TECHNOLOGY SOLUTIONS FOR WIND INTEGRATION IN ERCOT

INTERIM TECHNOLOGY PERFORMANCE REPORT #1

Rev 0 Chg 1

September 30, 2013

SUBMITTED FOR COOPERATIVE AGREEMENT

DE-OE0000194

PREPARED FOR

U. S. Department of Energy
National Energy Technology Laboratory

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Disclaimer

Acknowledgment

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Revision History

Version Identifier	Date of Issue	Summary of Changes
Rev 0 Chg 1	December 30, 2013	Incorporated the following changes: • Section 2.2 – added organizational chart • Section 2.3.2 – moved quantities to Section 4 • Section 2.3.2.3 – moved discussion of technical hurdles to Section 4 • Section 2.3.4 – added this section with key project milestones • Section 2.3.5 – add this section with key decision points • Section 3.1.1.2 – moved status discussion to Section 4 • Section 3.1.1.3 – moved status discussion to Section 4 • Section 3.4.1 – moved status discussion to Section 4 • Section 3.5.1 – moved status discussion to Section 4 • Section 5 – added this section for primary CCET and DOE contact information • Appendix A – added this appendix for most recent build metrics
Rev 0 Chg 0	September 30, 2013	Original Technology Performance Report submitted to DOE

This document contains information that is as complete as possible. Where final numerical values or specification references are not available, best estimates are given and noted To Be Reviewed (**TBR**). Items which are not yet defined are noted To Be Determined (**TBD**). The following table summarizes the TBD/TBR items in this revision of the document, and supplements the revision notice above.

Section	Description

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Figures and Tables

Preface

The Center for the Commercialization of Electric Technologies (CCET) has prepared this Technology Performance Report (TPR) for its smart grid regional demonstration project in response to specified DOE reporting requirements. The format of this document follows DOE's TPR Guidelines dated June 17, 2011.

As the first interim report, this TPR is based on less data than will be available for subsequent TPRs, including the final Technical Report which will be delivered at the end of the project. Although the original goal was to collect at least 24 months of data on all aspects of the CCET project, certain components such as the synchrophasor monitoring and visualization efforts have been collecting data from almost Day 1 while newer efforts, such as demonstration of unique cyber security protection schemes for synchrophasor networks, are still being implemented so data collection efforts have been limited. As a consequence, some reported results will have a higher level of certainty while others will be reported as initial findings based on data sets for limited durations.

Readers should view all findings in this report as preliminary and, at best, indicative of what the final results and lessons learned may be. These preliminary results may change due to additional data collection over longer periods of time, and also changes in the demonstration particulars over time.

1. INTRODUCTION

This document represents the first interim TPR for the CCET Smart Grid Regional Demonstration Project (SGRDP) entitled, “Technology Solutions for Wind Integration in Electric Reliability Council of Texas,” commonly known as Discovery Across Texas. The CCET project is partially funded by the DOE cooperative agreement DE-OE0000194 and partially funded by various CCET team members and ERCOT stakeholders.

This interim TPR summarizes the CCET SGRDP as of September 30, 2013 and includes information on the project technical components, the respective data collection efforts, the cost and benefit methodologies being applied to determine the value proposition, summaries of the key analytic results, and lessons learned as of that date.

2. SCOPE

This section provides relevant information on the overall project, its objectives, the major demonstration components and their relevant smart grid technologies and systems being demonstrated, the anticipated benefits, the team members, the basic approach for interoperability and cyber security, and interactions with project stakeholders.

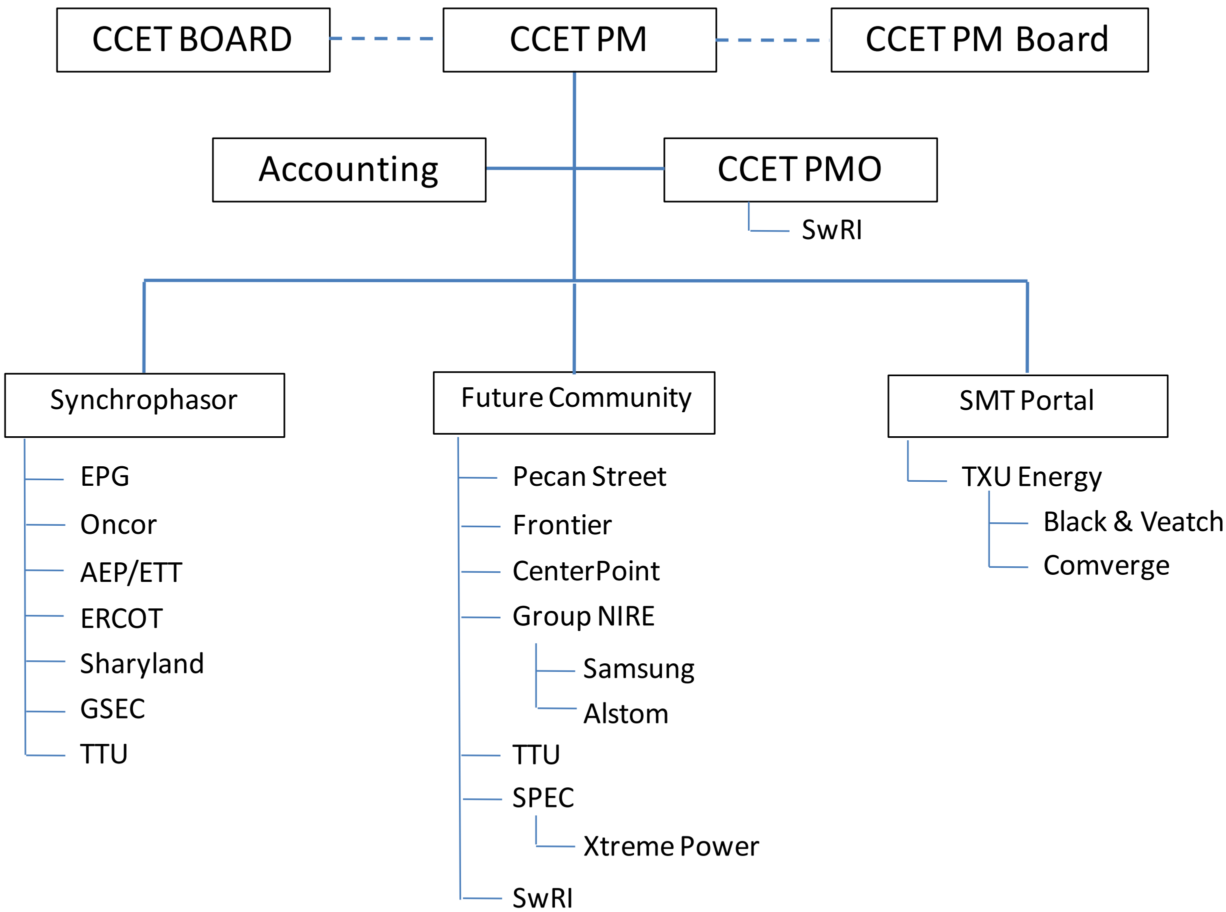
2.1 Overall Project Description

This project represents a multi-faceted synergistic approach to managing fluctuations in wind power in the large Electric Reliability Council of Texas (ERCOT) transmission grid through better system monitoring capabilities, enhanced operator visualization, and improved load management. It will demonstrate the use of synchrophasor technology to assist in better determining grid operating status and margins that avoid either conservative operating margins or grid instability when moving remote wind resources through the ERCOT transmission grid to consumers. By taking advantage of this technology, ERCOT grid operators will be better able to accommodate wind resource variability, unexpected transmission line outages, or instability developments. As necessary, ERCOT operators, transmission and distribution service providers (TDSPs) and retail electric providers (REPs) will leverage existing capabilities, including the Smart Meter Texas (SMT) Portal, to call upon controllable home area network (HAN) loads as part of initiated demand response (DR) events via the advanced meter systems (AMS) of utilities. These HANs will be part of an advanced integrated smart grid community of the future that combines distribution level energy storage systems and homes equipped with smart meters, 3-5 kW solar photovoltaic (PV), load-interruptible DR appliances, efficient building envelope standards, and electric vehicle (EV) charging to demonstrate consumer responsiveness to variable electric pricing schemes and an innovative DR program. All together, this project will help define a new business model for managing wind resources through complementary residential solar energy resources, DR, and storage by validating the value of combined yet separable smart grid components. ERCOT and other market participants will eventually be able to utilize this project’s collection of tools to shed load to meet reliability needs across the entire interconnection in response to wind lapses and related grid disturbances.

2.2 Team Members

This CCET project represents a collaborative effort on the part of four ERCOT region utilities, electric cooperatives, a large Texas REP, a university, an EV fleet owner, third-party vendors and technology firms. Additionally, this project benefits from advice and guidance provided by the CCET Board of Directors, a Project Management Board, and ERCOT, all of which comprise key players in the Texas electric market. The team member descriptions are provided below, and organized by those receiving DOE funds, those providing cost share, and others that provide technical advice and oversight.

To address the project goals, there are technical teams addressing three primary demonstration components: synchrophasors, future smart grid community, and the SMT Portal. The high level team organizational structure is shown below.



2.2.1 CCET

The CCET is a consortium of utilities, retail electric providers, and technology companies dedicated to developing new capabilities that will improve grid operations in Texas, and CCET has performed a number of projects in the ERCOT region. Most project team members are members of CCET and have worked together on many projects over the years. The CCET President serves as the Project Manager (PM) and is fully responsible for the successful execution of this project. He is governed by a Board of Directors that approves all projects. The CCET PM has access to Board members for assistance and support, and reports monthly to the Board on the programmatic status of the project. The CCET PM also has access to a special PM Board formed by technical leaders of the Board companies, and meets monthly with this group for advice and guidance on the conduct of this project.

2.2.2 DOE-Funded Partners

2.2.2.1 BV Services

For this project, BV Services is assisting CCET and TXU Energy with the SMT Planning portion, which involves dual-path demand response services. BV Services is planning and managing this part of the project as well as leading technical discussions and workshops regarding solution configurations, program design, testing approaches, and impacts to customers. BV Services resources have been working with TXU Energy and Comverge to support enhancements to the iThermostat program for the past couple of years.

2.2.2.2 Comverge

Comverge is a CCET member that provides intelligent energy management solutions to utilities and commercial and industrial companies. Comverge worked with TXU Energy to develop its current Brighten® iThermostat program for residential and small commercial customers, which includes installing programmable thermostats and gateways, and providing software to manage the registration, installation, operation, and support of that program. In this project, Comverge is participating in design, development, and testing of demand response solutions.

2.2.2.3 Electric Power Group

Electric Power Group (EPG), a CCET member, serves as the Team Lead for the Synchrophasor component. They have been involved in synchrophasor-related activities for many years in support of the Western and Eastern Interconnections. For this project, EPG provides software, including the Real Time Dynamics Monitoring System (RTDMS) and the Phasor Grid Dynamics Analyzer (PGDA), and professional and consulting services. They also have a phasor data concentrator (PDC), which may be deployed as well. EPG is also closely involved in the development and implementation of ERCOT's synchrophasor monitoring system, and will continue to provide that support.

Recently, EPG formed an alliance with Intel/McAfee to investigate a new cyber security capability that should greatly enhance the protection of data streams from PMUs and PDCs to the grid operator. As part of this project, EPG will integrate that new capability into a PDC and then demonstrate its ability to provide enhanced protection.

2.2.2.4 Frontier Associates

Frontier Associates, a CCET member, has been providing data collection, analysis, and various assessments for key utility players in Texas, including ERCOT. For this project, they are responsible for the overall data collection and analysis planning, the methodology for the pricing experiments, and analysis of electrical data collected by CenterPoint Energy on residential distribution service lines in Houston. They developed the metrics and benefits reporting plan, and worked closely with DOE to define the data metrics, formats, etc. for those programs. They are helping to design the consumer pricing experiments, and will be providing the majority of data analysis, economic value assessments, and other inputs to the TPRs. They also provide advice and guidance to other project members performing data collection and analysis.

2.2.2.5 Group NIRE

Group NIRE, a CCET member, is a clean energy development company that provides project development, finance and consulting services. It is currently developing wind projects and working with several renewable energy manufacturers of original equipment and component to commercialize new products and technologies. Group NIRE is affiliated with the National Institute for Renewable Energy and with the National Wind Resource Center.

Although Group NIRE does receive some minimal DOE funding, it is also a major cost share contributor for this project, and is providing facilities for field testing and validation of various wind turbines at the RTC in Lubbock, Texas. For this project, Group NIRE is facilitating access to the wind turbines and managing the installation of a utility-grade battery energy storage system that will be tested in various functional roles.

