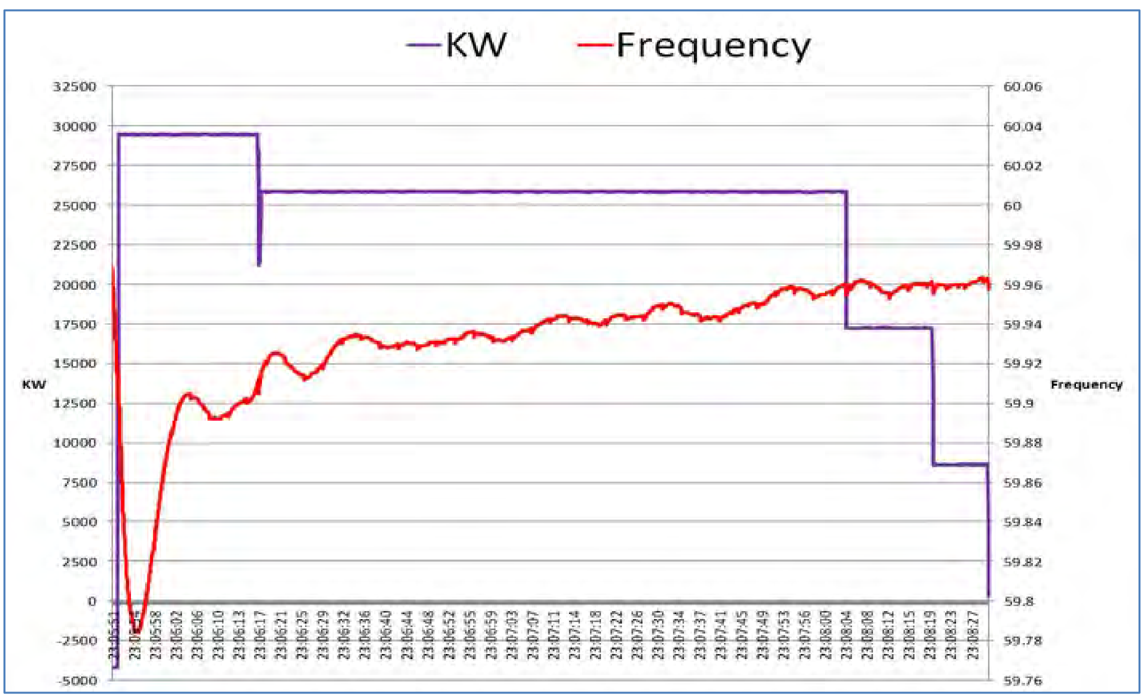

Figure 6-20
Event on March 7, 2013 (with high-resolution data) (Source: ERCOT)