2.2.2.6 Pecan Street

Headquartered at The University of Texas at Austin, Pecan Street Inc. is a nonprofit research and development organization focused on developing and testing advanced technology, business models, and customer behavior surrounding advanced energy management systems. Pecan Street is focused on advancing understanding and solutions addressing utility system reliability, climate change, renewable energy integration, and customer needs and preferences. Its specific research expertise consists of creating, managing, protecting, analyzing, and responsibly sharing the highest quality original research data on how customers use electricity, natural gas, and water in their homes and businesses. For the CCET project, Pecan Street is receiving DOE funds and is also a significant cost share partner. It will be involved in facilitating new electricity pricing models, electric vehicle research, and sub-circuit level energy use data collection among select volunteer participants located in Austin's Mueller community.

2.2.2.7 Southwest Research Institute

Southwest Research Institute (SwRI), a CCET member, is a large independent, nonprofit organization located in San Antonio, Texas, that provides applied research and development for both government and commercial clients. It has 11 technical divisions that offer a wide range of technical expertise and services in such areas as chemistry, space science, nondestructive evaluation, automation, engine design, mechanical engineering, electronics, and automation and data systems.

For the CCET project, SwRI is providing project management office (PMO) support including the preparation of required management and technical reports for CCET and DOE. SwRI is also leading the effort to provide fast response regulation service (FRRS) to ERCOT using fleet EVs.

2.2.2.8 Texas Tech University

Texas Tech University (TTU) is a teaching and research institution located in Lubbock, Texas. It is home to the Wind and Science Engineering (WiSE) Research Center, which is focused on how to efficiently harvest wind energy and mitigate wind-related damage. It is the only university in the nation that offers degree programs, from Bachelor to Ph.D., in wind energy related studies.

For the CCET project, TTU is providing its exceptional knowledge, expertise and analytic skills to facilitate the integration of wind turbines located at the Reese Technology Center (RTC) with a utility-scale battery system along with subsequent analysis of battery functionality to support dynamic, variable energy sources like wind. TTU is also working with several local electric cooperatives to install a synchrophasor network in the Texas Panhandle portion of the SPP. This network will serve to augment the data from the ERCOT network for the purposes of theory and model development and validation. The network will additionally be utilized as a test-bed for the cybersecurity fabric demonstration, where TTU cybersecurity researchers can provide an independent analysis of the system.

2.2.3 Cost Share Partners

2.2.3.1 American Electric Power/Electric Transmission Texas

American Electric Power (AEP) is a Board member of CCET and has been actively involved in the deployment of synchrophasor components. AEP is committing resources to this effort and is working collaboratively with ERCOT, Oncor, Sharyland Utilities, and Electric Power Group to accomplish the objectives of the synchrophasor component. AEP has installed PMUs, provides phasor data to ERCOT, and has determined the best utilization of phasor data for management of AEP stations and the ERCOT grid.

Electric Transmission Texas (ETT) is a joint venture between subsidiaries of American Electric Power and MidAmerican Energy Holdings Company. ETT owns and operates transmission facilities within the ERCOT region of Texas. For this project, ETT is installing a number of PMUs and providing the phasor data to ERCOT.

2.2.3.2 CenterPoint Energy

CenterPoint Energy is the TDSP for the Houston area, and a Board member of CCET. CenterPoint is completing its smart grid investment grant that provided for the deployment of smart meters and a distribution automation system in their service territory. As part of this project, they have installed a number of circuit monitoring devices with the intent of comparing load shape curves among two similar neighborhoods, one with high-efficiency homes and solar, and another without solar. They are collecting data from those devices, and will provide input to the TPRs on power usage, load profiles, and voltage levels for both communities. By comparing similarly sized homes at the two neighboring subdivisions, analysis will show the extent to which there is a sustained decrease in power usage and reduction in peak demand. CenterPoint will also compare the voltage levels at the two locations to determine if the levels are within normal range and if they are at a steady level or if they fluctuate.

2.2.3.3 Electric Reliability Council of Texas

The Electric Reliability Council of Texas (ERCOT) manages the flow of electric power to 23 million Texas customers - representing 85 percent of the state's electric load. As the independent system operator for the region, ERCOT schedules power on an electric grid that connects 40,500 miles of transmission lines and more than 550 generation units. ERCOT also performs financial settlement for the competitive wholesale bulk-power market and administers retail switching for 6.7 million premises in competitive choice areas. ERCOT is a membership-based 501(c) (4) nonprofit corporation, governed by a board of directors and subject to oversight by the Public Utility Commission of Texas and the Texas Legislature. ERCOT's members include consumers, cooperatives, generators, power marketers, retail electric providers, investor-owned electric utilities (transmission and distribution providers), and municipal-owned electric utilities.

The ERCOT serves as an advisor on the CCET Board of Directors, and is providing synchrophasor analysis and event reporting for this CCET project. The staff produces a daily PMU performance report that is distributed to members of ERCOT, and the CCET synchrophasor team. They also are introducing the capabilities of synchrophasor technology to organized ERCOT stakeholder committees that are important to the implementation of the technology for active grid management.

2.2.3.4 Oncor

Oncor, a CCET Board member, is a large transmission and distribution utility and also a key transmission avenue for wind energy from West Texas to other parts of the ERCOT grid for consumers. Oncor has been actively engaged in ongoing efforts to establish a phasor network within the ERCOT grid, providing PMU installations and communications for streaming data to ERCOT. Oncor has also supported the project’s SMT planning efforts by conducting testing of various end use components.

2.2.3.5 Sharyland Utilities

Sharyland Utilities, a CCET member, is involved in the synchrophasor component of this project. Sharyland is implementing PMUs at three locations, providing a phasor data stream to ERCOT, and determining the best use of phasor data for station management and the ERCOT grid.

2.2.3.6 TXU Energy

In 2002, the deregulated electricity market opened in Texas. At that time, TXU Energy began offering service as a certificated retail electric provider. One of their hallmark products is an intelligent thermostat and accompanying gateway that has been installed in thousands of consumer homes across Texas, and provides consumers with broadband access to the thermostats. For the CCET project, TXU Energy is undertaking a demand response program that involves sending load control signals through the Smart Meter Texas portal to the home thermostats and gateways. These devices will now be provisioned to the consumer smart meters so that they receive the signals via the AMS networks as well as via the residential broadband networks. TXU Energy is a Board member of CCET.

2.2.4 Other Partners Providing Technical Assistance or Oversight

2.2.4.1 Frito Lay

Frito Lay has a distribution facility with 11 fleet EVs that make deliveries during the nighttime and morning hours up until noon, and are therefore idle during the remainder of the day. For the FRRS portion of the project, Frito-Lay is providing the EV fleet and charging infrastructure to support this demonstration.

2.2.4.2 Golden Spread Electric Cooperative

The Golden Spread Electric Cooperative (GSEC) is a consumer-owned public utility that provides electric service for its rural distribution cooperative members. It serves consumers located in the Oklahoma Panhandle and an area covering 24 percent of Texas land area including the Panhandle, South Plains, and Edwards Plateau Regions. It provides the power and service for the South Plains Electric Cooperative which is involved in this project. For the CCET project, GSEC is deploying a number of PMUs to provide comparative data on their area of Texas with respect to wind events.

2.2.4.3 South Plains Electric Cooperative

The South Plains Electric Cooperative (SPEC) is a local, consumer-owned electric utility headquartered in Lubbock, Texas and serving the South Plains of West Texas. For this project, SPEC owns and operates the 1MW/1MWh battery energy storage system purchased by the project and located at the RTC.

2.2.5 CCET Advisory Boards

2.2.5.1 CCET Board of Directors

The CCET Board of Directors provides oversight of the project and assistance as needed. The Principal Investigator for the project is also the President and Chief Operating Officer of CCET and reports to the Board.

2.2.5.2 CCET PM Board

For this project, CCET has created a Project Management (PM) Board from member CCET companies with specialized technical expertise in the project focus areas. The members of this Board provide unbiased, objective evaluations and assessments of all technical aspects of the project. This Board meets monthly with the Principal Investigator and his team to review the technical project status, and provide advice and assistance on the direction of the project. Additionally, as the need arises, this Board is convened to address specific technical issues or risks and provide early resolutions.

2.3 Project Overview

Texas currently has the largest wind generation capability in the United States. With a growing electric load, the region served by the ERCOT grid reached a peak load of 68,305 MW in 2011. At the end of 2012, wind generation capacity of 10,407 MW represented 13% of overall generation capacity, and wind had supplied 9.2% of total energy to the ERCOT grid. With the completion of new transmission lines into West Texas and the Panhandle area of Texas, the capacity of wind generation can grow to 18,500 MW, and a significant number of interconnection applications are on file with ERCOT for wind farms that would take advantage of this new transmission capability. Further, wind farms also are being added in the coastal areas of South Texas, presenting somewhat different power profiles to system operators than the wind from West Texas. All wind farms are distant from the main load centers, and present grid management challenges for ERCOT's system operators in accommodating both grid reliability and generation dispatch related to wind variability.

The vulnerability to the Texas electric grid posed by additional growth in wind generation underscores the need to establish new response mechanisms to wind variability. This project represents a multi-faceted synergistic approach to managing fluctuations in wind power in the large ERCOT transmission grid through better system monitoring capabilities, enhanced operator visualization, and improved load management.

2.3.1 Project Location

This project is primarily being performed in the ERCOT region, although the utility-scale battery and some additional synchrophasor efforts are being performed in the Northwest area of Texas that is actually in the Southwest Power Pool (SPP) region. These regions are shown in the figure below.

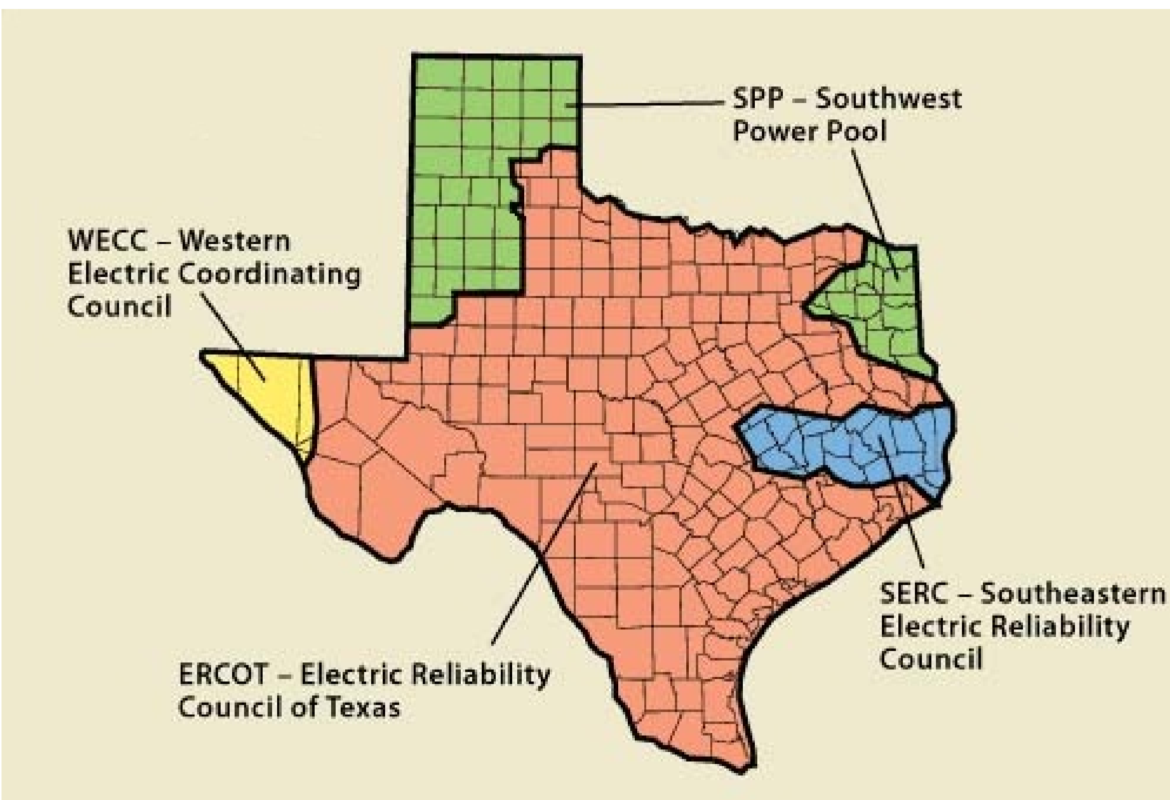


Figure 1. ERCOT and SPP Regions of Texas

Texas is unique among other regions with its high penetration of remote wind generation, one interconnection and one Independent System Operator (ISO), ERCOT. Texas includes a deregulated energy market for the large investor-owned segment, with TDSPs providing regulated wires and meter services to customers, and competitive REPs servicing and billing these customers. Texas not only leads the nation in wind generation plans, but also in the implementation of advanced metering systems. The most recent tally for the ERCOT region as of July 2013 indicates more than 6.5 million smart meters have been deployed, and there are plans for installation of about 250,000 more smart meters in the next year. Another unique aspect of Texas is the availability of the Smart Meter Texas (SMT) Portal which hosts the 15-minute incremental meter data from those smart meters and is used for settlement purposes as well as permitting customers to view and share their current and historical electrical usage information, and provision home area network devices to their smart meter.