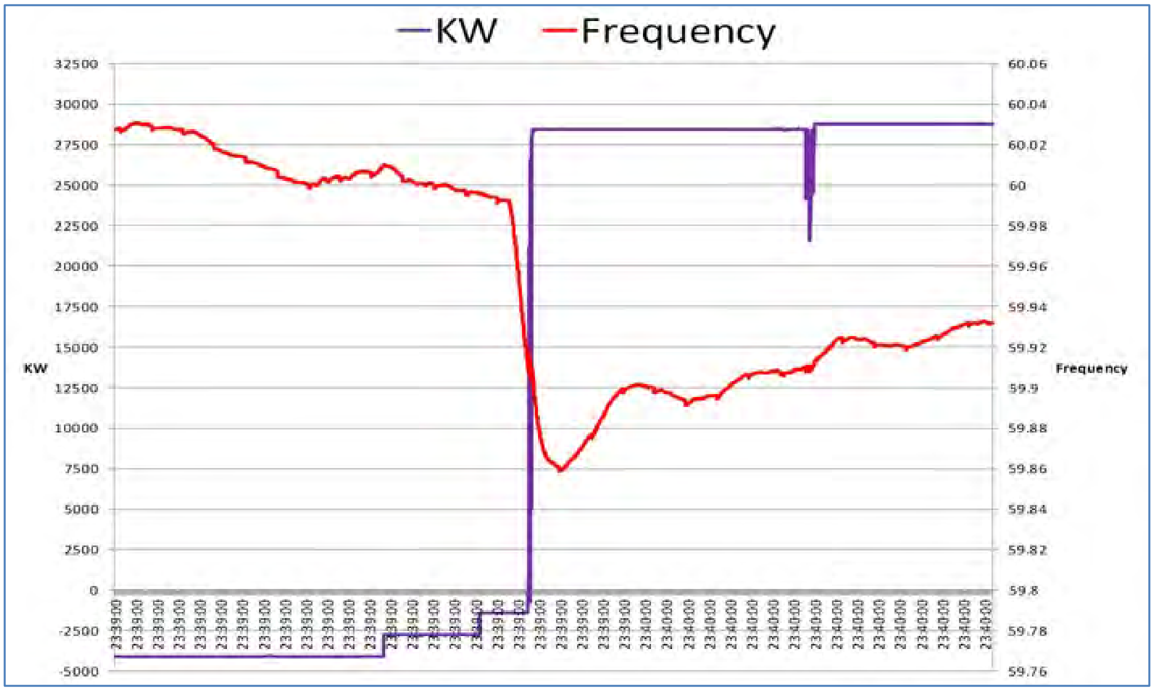

Figure 6-21
Event on March 15, 2013 (with high-resolution data) (Source: ERCOT)

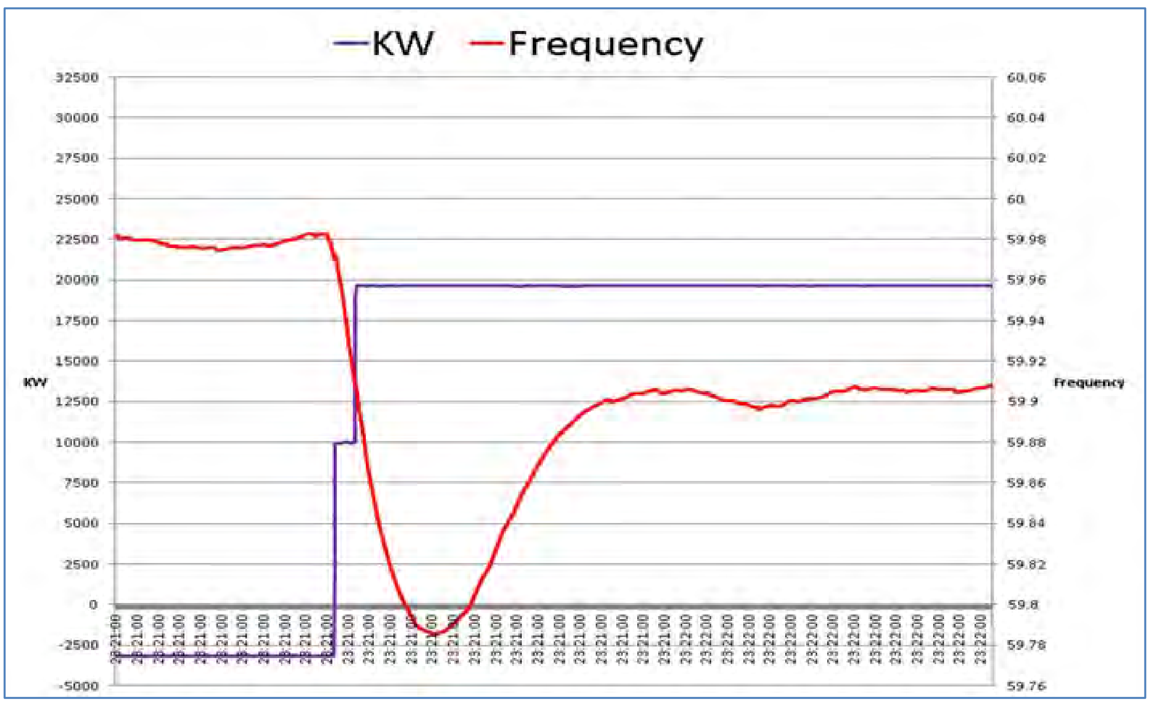

Figure 6-22
Event on April 9, 2013 (with high-resolution data) (Source: ERCOT)