2.3.2 Project Objectives

This project will demonstrate that Texas, and the rest of the nation, can manage increasing levels of wind power through smart grid technologies applied at the system operator level through wide-area visualization; related operator control through DR as a resource utilizing AMS capability; wind variability control through energy storage; and application of DR, distributed generation (DG), and load curtailment at an advanced smart grid community.

2.3.2.1 Demonstrating Wide-Area Grid Monitoring and Visualization using Synchrophasors

The Synchrophasor Team was originally comprised of ERCOT, TDSPs, and Electric Power Group (EPG). This group had already recognized the need to monitor the grid variability due to wind resources and had deployed phasor measurement units (PMUs) at three locations. The project permitted this group to expand this effort, initially with a plan to increase the number of locations to 16. Internal to ERCOT, the data management, visualization, and post-event analysis software has been upgraded to a commercial readiness status. PMU data is providing new tools and insights to grid operations personnel who support the grid operators, and will eventually provide a much-needed alert capability for the grid operator.

Additionally, this team has been expanded to include Golden Spread Electric Cooperative (GSEC), which is deploying and managing other PMUs in the northern Texas panhandle area (4 to date), and Texas Tech University (TTU), which is providing technical and operational assistance and data analysis.

The overall role of this component is to stream data from the PMUs to the respective TDSPs that then furnish it to the grid operator (ERCOT), and then demonstrate the benefits of synchrophasor monitoring and analysis in effectively managing power reliability associated with variable wind power resources. This requires a collaborative effort to implement and maintain the supporting infrastructure, develop effective monitoring metrics, and identify, design, test, and deploy tools and procedures to improve overall grid operations and control based on the synchrophasor data system.

EPG brings considerable experience with synchrophasor tools and applications, and the underlying PMU data acquisition, communications and management, from its projects in the Eastern and Western

Interconnections of North America. Each of the TDSPs includes representatives with power system engineering backgrounds, knowledge of PMUs and synchrophasor technology, and specific knowledge of the ERCOT grid. ERCOT brings the unique perspective of operating the integrated smart grid across 85% of Texas. The addition of GSEC will provide measurement capabilities for adjoining areas of Texas that are part of the Southwest Power Pool (SPP), and specifically measurement and analysis of various wind turbines installed at the TTU Wind Science and Engineering (WiSE) Research Center.

2.3.2.2 Demonstrating Aspects of the Future Smart Grid Residential Community

The Future Community Team originally comprised entities in an area North of Houston, and their goal was to demonstrate the benefits of equipping a solar community with a variety of smart grid technologies, including HAN devices, home energy management (HEM) systems, residential storage systems, and plug-in electric vehicles (PEVs), and then perform various electric pricing experiments to measure consumer behavioral changes in response to variable pricing schemes. This project team was restructured in 2012, and now leverages an existing smart grid community equipped with similar technologies in Austin. However, the intent of conducting consumer pricing experiments remains the same, and this team has planned, recruited participants for, and executed the experiments, and is continuing to collect and analyze the data from ongoing pricing experiments.

Additionally, the original project envisioned a large battery system to support community assets such as a water treatment plant and potentially community PEV charging stations. This battery, which was recently installed at the RTC in Lubbock, is now being used in conjunction with adjacent wind turbines to demonstrate a variety of ways that utility-grade energy storage systems can support the integration of wind into the electric grid.

Finally, the TDSP in the Houston area installed a number of monitoring devices to assess the differences between two similar neighborhoods, one with solar and one without solar. This data continues to be collected and analyzed.

2.3.2.3 Demonstrating Demand Response by Leveraging the Smart Meter Texas Portal

The SMT Portal Team initially envisioned a planning effort to define additional functionality for enhancing the SMT Portal. As the SMT Portal has continued to be enhanced, this Team has expanded its focus to utilize the SMT Portal to support demand response (DR) initiatives. Many of these programs already exist and typically operate by sending signals through residential broadband networks to various HAN devices that then curtail the devices or adjust settings to conserve energy use during critical times; however, for a variety of reasons, the broadband approach has been limited in success. The Team is, therefore, focused on demonstrating that those DR efforts can be improved by also transmitting the DR signals through the SMT Portal and across the TDSP AMS networks to the same residential HAN devices located behind the smart meters.

2.3.3 Project Timeline

This section includes a high-level schedule of the CCET project activities being performed by the various project components. Phases I and II of this project, 1) Planning and NEPA Compliance, and 2) Design and Installation, were completed in the fourth quarter of 2012, and some of that time was spent restructuring the project. The schedule shown below is for Phase III, the final phase, which is currently ongoing and will continue until January 2015.

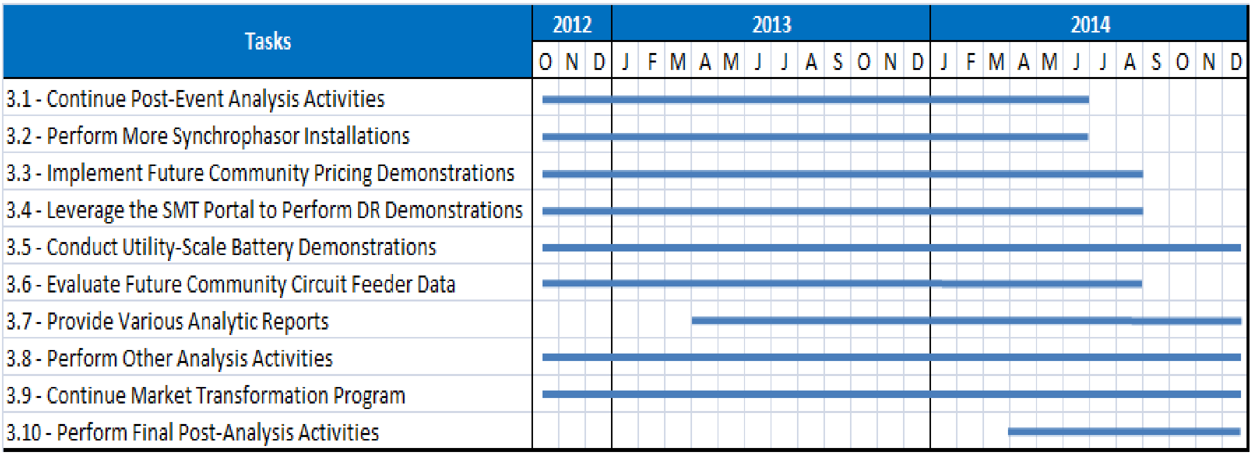


Figure 2. CCET Project Phase III Timeline

2.3.4 Key Project Milestones

The key project milestones for the CCET project are listed in the table below. The milestones serve as key verification dates for measuring progress, and they are typically characterized as deliverables to provide a verification method for accomplishing the milestone on time. During project performance, CCET reports the milestone status as part of the required Monthly Progress Report.

The table identifies the respective project phase, milestone description and planned completion date.

Table 1. Key Project Milestones

Phase	Milestone Description	Planned Completion
I	Update the PMP	05/25/2010
I	Prepare NEPA Environmental Questionnaires	02/26/2010
I	Update I&CS Plan	03/08/2010
II	Update the PMP	11/26/2010
II	Update I&CS Plan	11/26/2010
II	Develop metrics and benefits reporting plan	01/28/2011, 05/16/2011
II	Complete system design documents	09/09/2011
II	Provide quarterly build metrics	Quarterly as of 3Q11
II	Create initial market transformation plan	12/16/2011
III	Update the PMP	12/14/2012
III	Update the I&CS Plan	01/15/2013
III	Update the metrics and benefits reporting plan	01/30/2013

III	Provide quarterly build metrics	Quarterly as of 4Q12
III	Prepare interim TPRs	09/30/2013,04/30/2014
III	Prepare Final Technical Report and TPR	12/30/2014

2.3.5 Key Decision Points

Decision points are used by the CCET Team and DOE to assess the technical status, results, funding requirements, programmatic needs, and relevant risk factors of the project. The success criteria at these decision points are used to assess achievement of specific goals which are typically at the end of each phase or at appropriate points in the project execution.

The success criteria shown below are objective and stated in terms of specific, measurable and repeatable data. Some of these success criteria pertain to desirable outcomes, results and observations from the demonstration efforts, and encompass certain project aspects such as:

- Validation/confirmation/identification of scientific/engineering knowledge
- Cost savings expected over existing technologies
- Performance enhancements to existing technologies
- Reduction in health, safety and environmental risks
- Ease of installation, operation, and maintenance
- Decrease in capital, operating, and maintenance cost

Listed below are the decision points and success criteria for each one.

Decision Point 1 – Planning and NEPA Compliance

- Updated PMP is completed and submitted to DOE
- NEPA Environmental Questionnaires are completed and provided to DOE
- Interoperability & Cyber Security (I&CS) Plan is completed and provided to DOE

Go/No-Go Decision Point 1 – End of Phase I

- Previous Decision Point 1 was successfully accomplished
- Project efforts are on schedule and within budget
- Plans for Phase II are approved

Decision point 2 – Design and Installation

- System design documents are completed and provided to DOE
- Market transformation plan is completed and provided to DOE
- Quarterly build metrics are provided to DOE

Go/No-Go Decision Point 2 – End of Phase II

- Previous Decision Point 2 was successfully accomplished
- Project efforts are on schedule and within budget
- Plans for Phase III are approved

Decision Point 3 – Demonstration and Analysis

- Quarterly build metrics are provided to DOE

- Interim TPRs are provided to DOE
- Final technical report is provided to DOE

2.4 Major Demonstration Components and Smart Grid Technologies and Systems

As summarized earlier in this report, the project began with three primary components: synchrophasor, future community, and SMT portal. As a result of a restructuring effort that ultimately attracted new team partners, and while retaining the same project goals and objectives, the project expanded its scope to now include seven technical demonstrations as part of these three components.

- Synchrophasor
  - Synchrophasor monitoring, visualization and event report
  - Synchrophasor Security Fabric
- Future Community
  - Residential circuit monitoring
  - Residential time-of-use pricing trial
  - Distribution-level battery energy storage system
  - Fast response regulation service with fleet electric vehicles
- SMT Portal
  - Residential demand response

This TPR section provides the relevant details on each of these seven demonstration efforts including their smart grid technologies and systems.

2.4.1 Synchrophasor Monitoring, Visualization, and Event Reporting

This demonstration effort will enable ERCOT to better manage the transmission grid to accommodate the very large quantities of wind generation that are coming onto the grid in remote locations, and to detect and identify potential undesirable conditions on the grid and enable ERCOT operators to make adjustments to resolve the conditions. These activities will improve the overall operating reliability of the grid and provide economic value by increasing the amount of wind that can be successfully integrated with the transmission grid.

This effort will demonstrate:

- A method for establishing and maintaining a reliable synchrophasor network to provide real-time dynamic information on large-scale wind resources and their impact on the transmission grid, including assessing the optimal number and location of PMUs for effective wind integration, thereby advancing transmission operations management practices.
- The use of synchrophasor measurements to identify precursor conditions to undesirable grid performance and behavior, or to grid interruptions which, in turn, can lead to analysis, investigation, and ultimately changes in operating procedures or actions to facilitate integration of intermittent resources, hence improving grid reliability when employing large amounts of variable renewable energy sources.

- Defining the value of the demonstration in replicating and transferring lessons learned for this wind dynamics monitoring and management to other parts of the U.S, thereby promoting the use of variable renewable energy sources.

Measurements that might be collected for recalibrating the engineering models could include voltages, transmission line loadings and angle measurements, small signal stability monitoring, and damping. Measurements that might be collected for identifying precursors to grid interruptions could include low voltage margins, poor system damping, low frequency oscillations, and transmission system angles. Lessons learned that could be transferred from this project component's efforts include data adequacy, data quality, reliability and robustness for real time grid operations, wind integration, and reliability management.

The key project activities include:

- Establishing a robust synchrophasor network
- Validating and managing the synchrophasor data
- Performing analysis and assessment of grid performance based on synchrophasor data
- Reviewing and updating policies and procedures related to managing and maintaining the synchrophasor network and data storage archives.

At the inception of this project, the ERCOT network was being monitored by PMUs at three locations (one in northwest Texas, and two in southern Texas). Synchrophasor data was being captured and streamed from those devices to a phasor data concentrator (ePDC) at ERCOT. The data was then synchronized based on timestamps and displayed via the EPG Real Time Dynamics Monitoring System (RTDMS), which was running in the test environment at ERCOT. As part of this demonstration project, three TDSPs (Oncor Electric Delivery, American Electric Power, and Sharyland Utilities) committed to install PMUs at 13 additional locations, and to stream their synchrophasor data to ERCOT for monitoring and display in the RTDMS. After recognizing the true value proposition of this early warning network of devices, the TDSPs began adding PMUs at even more locations on their networks. As of the end of July 2013, there were a total of 48 PMUs, at 28 different locations, delivering synchrophasor data to the ERCOT RTDMS. These efforts also attracted the attention of other utilities across Texas who began planning for deployment of additional PMUs. By early 2014, it is anticipated that the number of PMUs will grow to nearly 60 devices at 36 locations across ERCOT. This network of PMUs currently provides monitoring of about 54% of ERCOT's regional grid footprint, and this should increase to about 75% coverage by the end of the project.

In addition to the ERCOT synchrophasor network, TTU is working with several electric cooperatives to deploy a synchrophasor network in the Texas Panhandle portion of SPP. This includes a few devices that will be situated near wind turbines at the RTC, not only providing close proximity to wind turbine measurements, but also supporting a distribution grid. Additionally, this network provides a unique value to this project given its location. As this network is electrically isolated from ERCOT, but located closely to the ERCOT transmission grids, it is likely that any events which occur in both systems can be attributed to environmental factors in the region such as high temperature or high winds. Additionally, this region is effectively a peninsula with limited connectivity to the rest of the SPP and the Eastern

Interconnect. These factors make this synchrophasor network an ideal complement to the ERCOT system, providing an independent dataset for the testing of theories and the development of new engineering models which will aid future wind energy efforts.

2.4.2 Synchrophasor Security Fabric

Another synchrophasor demonstration effort is focused on incorporating enhanced security protection mechanisms in the synchrophasor network. For this effort, Intel/McAfee is providing Security Fabric components that are architected to address the seven security tenets of the NIST-IR 7628 for synchrophasor networks. EPG is integrating these capabilities with its monitoring, visualization and reporting platforms (ePDC, RTDMS, and Security Fabric Gateway) to demonstrate secure data transport and data visualization.

One of the key concepts of the Security Fabric approach is the separation of protection and security. *Protection is a mechanism* while *security is a policy.* Therefore, making the protection-security distinction for separation of mechanism and policy principle is important. Protection is provided as a fault tolerance mechanism by hardware/firmware and kernel whereas the operating system and applications implement their security policies. In this design, security policies rely therefore on the protection mechanisms and on additional cryptography techniques.

The technical objectives of this effort include:

- Intrusion detection using protocol whitelisting
- Attack detection and remediation
- Secure encryption communications operating efficiently at all levels
- Audit logging and real-time correlation
- Upgrades for devices already operating in the field

The project will employ contemporary concepts of silicon-driven security to stop attacks that easily defeat software-only security attempts. It will provide whitelist attestation to verify the trust basis for all changes and transition control to promote changes at a safe and convenient time.

For this demonstration, EPG is designing, integrating, validating, and testing the Security Fabric enhancements to its ePDC and RTDMS applications in its laboratory environment. This testing is ongoing presently. Once it is proven successful in the laboratory, a field demonstration will be performed on the TTU synchrophasor network to demonstrate the use of the Security Fabric to secure the phasor data stream between a “virtual Transmission Owner/Utility” and a “virtual Independent System Operator”. The goal of the demonstration is to validate that the phasor data stream can be successfully secured from cyber-attack while still delivering timely phasor data to the “virtual ISO’s” wide-area monitoring and visualization system.

2.4.3 Residential Circuit Monitoring

With the proliferation of residential rooftop solar photovoltaic (PV) distributed generation comes increasing power quality impacts to distribution circuits, such as harmonic voltage and current distortion

(THD_v, THD_i), thought to originate largely from the solar PV inverters, and voltage fluctuations from varying solar output due to weather variations. By IEEE Standard 519, THD_v must be limited to 5%.

For one of the future community aspects of the project, CenterPoint Energy is undertaking an effort to examine correlations between solar PV and electric circuit power quality impacts by comparing two neighborhoods in an area north of Houston. The goal of this monitoring and analysis is to identify (and quantify if possible) the drivers, impacts, and corrective measures for power quality and/or operating voltage problems in neighborhoods with extensive solar PV generation.

One of these neighborhoods, Harmony (formerly Discovery at Spring Trails), emphasizes homes with very efficient building features, energy efficient appliances, rooftop or trestle-mounted solar, and HEM systems for monitoring electric and water use. The second neighborhood, Legends Ranch, includes similar type homes but they are built without enhanced energy efficiency features and are not equipped with solar or HEM systems, representing more typical Texas neighborhoods.

For this effort, CenterPoint Energy is monitoring three 38kV distribution lines in each of the two neighborhoods. They installed monitoring on 3 underground residential distribution (URD) circuits in the Harmony community and 3 more on URD circuits in the Legends Ranch community. This is allowing them to monitor the data related to 158 homes in Harmony and 182 homes in Legends Ranch.

There were some technical issues related to fiber access, streaming of data, and data storage, as well as data integrity, but most of these issues have been resolved and data is now being captured, stored, displayed, and analyzed. Extensive power quality data is now being collected by CenterPoint Energy in five-minute intervals, and Frontier Associates is analyzing the data to quantify the solar PV impact on power quality at distribution voltage.

2.4.4 Residential TOU Pricing Trial

In addition to using technology-based tools to address load management challenges, utilities and regulators are evaluating the viability of demand management methods that produce changes in customer behavior and consumption. Metrics that utilities frequently apply to customer behavior-based load management include:

- Predictability – does the method produce an immediate and lasting change in customer electricity usage that is sufficiently predictable for incorporation into system planning?
- Cost/Savings – what are the costs and potential savings for both customers and utilities?
- Complexity – how complex are the devices and pricing programs to implement and sustain for both customers and utilities?
- Satisfaction – how satisfied are customers with the pricing programs?
- Impacts – how are the impacts different for specific customer groups such as older or low-income customers?

To evaluate the effectiveness of behavior-based tools for managing and shifting customer consumption, this part of the future community effort involves a 20-month experiment using varied pricing programs. The experiment, running from March 2013 through October 2014, will include 62 homes in a time-of-use (TOU) pricing group and a control group consisting of another 60 homes. The purpose of this experiment is to determine the degree to which electric customers are willing to alter their pattern of electricity use in response to prices that vary with the time of day. Section 3.4.1 details the experiment design, communication, and data management considerations for the residential TOU Pricing Trial.

At present, the pricing experiment consists of two main pricing programs: 1) a reduced night-time price per kilowatt hour based on availability of wind generation during the five windiest (shoulder) months, and 2) a much more expensive price during designated peak hours on ”critical peak” days during four summer months.

The homes within the TOU pricing group and the control group have been outfitted with HEM systems. These devices attach to the home’s electrical breaker panel(s) and collect whole home and circuit (appliance) level energy use data at a one-minute interval. The energy use data is used to perform comparative analysis among the TOU and control groups based on the TOU group’s response to the pricing programs.

2.4.5 Residential Demand Response

TXU Energy launched the Brighten® iThermostat and Brighten® Conservation Program in June of 2008. The program includes a Zigbee-enabled programmable thermostat that communicates to a Zigbee-enabled gateway. The gateway is connected to the Internet via a customer-provided router to give customers a full range of remote thermostat controls and reporting, which can be accessed from most computers and smart phones. The initial 2008 pilot started as a customer self-install model with the option for professional installation. The program was converted to a 100% professional installation model in 2009 where trained technicians install the thermostat and gateway, then provision the equipment to ensure remote connectivity.

Results of the self-install model quickly revealed that less than 35% of the devices came “online” primarily because customers didn’t bother to install the thermostat and/or the gateway. By switching to a professional installation model TXU Energy was able to ensure initial connectivity; however, the online devices percentage still remains well below anticipated levels. While some of the offline devices can be attributed to hardware/software issues, the majority are assumed to be the result of other customer driven issues (disconnecting the gateway, Internet issues, etc.). As the customer base grows, so does the number of offline devices that are not able to receive a DR command.

Based on the historical online percentage, for every 10,000 thermostats participating in the Brighten® Conservation Program, TXU Energy is only able to cycle approximately 5,500 air conditioners. Assuming each air conditioning system uses an average of 1.5 kW, then the remaining 4,500 offline devices equate to approximately 6,750 kW. By creating a dual communication path to the thermostat, both through the Internet and through the smart meter via the utility AMI network, TXU Energy expects to increase the percentage of controllable devices to over 95%.

The devices for this effort include:

- Gateway configured as a router. Early tests using a gateway configured as a coordinator (standard installation) demonstrated that this device could not pair to the residential smart meter. The current gateway configured as a router is an iDigi X2e device. The gateway is expecting to access (via Ethernet) a customer's existing Internet connection via the customer's existing cable/DSL modem.
- Programmable control thermostat (PCT). The PCT controls a home's heating and cooling system and it can be programmed to automatically change temperature at certain times of the day, generally to save energy. TXU Energy has deployed various models of PCTs in support of its iThermostat DR program, and for the CCET project, they will be leveraging Carrier PCTs.
- Smart meter. Texas has installed more than 6 million residential smart meters, and homes participating in this project are so equipped. For the initial demonstrations, this project will leverage the Landis & Gyr smart meters deployed in the Oncor Electric territory.
- Cable/DSL modem. These devices support the existing DR programs which use the Internet and provide the customers with the ability to control their PCTs and monitor various results.

The figure below illustrates the devices and the proposed architecture:

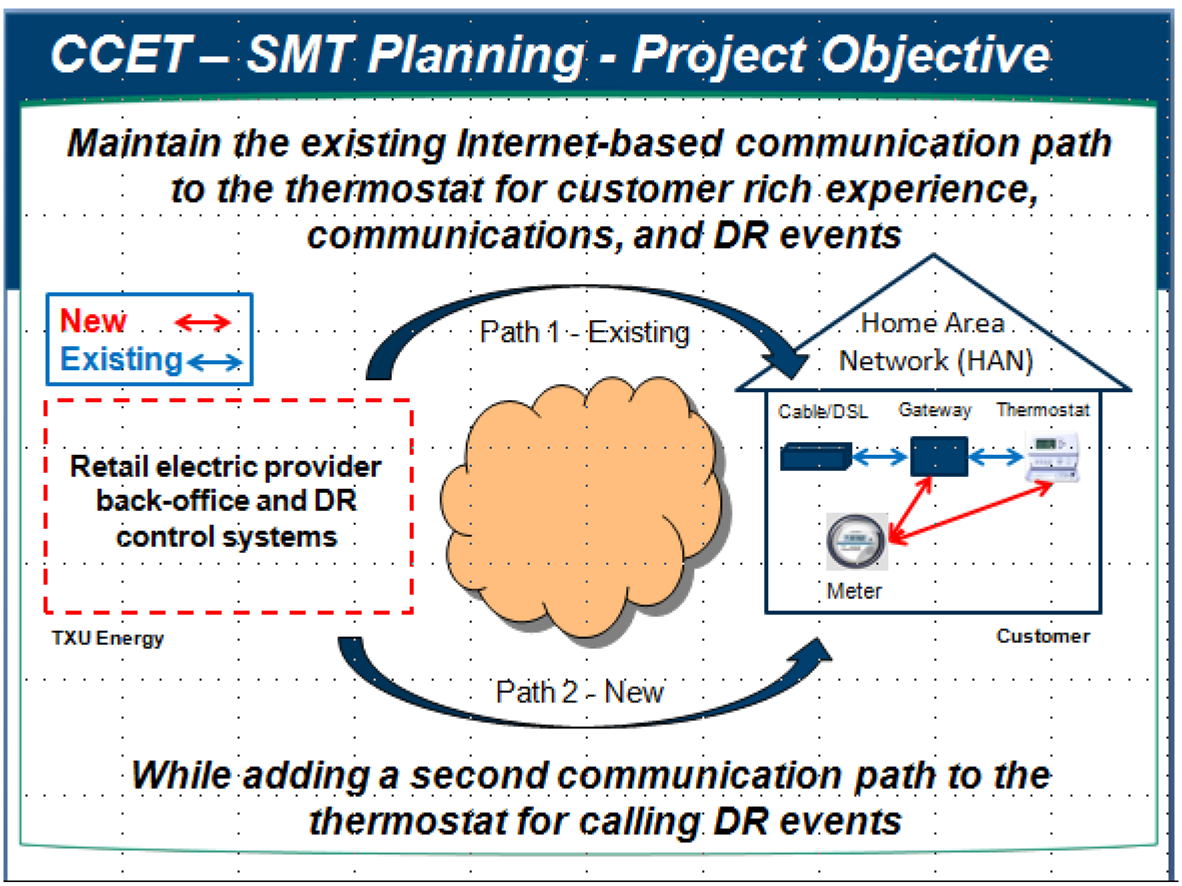


Figure 3. SMT Planning Project Objective

2.4.6 Distribution-Level Battery Energy Storage System (BESS)

As part of the future community component, a 1MW grid-connected battery energy storage system (BESS) has been installed at the RTC, and is shown below.