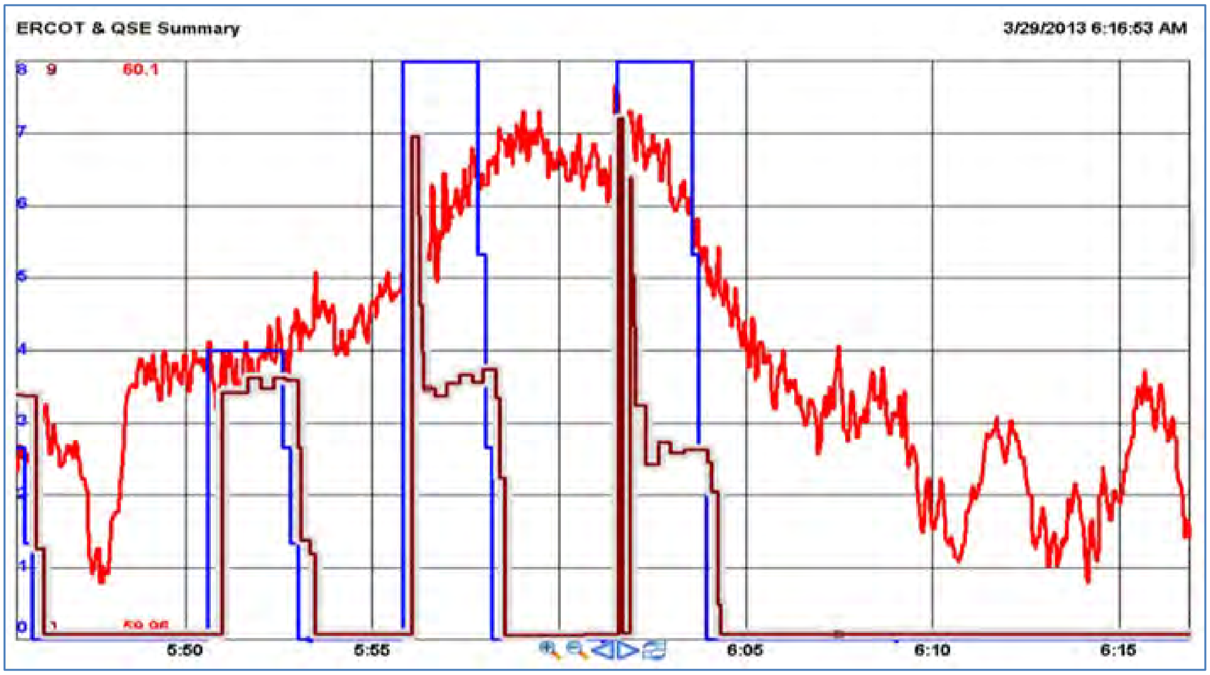

Figure 6-23
High-Frequency Event on March 29, 2013 (Source: ERCOT)