Figure 4. BESS Installed at the RTC

The BESS uses 18 racks with 256 Li-Ion batteries totaling 4,608 battery cells with a combined energy storage capacity of 1 MW-hr. Depicted above on the right side of the unit are the air conditioning systems.

The BESS will operate in conjunction with about 2.6 MW of wind generation at the site. This includes an Alstom ECO86 1.67 MW wind turbine, and three V27 300kW Vestas turbines that were recently deployed by Sandia National Laboratories as part of its new Scaled Wind Farm Technology (SWiFT) facility which currently produces 900kW, and will eventually be expanded to produce 3.6 MW. The site also includes a 200-meter meteorological tower to provide atmospheric measurements for wind analysis. Two images of the SWiFT facility are shown below. The first image shows a view of the three SWiFT turbines and the meteorological tower. The second image shows an aerial view of the SWiFT turbines and the close proximity of the BESS.

Figure 5. SWiFT Facility at Reese Technology Center

Figure 6. Aerial View of the BESS and the SWiFT Facility Turbines

The BESS will be utilized to supply some of the energy necessary to meet the demands of a local substation electric load, especially during peak periods. The battery and wind generation are connected such that they are only used for local capacity and do not feed back onto the transmission grid. The electrical system layout is shown below.

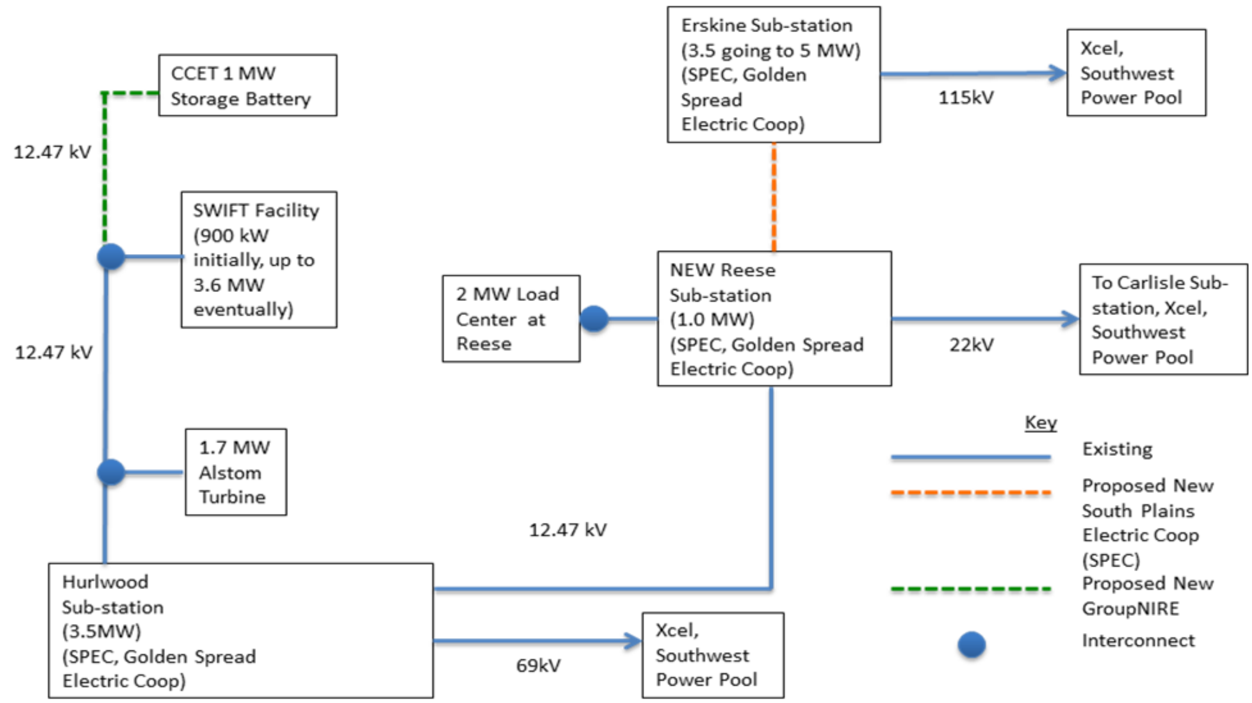


Figure 7. Reese Technology Center Electrical Layout

The BESS utilizes a series of deep-cycle Lithium Manganese Oxide (LMO) batteries developed by Samsung and designed for use in renewable energy applications. The BESS is connected via a bi-directional converter through a transformer to the main distribution grid. The energy produced by wind generation is intermittent, so the BESS serves as a backup storage unit to supply power to the grid at peak demand times which often coincide with low instantaneous wind power generation. The BESS is connected at the 12.47 kV medium voltage level, and it can be charged or discharged by the bi-directional converter as shown below to manage power flow into the grid.

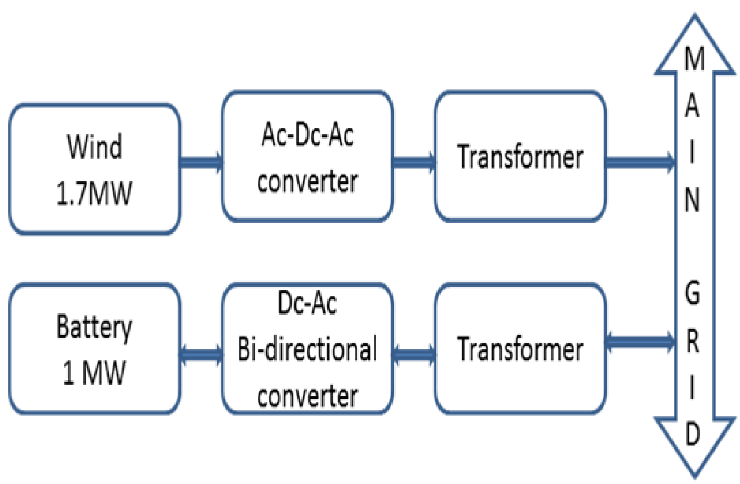


Figure 8. BESS Block Diagram

In addition to peak shaving for the local cooperative, South Plains Electric Cooperative (SPEC), the BESS is also designed to perform other operations such as mitigating intermittent fluctuations of a number of nearby wind turbines, regulating the distribution bus voltage, serving as spinning reserve, and providing frequency support during the loss of generation. These and other potential uses of the BESS will be exercised and evaluated as part of its ongoing operation.

2.4.7 Fast Response Regulation Service with Fleet Electric Vehicles

Frequency regulation is a grid ancillary service that allows electricity generators to bid services into the energy market to assist in maintaining grid frequency at 60Hz. Providers of this type of service guarantee to be able to adjust generation during a specified time period by either ramping up or ramping down production according to ERCOT instructions in order to maintain the balance of generation/load on the grid, and thus the frequency. Traditionally this was accomplished through the use of a four-second signal generated by ERCOT, with each frequency regulation generation resource then responding within their pre-established ramp rate until they met the full capacity specified in the signal. Participants in the frequency regulation market get paid whether they are called upon to adjust power or not, thus they are paid to be "on standby".

In January 2013 ERCOT began a new pilot program to provide Fast Response Regulation Services (FRRS). In FRRS, signals from ERCOT are responded to at full power within one second of signal receipt. Additionally, participants in FRRS monitor grid frequency, and can respond automatically when a deviation of .09Hz or greater is detected. ERCOT's goal is to develop regulation services that can respond faster to grid frequency deviations, thus saving both in reduced congestion (and its associated costs to the market) and in reduced frequency regulation services by having services that can respond faster to a deviation which requires less participants to be standing idle and ready to provide frequency regulation.

Batteries can serve as an ideal provider for FRRS, since batteries have a much faster response time than gas or coal-fired generators, which must ramp to the regulation goal based on the simple physics of heating or cooling boilers. A great resource for batteries that could serve this purpose without significant investment (such as a utility scale battery) is electric vehicles (EVs). In particular, supporting regulation-up services (the reducing of load on the system) can be as simple as "flipping a switch", i.e. turning the EV charger off. Regulation-down (the addition of load on the system) could be provided almost as quickly although the delivery of load to the grid would be managed by the EV battery management system (BMS) and so would be slightly slower.

The purpose of this part of the CCET project is to demonstrate an FRRS capability using an EV fleet at the Frito-Lay Distribution Facility in Fort Worth, Texas. Frito-Lay has a fleet of 11 EVs that are used primarily at night for deliveries around the Dallas/Fort Worth metroplex. These vehicles are typically charged during the day, when grid loads are highest and the need for frequency regulation is most apparent. This effort will entail the development and demonstration of an EV aggregation control system to support regulation-up services in response to either an ERCOT signal or a detected deviation of grid frequency of greater than .09Hz. FRRS services will be bid into the market in one-hour intervals during the time the vehicles are absorbing full load from the grid, thus providing an excellent source for power reduction to support FRRS.

2.5 Anticipated Project Benefits

Broadly, the expected benefits of the CCET demonstration project will be derived from a more reliable electric grid that can facilitate effective management of and responses to increased wind resources in Texas and from supporting the deployment of new products, technologies, and infrastructure to help customers make informed decisions about their energy usage. Customers will be empowered to effectively and reliably manage their peak demand, therefore resulting in reduced customer electricity costs, reduced system-wide capacity needs, reduced electrical losses, and reduced environmental impacts.

Specific smart grid benefits that are potentially supported by CCET's project and aligned with the functions identified by DOE are included below:

- Economic
  - Arbitrage revenue
  - Capacity revenue
  - Ancillary service revenue
  - Optimized generator operation
  - Deferred generation capacity investments
  - Reduced ancillary service cost
  - Reduced congestion cost
  - Deferred transmission capacity investments
  - Deferred distribution capacity investments
  - Reduced electricity losses
  - Reduced electricity cost
- Reliability
  - Reduced sustained outages
  - Reduced major outages
  - Reduced momentary outages
  - Reduced sags and swells
  - Enhanced resource planning
- Environmental
  - Reduced carbon dioxide emissions
  - Reduced SO_X, NO_X, and PM-2.5 emissions
- Energy Security
  - Increased reliance on domestic sources of energy
  - Reduced oil usage
  - Reduced wide-scale blackouts

2.6 Basic Interoperability and Cyber Security Approach

One of the key requirements for the DOE SGRDPs is to ensure that interoperability and cyber security are addressed. For this project, CCET chose a cross-cutting approach whereby interoperability and cyber security efforts were integrated into each technical component of the project. The technical approaches for performing these cross-cutting efforts are outlined in the next two sub-sections.

2.6.1 Interoperability

The CCET project members take measures to ensure that technologies in this project comply with documented standards for interoperability. During the project, the demonstrated technologies are exercised and evaluated to ensure they interoperate with both the existing electrical infrastructure as well as anticipated grid enhancements.

- **Synchrophasor network**: The teams have chosen devices from proven commercial vendors that have been in field use for years and have been validated by their vendors as satisfying interoperable standards. Although communication issues have been defined, these are related more to operating frequencies, environment and atmospherics rather than interoperability.
- **Utility-scale BESS**: For the BESS, the vendor, the local cooperative SPEC, and TTU are responsible for any necessary interoperability testing. The BESS vendor performed laboratory testing and replicated that testing when the BESS was fielded. Since the BESS is a self-contained unit, using proven and reliable technologies, no issues were anticipated and none were revealed. There is still potential data transmission, storage and data visualization issues, but none of these are expected to be related to interoperability and field testing should verify this.
- **Residential home area networks (HANs)**: The HAN devices are chosen by the partners based partly on compliance with standards and partly on their technological capabilities. One set of these HAN devices that have been selected for the pricing program has been rigorously tested as part of its own demonstration project.
- **SMT Portal and DR**: Another set of HAN devices that are being used for DR have undergone both laboratory and field testing to demonstrate interoperability with both smart meters and broadband networks. The testing did in fact reveal that some older fielded devices actually had issues with interoperability and these findings were documented and revealed to the respective REP. To continue the DR program, the REP and CCET chose to leverage newly fielded devices that were guaranteed by the vendor to be compliant with interoperability standards. These devices have also undergone both laboratory and field testing to validate their compliance.
- **Distribution-level monitoring systems**: The TDSP implementing the neighborhood circuit monitoring effort is responsible for performing all necessary interoperability testing.
- **FRRS**: The team is following established ERCOT standards implemented in similar efforts and verified through a certification process.

2.6.2 Cyber Security

The CCET project members recognize the importance of cyber security assessments as part of the project, and they are committed to ensuring adequate protection of all significant project components.