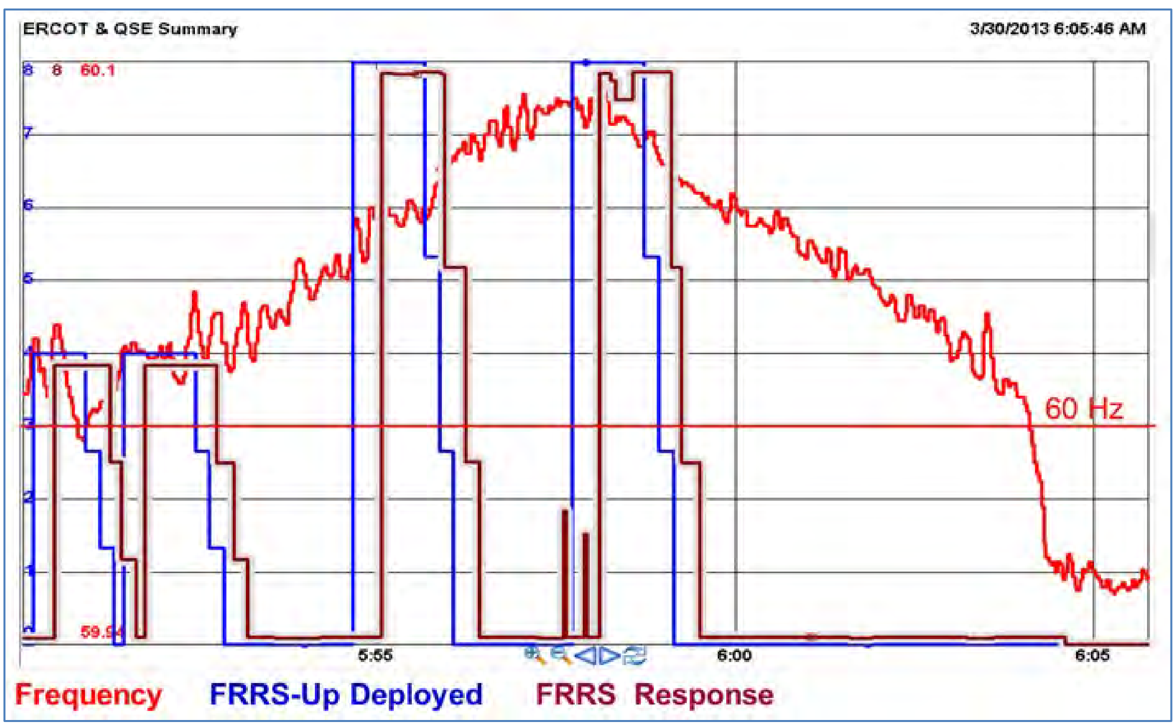

Figure 6-24
High-Frequency Event on March 30, 2013 (Source: ERCOT)

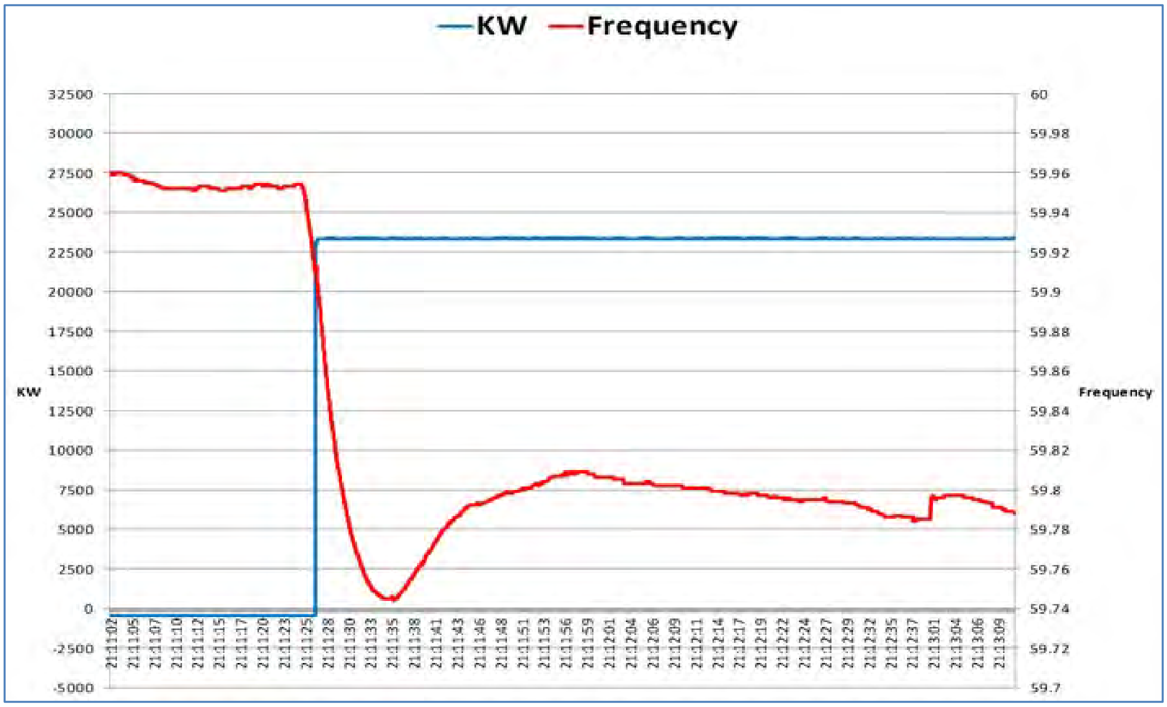

Figure 6-25
Frequency Event on May 22, 2013 (Source: ERCOT)