However, many of the cyber security activities identified in NIST IR 7628 are either being performed outside the project scope, or the project activities have not yet matured to the point where cyber security assessments have been conducted.

As part of this project, CCET has implemented a compliant cyber security strategy to ensure protection of several key components:

- **Synchrophasor network**: The two largest Texas TDSPs and ERCOT have implemented a network with PMUs and PDCs. This network employs secure communications and is not yet being used for grid control. When the latter occurs, the TDSPs will be responsible for expanding their current cyber security audits to include their portions of the synchrophasor network. Additionally, CCET will be demonstrating a new data protection scheme (Security Fabric) later this year that addresses the seven tenets of NIST IR 7628 and is designed specifically to monitor and deny intrusions between the virtual Transmission Owner/Utility's PDC and the virtual Independent System Operator's ePDC/RTDMS.
- **Utility-scale BESS**: The BESS was just recently installed and is still undergoing field testing to ensure that is satisfies all functional specifications, and is capable of performing all defined functions. As part of this effort, the BESS vendor will be performing cyber security assessments.
- **Residential home area networks (HANs)**: This project is leveraging HAN assets of another DOE SGDRP to evaluate the effect of various consumer pricing models. That other project is responsible for all cyber security assessments on their HAN devices and PEVs.
- **SMT Portal and DR**: This project will include DR events utilizing HAN assets that belong to a REP in Texas. These experiments will leverage the control capabilities of the SMT Portal to distribute pricing signals over TDSP networks to HAN devices located behind residential smart meters. The TDSPSs are responsible for ensuring adequate cyber security protection on their meter networks, and the HAN device vendors and the REP will ensure that the specific devices are compliant with all cyber security standards. Also, the SMT portal has undergone a series of independent cyber security assessments and all findings have been resolved.
- **Distribution-level monitoring systems**: One TDSP has deployed monitoring systems on a distribution network to provide comparative analysis of two different residential communities, one with solar and one without solar. That TDSP is responsible for ensuring adequate cyber security protection on that monitoring network.
- **FRRS**: This effort will utilize data capture and reporting mechanisms that are similar to those in use by other market participants, and all of this is verified during the certification process.

2.7 Interactions with Key Stakeholders

The stakeholders in this project include various offices within ERCOT, the CCET Board member companies, and others providing cost share. In addition, CCET and the project team members occasionally interact with DOE, NIST, and other organizations participating in standards development.

3. TECHNICAL APPROACH

This section provides a detailed description of the technical approach, the questions to be addressed, and the methods used to answer them. It is organized by technical component. The first part of each discussion, Project Plan, includes illustrations of the system configurations, defines initial steps to achieve effective deployment, identifies the steps taken to demonstrate the technology (including test procedures), and outlines the approach to conduct analysis to assess performance. The second part of each discussion, Data Collection and Benefits Analysis, defines the technical approach for conducting the benefits analysis, including the methodology and algorithms when appropriate.

3.1 Synchrophasor Monitoring, Visualization, and Event Reporting

This section covers the project plan and data collection/benefits analysis for the primary focus of the synchrophasor component – monitoring, visualization and event reporting.

3.1.1 Project Plan

3.1.1.1 Key Tasks

For the Synchrophasor component, the key tasks include:

- Establish a robust synchrophasor network
    - Design and implement a communications network capable of delivering synchrophasor data from each of the TDSPs to ERCOT in a timely and reliable manner
    - Design and implement a production grade computer environment to support the RTDMS wide-area monitoring and visualization system
    - Provide the capability for the participating TDSP operators to view the RTDMS displays remotely from their respective offices, thus providing the capability for both ERCOT and the TDSP operators to view the same screens and see the same information during grid events
    - Provide training to both ERCOT and TDSP operators in the use and interpretation of the RTDMS wide-area monitoring system
- Validate and manage the synchrophasor data
    - Evaluate the PMU data collection, reliability and robustness
        - Validate that all data sent by a TDSP is successfully and timely received by ERCOT
        - Validate that all data received by ERCOT is faithfully archived in the appropriate phasor data base
    - Evaluate the overall reliability of the PMU data communications network
    - Develop phasor data performance standards
    - Implement and maintain a phasor performance monitoring system
- Perform analysis and assessment of events

  - Perform baseline angle separation and alarm limit analyses for the ERCOT grid
  - Perform post-event analysis and forensics on grid events and disturbances
  - Develop baseline performance measures for wind generation
  - Assess the impact of wind generation on system inertial and governor frequency response
  - Assess low voltage ride through performance of wind generation
  - Detect, monitor and analyze power system oscillations and the interaction of wind generation
  - Validate monitored dynamic response of model-based predictions of generator response to disturbances (model validation)
- Develop, update, and manage policies and procedures related to managing and maintaining the synchrophasor network and the data archives
  - Phasor data repository design and implementation requirements and data archiving policies
  - Data sharing policies (inside and outside ERCOT)
  - Phasor data management policies (e.g. PMU naming convention, change management)
  - PMU location selection principles and criteria
  - PMU use cases

3.1.1.2 ERCOT Synchrophasor Network

When the CCET effort began in January 2010, the ERCOT grid contained PMUs at three locations and the plan under the DOE cooperative agreement was to increase this number to 16 locations total. Although not all directly related to the project, the ERCOT grid now a much larger number of PMUs and this number is expected to continue to increase in the future. ERCOT now recognizes the tremendous value that synchrophasors can offer its grid operators, so it is making plans to transition the data streams and internal monitoring software to production grade hardware so that operators can begin taking advantage of the alert features.

Regarding the network topology, the TDSPs have tried various communication configurations to transmit the PMU data to ERCOT. Those in well established areas of the state have had fewer issues with communications, but it also has to do with placements of the PMUs. Some TDSPs transmit their data streams from their respective PDCs to the ERCOT ePDC some TDSPs transmit the streams directly from PMUs to the ERCOT ePDC.

3.1.1.3 TTU Synchrophasor Network

The synchrophasor network being deployed by TTU in the Texas Panhandle portion of SPP began in late 2012. Currently, the system consists of four PMUs, an ePDC server located at the RTC and an RTDMS server located on the TTU campus. The first operational PMU is a National Instruments PMU located at the TTU campus. A second operational PMU is located in a Lyntegar Electric Cooperative-owned substation in Lynn County. Two additional PMUs are located at the RTC. These two PMUs are also functioning as revenue meters for two wind generation assets: the 1.67 MW Alstom wind turbine and the three wind turbines at the SWiFT facility.

An expansion of the TTU network to eight PMU locations is planned for late 2013 / early 2014. One of these units will be collocated with the BESS. Three other units located in Hale, Plains and Oldham counties will significantly expand the geographical area of the network. These three units will also each be located near significant wind or natural gas generation assets. All these units, as shown on the image below, should be installed and operational by early 2014 to provide data input to the subsequent reports.

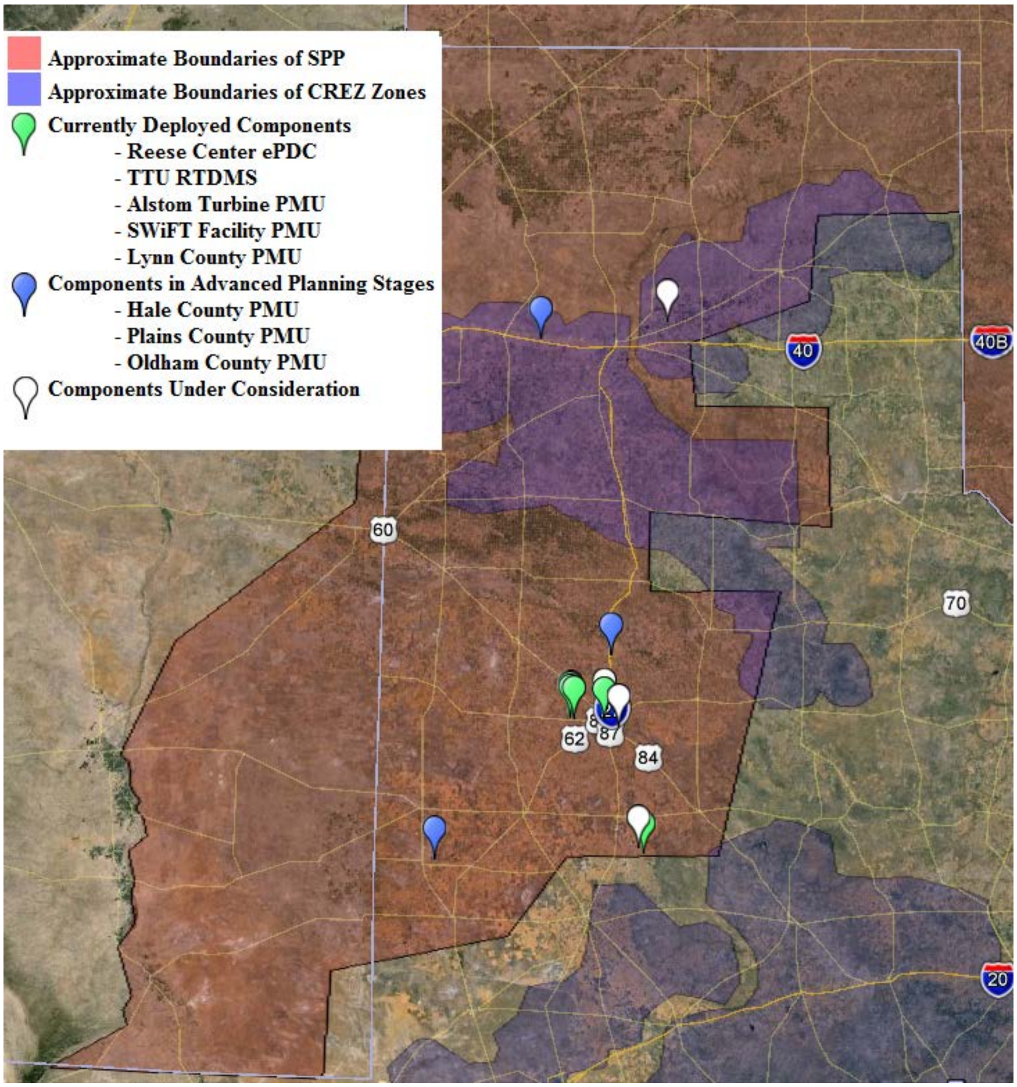


Figure 9. Current and Planned TTU PMU Locations

3.1.2 Data Collection and Benefits Analysis

To support the validation and analysis portions of the Synchrophasor component, the following data will be collected, retained, and analyzed:

- Synchrophasor data will be retained in full resolution for the entire demonstration period. This data contains at least voltage, frequency, location, and time. Most of the PMUs sample at 30 samples per second while others record at 20 samples per second. This data will be used for the baselining analysis, together with State Estimator data recorded by the ERCOT Energy Management System (EMS). This data will also be used to monitor the overall performance of the PMU network, including the communications network and the computer network infrastructure.

- Daily reports summarizing the overall performance of each of the PMUs reporting to the ERCOT ePDC are prepared and monitored. These reports help to identify poorly performing PMUs, and identify communications and computer network delays which can interfere with reliable delivery and presentation of synchrophasor data to the ERCOT grid operators.
- ERCOT grid events, such as loss of generation or load, severe voltage dips, or sustained oscillations that are detected by the RTDMS wide-area monitoring and visualization system are also retained and analyzed. The events can be played back for review and operator training, and can be analyzed using an offline tool, the phasor grid dynamics analyzer (PGDA).

Additionally, the full synchrophasor data is scanned for unusual signatures, such as low-level oscillations that are characteristic of electromechanical interactions between generation and load, as well as control-system driven oscillations. Synchrophasor data will also be used and compared to dynamic simulations to validate the performance of generator dynamic models with recorded performance.

The TTU portion of the synchrophasor network allows for positioning of PMUs at sites that have value for both wide area monitoring and for gathering data on individual generation or load assets. This ensures that the data set will be extremely useful for a wide variety of wind-related research. The TTU team will also identify events such as generation trips and sub-harmonic oscillations and correlate those events to SPP wind energy contribution data, the operation of specific wind generation assets, or events which are also noted in ERCOT for which a cause has not been established.

3.2 Synchrophasor Security Fabric

This section covers the project plan and data collection and analysis for the synchrophasor Security Fabric project.

3.2.1 Project Plan

The Security Fabric project is intended to demonstrate the capability to securely deliver synchrophasor data between two separate entities (e.g. a Transmission Owner/Utility and an Independent System Operator) while defending against cyber-attack. This demonstration will be developed in three phases.

In the first phase, several PMUs installed near Texas Tech University (on the campus, at the RTC, and in nearby utility substations), will deliver their synchrophasor data to an ePDC located at the RTC. One of the unique features of this network is that it will be directly monitoring the output of several wind generators connected to the local distribution utility network. This will enable “close-up” monitoring of any wind-related interactions with the grid. The ePDC at the RTC will represent, for the purposes of this demonstration project, a “virtual Transmission Owner/Utility” phasor data concentrator. The time-aligned synchrophasor data stream from the RTC ePDC will be delivered over the TTU communications network to an ePDC located in the Engineering Building on the TTU campus, and from there into the

RTDMS wide-area monitoring and visualization system. The equipment located in the Engineering Building will represent, for the purposes of this demonstration project, a "virtual Independent System Operator". At TTU, the synchrophasor data will be displayed in RTDMS, and stored in a phasor archiver for post-event analysis using the PGDA.

In the second phase, a test configuration consisting of a Security Fabric-enabled ePDC (SF-ePDC) together with a Security Fabric-enabled RTDMS (SF-RTDMS) will be established in the EPG laboratory in Pasadena, CA. A simulated data stream will be delivered into the SF-ePDC, and the SF-RTDMS will be configured to provide wide-area monitoring and visualization of that data. This test system will then be subjected to cyber-attack, to validate the design and performance of the Security Fabric elements, monitor the impact of the Security Fabric on the overall performance of the synchrophasor tools (SF-ePDC and SF-RTDMS), and measure the latency introduced by the Security Fabric.

In the third phase, a second instance of the ePDC, equipped with the SF-ePDC, will be installed at the RTC, and a synchrophasor data stream from the first ePDC will be delivered to the SF-ePDC. The output synchrophasor data stream from the SF-ePDC will be directed to the SF-RTDMS located in the Electrical Engineering Building on the TTU campus. Like the first instance of RTDMS, this SF-RTDMS will also provide wide-area monitoring and visualization, and the data stream will be stored in a phasor archiver. Once startup testing of this parallel configuration is completed, cyber-attack testing of the system is planned, and side-by-side performance monitoring will be performed.

Upon completion of the testing, the Security Fabric-enabled components will remain in service to continue to gather and analyze wind performance data on the TTU network.

An illustration of the basic synchrophasor network and the Security Fabric-enabled network at Texas Tech is presented below;

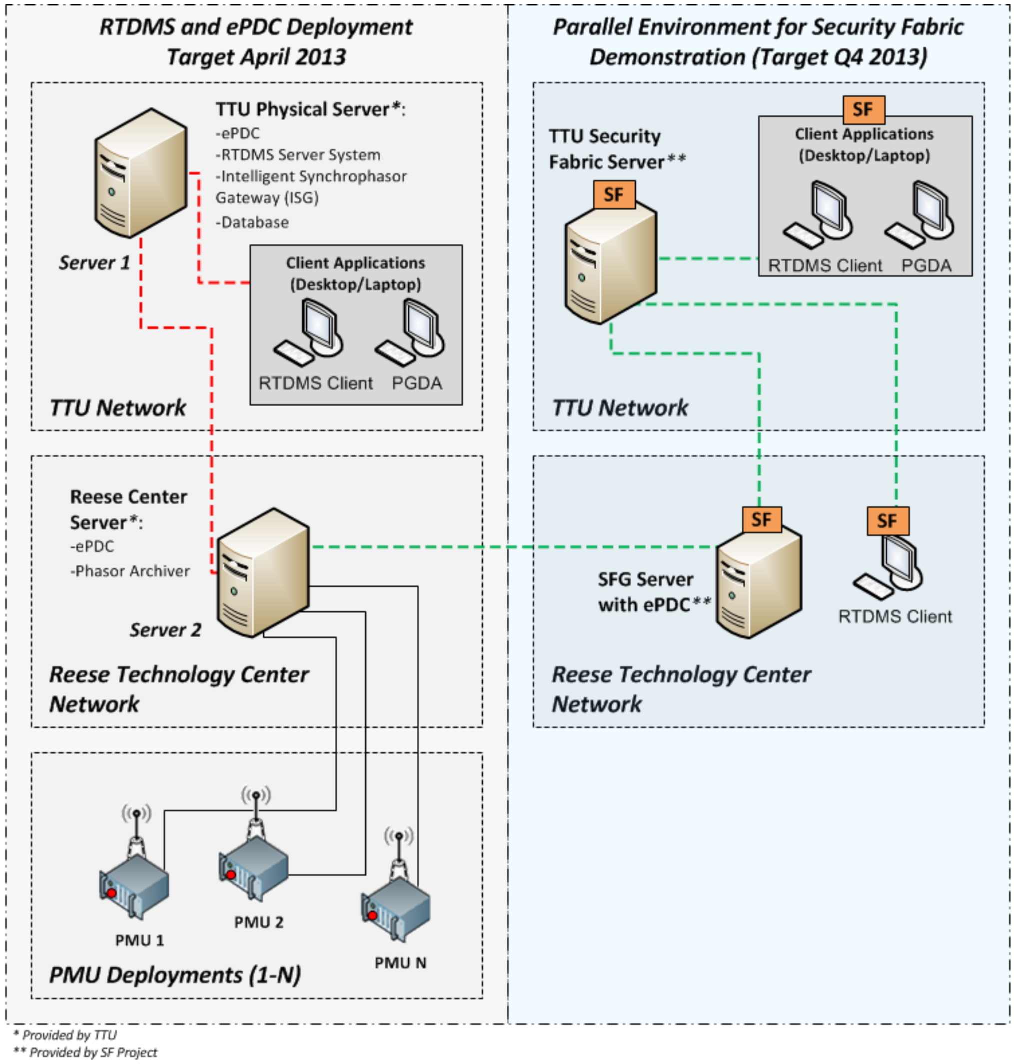


Figure 10. Basic Synchrophasor Network and the Security Fabric-enabled Network at TTU

3.2.2 Data Collection and Benefits Analysis

To support the validation and analysis portions of the Security Fabric component, the following data will be collected, retained, and analyzed:

- Synchrophasor data will be retained in full resolution for the entire demonstration period from both the phase one ePDC-RTDMS network and the phase three SF-ePDC – SF-RTDMS networks. This data will be used to monitor the overall performance of the TTU PMU network, including the communications network and the computer network infrastructure. Data from the two phases will be compared to validate that the data flowing through the SF-enabled network is unaltered by the Security Fabric components.
- Grid events, such as loss of generation or load, severe voltage dips, or sustained oscillations that are detected by the TTU RTDMS wide-area monitoring and visualization system will also be retained and analyzed.

Additionally, the full synchrophasor data will be scanned for unusual signatures, such as low-level oscillations which are characteristic of electromechanical interactions between generation and load, as well as control-system driven oscillations. Because the TTU PMU network will be monitoring a distribution network with both local thermal and wind generation, it is expected that interactions between different types of generation may be more visible in this network.

Performance metrics from both the phase one network and the SF-enabled network will be compared both during normal operation and during cyber-attack testing to identify and calibrate the impact of the Security Fabric on the overall delivery of synchrophasor data between the SF-ePDC and the SF-RTDMS components.

3.3 Residential Circuit Monitoring

This section covers the project plan and data collection and analysis for the residential circuit monitoring project.

3.3.1 Project Plan

The goal of this monitoring and analysis is to identify (and quantify if possible) the drivers, impacts, and corrective measures for power quality and/or operating voltage problems in neighborhoods with extensive solar PV generation. Implementation steps include:

- Identify potential drivers of power quality impacts in neighborhoods with extensive solar PV generation.
- Identify data needed for analysis to identify and quantify impacts.
- Identify, procure and install data collection equipment.
- Connect data collection equipment to fiber optic networks or other communications.
- Develop system for storing data and software for displaying real-time data.
- Perform data analysis (Frontier Associates) and system electrical analysis (CenterPoint Energy).
- Develop utility-side and customer-side solutions to maintain quality of service.

3.3.2 Data Collection and Benefits Analysis

For this effort, CenterPoint Energy is monitoring 158 homes in Harmony (492,000 square feet total), and 182 homes in Legends Ranch (413,000 square feet total). Data collection is to first confirm the solar panels and inverter do not affect other customers on the distribution circuit. Second, the data will confirm if the Harmony community uses less energy per square foot of home living space.

Data to be collected by CenterPoint Energy for each distribution circuit:

1. Power factor
2. Frequency
3. Voltage
4. Current
5. THD_v
6. THD_i

7. Real power
8. Apparent power
9. Reactive power
10. Phase angle

Additional data to be furnished (if available) by CenterPoint Energy to support the analysis:

1. Installed solar PV (and date installed if after 7-1-13)
2. Installed orientation of solar panels
3. Ongoing updates of circuit loadings and demographics (e.g. houses added to monitored circuits)
4. Electric vehicle ownership and charging behavior
5. Data from monitoring on the load side of the service transformers

Data obtained by Frontier Associates to aid the analysis:

1. Weather data for site (hourly or 15-minute temperature and relative humidity)
2. Hourly or 15-minute solar irradiance (direct and horizontal)

The analysis will look for correlations between harmonic distortion (5% limit) and voltage excursions (10% limit), weather, solar PV output, electric vehicle charging, and distribution service line load. Power quality impacts at Legends Ranch (no solar) and Harmony (solar) will be compared. If information exists to compare power quality performance to homes elsewhere (such as the Pecan Street pricing group), which characteristically have rooftop solar installations, comparisons will be considered.

3.4 Residential TOU Pricing Trial

This section covers the project plan and data collection and analysis for the residential TOU pricing trial.

3.4.1 Project Plan

Pecan Street's electricity pricing trial consists of an experimental rate structure design, definition of resident groups (a volunteer TOU trial group and a control group), participant communication strategy, participant incentive credit accounts, energy data collection, data management and cyber-security considerations, data visualization, and data analysis. The project's goal is to use an integrated approach using current and available technology to study the impacts that TOU pricing has on consumer behavior.

The experimental TOU trials are defined in two parts – a Critical Peak Pricing (CPP) model and a Wind Enhancement Pricing model – as detailed below.

The control group (60 homes) was defined and consists of residents received no communication regarding the TOU pricing.

The TOU trial group (62 homes) is a volunteer group that agrees to respond to CPP and wind pricing by altering behavior to achieve energy savings that will build value in their incentive credit accounts, which they may ultimately claim as a cash payout at the end of the 20-month trial. They are not at risk of paying higher bills if they do not alter their behavior.

Residents and their homes in both groups are of similar makeup, both having energy efficient homes, solar PV generation, and EVs. Both groups have their end-use appliance circuits sub-metered in similar fashion as described below.

Experimental Rate Structure Design and Incentive Account Tracking

Over the course of this 20-month experiment (March 2013 – October 2014), the TOU group and control group will continue to receive and pay their usual Austin Energy electric bills which will reflect the normal Austin Energy electric rates.

A monetary incentive is used to entice TOU group participants to either shift their energy load to "wind enhancement times" or to reduce energy consumption during critical peak times. The latter are called a day ahead based on forecasted weather conditions and ERCOT peak loads. The two TOU pricing structures do not coincide or overlap at any time.

The project established a credit account with an initial balance of $200 for each participant in the TOU group. The credit account balance trend reflects a participant's degree of response to price signals. A participant is able to view their credit account through an online web portal as shown below.

PERIOD	USAGE	PRICING TRIAL BILL	AUSTIN ENERGY BILL	ADJUSTMENT CREDIT
Mar 1, 2013 - Mar 31, 2013	674 kWh	$59	**$62**	$3
Apr 1, 2013 - Apr 30, 2013	703 kWh	$58	**$67**	$9
May 1, 2013 - May 31, 2013	658 kWh	$54	**$58**	$3
Jun 1, 2013 - Jun 30, 2013	1050 kWh	$128	**$138**	$10
Jul 1, 2013 - Jul 31, 2013	1088 kWh	$114	**$128**	$14
Total	4173 kWh	$413	$453	$239.0

Figure 11. Web Portal's Display of Representative Pricing Trial Information for One TOU Participant

The value of the credit in the account is adjusted every month at the time the participant receives his or her electric bill. The adjustment will reflect the difference between what the participant actually pays Austin Energy and what they would have paid if the pricing trial rate were actually in effect. Account balances are a primary metric for this experiment.

The pricing trial electric rates are structured as follows and designed to be revenue-neutral to the utility:

1. A Critical Peak Price (CPP) applies only during certain designated hours (4 p.m. – 7 p.m.), is called a day ahead by Frontier Associates in the summer months (June, July, August, and September), and is designed to entice the customer to minimize load during forecast grid peaks.

2. A very low night-time "wind enhancement" price, which applies during the five windiest months (March, April, May, November, and December) and is designed to entice the customer to shift load into the 10 p.m. – 6 a.m. time frame where it can be served by wind generation.

During the remaining three months of January, February and October, the pricing trial rate will be the same as the current Austin Energy rate.