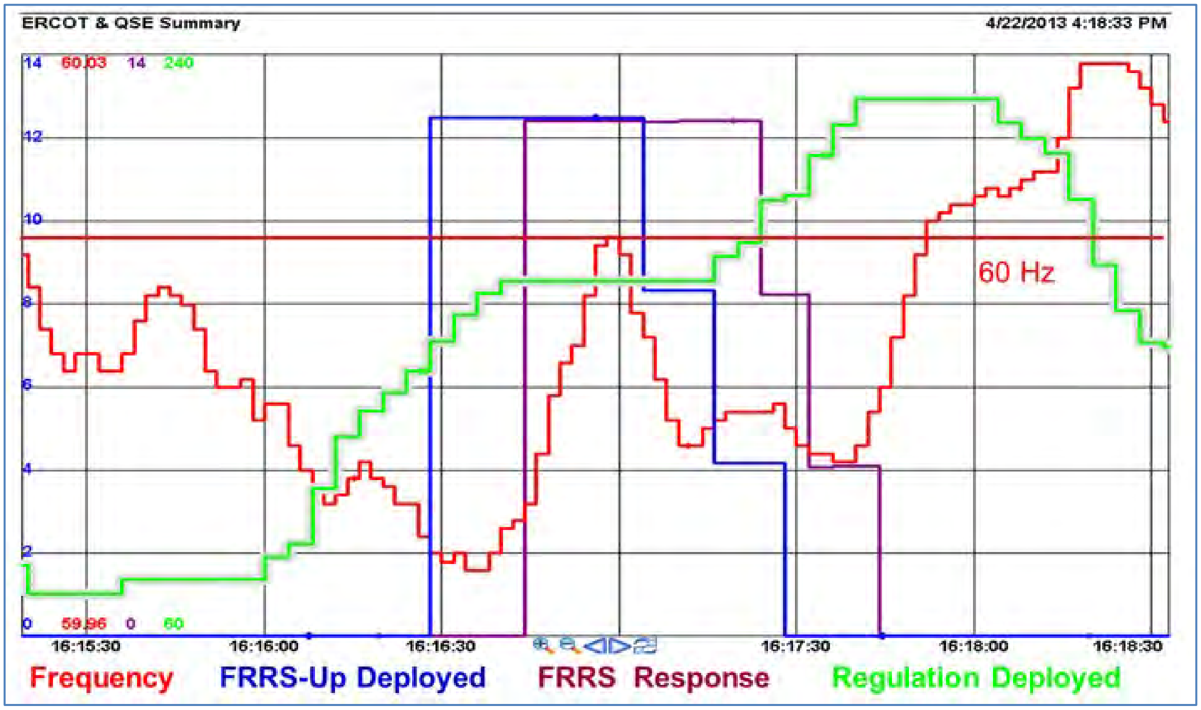

Figure 6-26
Effect of FRRS-Up on Frequency and Reg-Up, April 22, 2013 (Source: ERCOT)

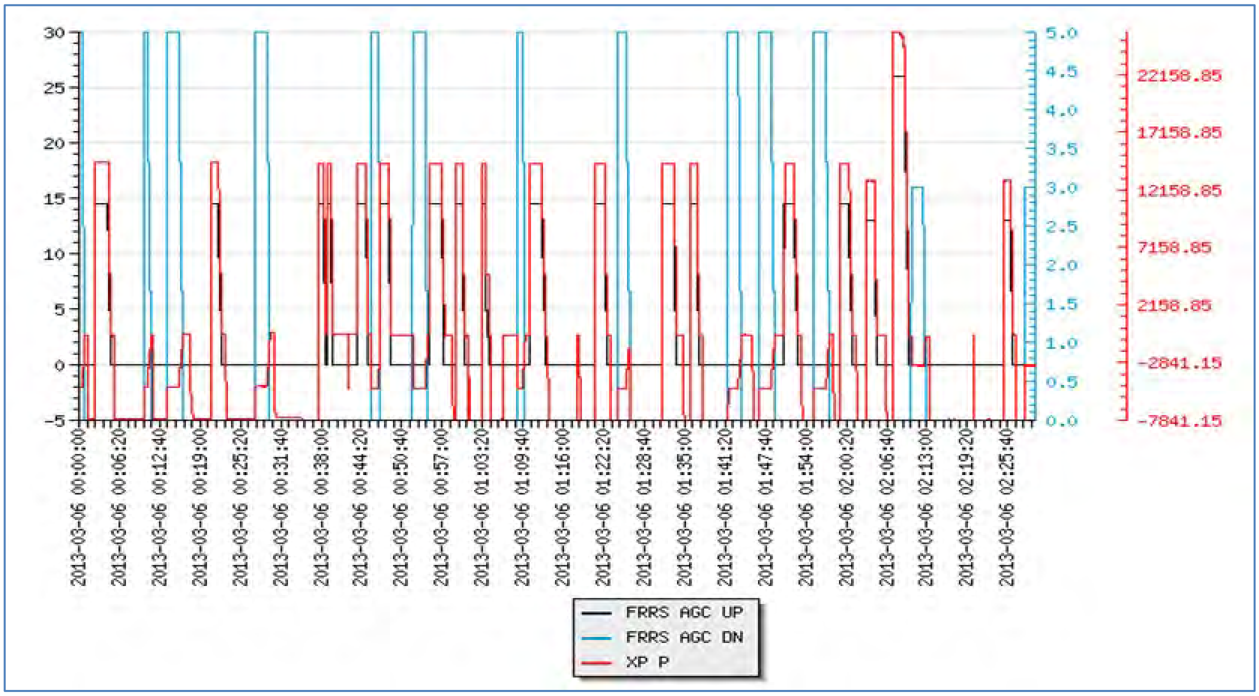

Figure 6-27
Response of BESS (in red) to ERCOT Regulation Signals, March 6, 2013 (Source: Xtreme Power)

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.

2012 Baseline Metrics

Table 6-1 contains 2012 baseline system values. The values for the BESS project are all zero. These system values are provided for comparison to those that will be provided in later years.

Table 6-1
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) Peak Generation (Operations)	MW MW	0 0	N/A 66,583	[4] on 15-min
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]
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]

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*. 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.

2013 Impact Metrics

Storage system impact values for 2013 corresponding to the baseline values provided in Table 6-1 are being analyzed and will be reported in the Final Technical Report.

6.5 Overall BESS Operation and Performance

The Xtreme Power 36-MW/24-MWh BESS at the heart of the Notrees Wind Storage Demonstration Project, along with its accompanying infrastructure and balance of plant, was installed during 2012. Following a comprehensive Startup Testing & Commissioning Plan, the BESS passed the inspections, checks and tests detailed in Chapter 4. The BESS 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.

No significant unscheduled shutdowns or maintenance events have occurred to date. The BESS continues to perform as specified.

In 2013, EPRI drafted requirement specifications for software being developed to analyze data collected from the Duke Notrees BESS and the ERCOT electricity markets. These specifications codify the data format and reporting frequency by which information will be transmitted from the Notrees Data Acquisition System (DAS) to EPRI's Data Processing System (DPS) for analysis and reporting to DOE. At this writing in November 2013, initial data on BESS operation and performance is forthcoming but will not be available for reporting and analysis before the Technology Performance Report (TPR) deadline. Duke Energy and EPRI will continue to pursue the Analysis Methods and Objectives described in Chapter 3, and report those results in future interim and final TPRs.

7 FUTURE PLANS

7.1 Project Phases and Milestones

As noted, the Notrees Wind Storage Demonstration Project consists 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 is considered a milestone. Executive approval to enter the next phase is 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.	February 25, 2015

Phase 1 was completed on June 22, 2011. The project is currently in Phase 2. Tables 7-2 and 7-3 provide more details about the specific tasks that comprise each phase.

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	February 25, 2013
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 will evaluate the system's performance and results, and could decide to continue the FRRS pilot program.

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 is assisting with the documentation of the project. In addition to this 2013 interim report, EPRI will prepare an annual interim report for 2014. These will provide operations results and benefits assessments.

7.3 Further Technology and Market Development Activities

Duke Energy has used the Notrees Demonstration project as a vehicle to understand and help to develop the FRRS market in the ERCOT region. In addition, we believe that the demonstrated success of a large grid scale energy storage project in the ERCOT region might be a factor in other regions following with energy storage mandates. In addition, this project has helped Duke Energy to take lessons learned from Notrees and apply them to our commercial offerings in other control areas.

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

8
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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)}
State of charge (SOC)		%	TBD	float	

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