Critical Peak Pricing Trial

A CPP price of $0.64 per kilowatt (kWh) is only applied to the TOU group participant's energy consumption during the weekday (Monday – Friday) afternoon hours of 4 p.m. – 7 p.m. on "critical peak" days. Up to 15 critical peak days will be called during the four summer months. The day-ahead critical peak call by Frontier Associates simulates a call by ERCOT anticipating extremely high next-day system load.

The process used by Frontier Associates in determining and calling the critical peak days is charted below.

CPP Decision Flow Diagram:

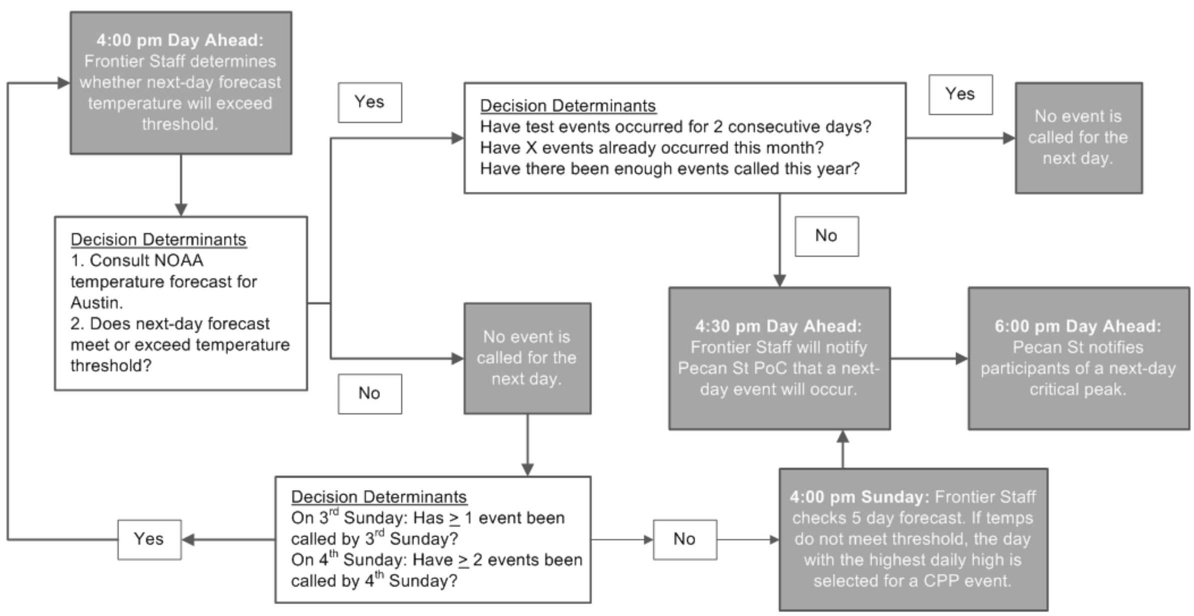


Figure 12. Flowchart for Calling Next-Day Peak Events

By notification of a next day peak event, participants are enticed to take appropriate measures to shift energy use to outside the peak time frame the following day.

The original goal is to call a maximum number of monthly critical peak events each month according to the table below. It defines each month along with the minimum threshold temperature and the maximum number of events to be called in that month.

Table 2. Goals and Thresholds for Calling Peak Days

Month	Threshold Temperature (°F)	Maximum Monthly Peak Events
June	102	3
July	103	4
August	103	5
September	102	3

Wind Enhancement Pricing Trial

For the wind enhancement pricing trial, the night-time electric rate for the TOU group during the five windiest months (March, April, May, November, and December) is lowered to $0.0265 per kWh. This price applies to energy consumption in the hours from 10 p.m. – 6 a.m. on all days during those months. There is an offsetting surcharge of approximately $0.02 per kWh on the participant's energy consumption during all other hours of those five months.

Calculation of Pricing Trial Electric Bills

The pricing trial electric rates consist of these components:

1. Customer charge (the same as Austin Energy's charge) – a flat rate of $10.
2. Baseline (existing Austin Energy) rates – applied only to consumption during non-wind hours and non-critical peak hours.
3. Surcharge rates – applied to total monthly consumption during non-wind hours.
4. Discount rates – applied to total monthly consumption during non-critical peak hours.

The pricing trial rate formulas:

1. Wind Enhancement Period:
   Customer charge + [Baseline rates x (consumption between 6 a.m. – 10 p.m.)] + [Wind Price x (consumption between 10 p.m. - 6 a.m.)] + [Surcharge Rate x (consumption between 6 a.m. – 10 p.m.)]
2. Critical Peak Period:
   Customer Charge + [Baseline rates x (consumption during all hours other than during called critical peak days, 4 p.m.-7 p.m.)] + [Critical Peak Price x (consumption during 4 p.m.-7 p.m. on called critical peak days)] + [Discounted rate x (consumption during all hours other than critical peak hours on called critical peak days)]

If the TOU participant's pricing trial bill is lower than their actual Austin Energy bill, the difference is credited in their credit account. If the pricing trial bill is higher, the difference is deducted from their credit account. At the end of the pricing trial (after October 2014), payments will be issued to each participant equal to the amount of the final credit in their account, up to a maximum of $700 per customer. If there is a negative credit in a participant's account, the participant will not owe anything.

Participant Communication Strategy

Recruitment of TOU participants began February 2013 with an outreach program designed by Pecan Street that targeted residents living at the Mueller community in Austin. Owners of single-family residential homes in Mueller were contacted via email by Pecan Street and asked for their participation in the TOU pricing trial. Most residents contacted were part of an earlier Energy Internet Demonstration (EID) program funded by another DOE cooperative agreement. EID participants enrolled into the pricing trial had the requisite HEM systems and legal participation agreements in place. The primary goal of recruiting from the EID pool for the pricing trial was to get a representative sample of participants that had an electric vehicle. The control group participants were also selected from the EID participant pool with an emphasis on those that had an electrical vehicle.

Before the official start of the experiment (March 2013), the TOU group received email communications outlining the experiment design and ways they can shift or reduce their energy consumption. For instance, shifting loads of laundry to after 10 p.m. during the wind enhancement period or reducing air conditioner operations during critical peak hours during the summer months. Pecan Street held one in-person workshop for the TOU group to further detail the trial's design, goal, and research benefits. Each of the TOU participants were given secure access to an online web portal to check the monthly status of their energy usage in kilowatt hours (kWh), pricing trial bill, Austin Energy bill, and any adjustment credit earned.

On the web portal, in addition to pricing trial information, the TOU participants have access to the following information:

- Monthly whole home energy use in kilowatt hours (kWh)
- Monthly energy cost in U.S. dollars per appliance
- Energy generation cost in U.S. dollars if the participant has solar panels
- Real-time energy consumption in kWh
- Monthly energy cost comparison to other participants within the same zip code
- Monthly energy usage trends

During the summer months, TOU participants also receive cell-phone Short Message Service (SMS or "text") messages and email communications the day before a CPP day. Pecan Street uses a mass-messaging service to send out text and email notifications by 6:00 p.m. to TOU participants the day before the CPP day. The text message content shown below is strictly a factual reminder about the upcoming CPP day and their pricing rate.

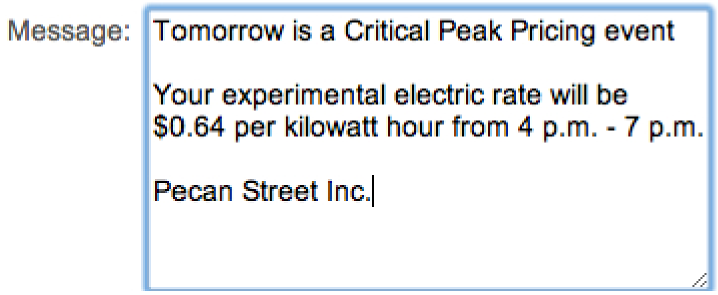


Figure 13. TOU Group Text Message

3.4.2 Data Collection and Benefits Analysis

This section provides details on the data collection and benefits analysis.

Energy Data Collection

The HEM system selected for this study is a commercially available, off-the-shelf product extensively tested against other competing systems installed in 100 single-family homes during a one-year test bed trial in 2011. The results of the tests found the selected HEM systems to have superior reliability, durability, accuracy and customer support. Pecan Street's licensed master electricians installed a majority of the HEM systems under the EID program and are currently maintaining the HEM devices for the EID and TOU pricing trial participants. Participating homes can have one or two HEM systems installed, based on their unique circuit configuration.

Each HEM system is comprised of:

- HEM device (energy data monitor)
- HomePlug adapter (power line communication device) allowing communications from the HEM system to the participant's internet gateway
- Up to twelve (12) 50-amp current transformers (CTs) for measuring consumption on individual circuits within the home

The HEM system directly measures electricity use for the whole home and a number of circuits at one-minute intervals. Individual circuits monitored include:

- Refrigerator
- Furnace and air handler
- Dishwasher
- Clothes drier
- Clothes washer
- Dishwasher
- Oven and cook-top range
- Microwave
- Electric vehicle level II charger
- Lighting - whole home

- Lighting - individual room
- Plug loads
- Solar generation (if installed)

The HEM system allows Pecan Street to collect high-resolution (one-minute interval) disaggregated data at a resolution that can detect granular changes in the energy use of individual appliances. The HEM system's ability to detect small, near real-time changes is critical in determining behavioral changes in response to pricing signals. The data from the HEM system is streamed through the participant's Internet gateway to Pecan Street's server cluster located at the Pike Powers Laboratory where it is stored in the secure database environment.

Data Management and Cyber-Security Considerations

Data from Pecan Street's research projects, including the TOU pricing trial, constitutes a very large database of original consumer energy use data that can be shared with appropriate parties.

As of August 2013, the TOU database contains over 80 million records and is currently growing at a rate of 3 million records per day. Given the size and diversity of data, Pecan Street established a highly available, scalable database architecture that adheres to the organization's DOE-approved cyber-security plan protecting the identity of all participants while organizing the data so that it is accessible to appropriate parties. A data warehousing strategy was employed that integrates the energy use, participant and survey data sets into common schema or systems, with emphasis on commonalities in the data such as participant, measurement type, and time-stamp.

Due to the intimate and confidential nature of some data being collected, data security is a critical aspect of the data integration and storage. As such, the main security principle applied is protection of the project participants' identities and privacy pursuant to the Internal Review Board (IRB) procedures to protect confidentiality of all participants. The database adheres to Pecan Street's Cyber-Security Plan approved by the DOE, which protects the identity of all research participants and organizes the data so that it is accessible to approved researchers. The plan requires that any personally identifiable information must be kept in a separate database from all other data on the home and linked by a master database accessible only to Pecan Street staff via a 2-factor authentication process.

Data Visualization

Pecan Street is working to create a series of anonymized data visualizations rendered through an online web portal to communicate the energy data collected from pricing trial and control group participants. These visualizations will show energy load profiles for the TOU and control groups and a geospatial "heat map" rendering of energy consumption that is scaled and generalized at the community level in order to protect against identification of individual home locations.

Data Analysis

Frontier Associates will perform demographic and statistical analysis (described below) on the interval consumption data collected during the pricing trial. The goal is to analyze the impacts on participant energy usage and report results at the end of each 'season' (wind enhancement months, summer critical peak period, fall/winter 'non-event' months, etc.) for the duration of the project. The analysis is intended to provide insights into TOU energy use patterns and the effects TOU rates and pricing signals have on energy consumption, both at the whole home and sub-metered end-use appliance level.

Frontier Associates has performed the following preliminary statistical analyses based on the dataset provided by Pecan Street:

(1) Preliminary descriptive statistical analysis on the effect of wind enhancement trial pricing: Analyzed hourly load patterns to compare control group and TOU group during trial months and non-trial months to detect a shift in consumption patterns attributable to the pricing. "Consumption patterns" examined include not only overall hourly usage, but also hourly energy consumption of sub-metered circuits serving electric car chargers, kitchen appliances and laundry.

(2) Preliminary peak kW savings calculation from six (thus far) CPP events: For each CPP event, calculated estimated kW savings based on the following equation:
kW savings = Baseline Average Peak kW– CPP Period Average Peak kW
Where:
- Baseline Average Peak kW = average kW demand recorded 4:00 p.m. - 7:00 p.m. during the four non-peak weekdays immediately preceding the called peak day
- CPP Period Average Peak kW = average kW demand recorded 4:00 p.m. - 7:00 p.m. on the called peak day

3.5 Residential Demand Response

This section covers the project plan and data collection and analysis for the residential demand response project.

3.5.1 Project Plan

The SMT Planning project has been broken down into two phases. The first phase focused on defining the appropriate architecture and the best equipment configuration to support the objectives, discovering any issues that may need to be resolved, and generally proving out the concept. The second phase will then be focused on building and deploying the technologies to demonstrate the dual-path DR capability. The objectives for these two phases are shown in the figure below.

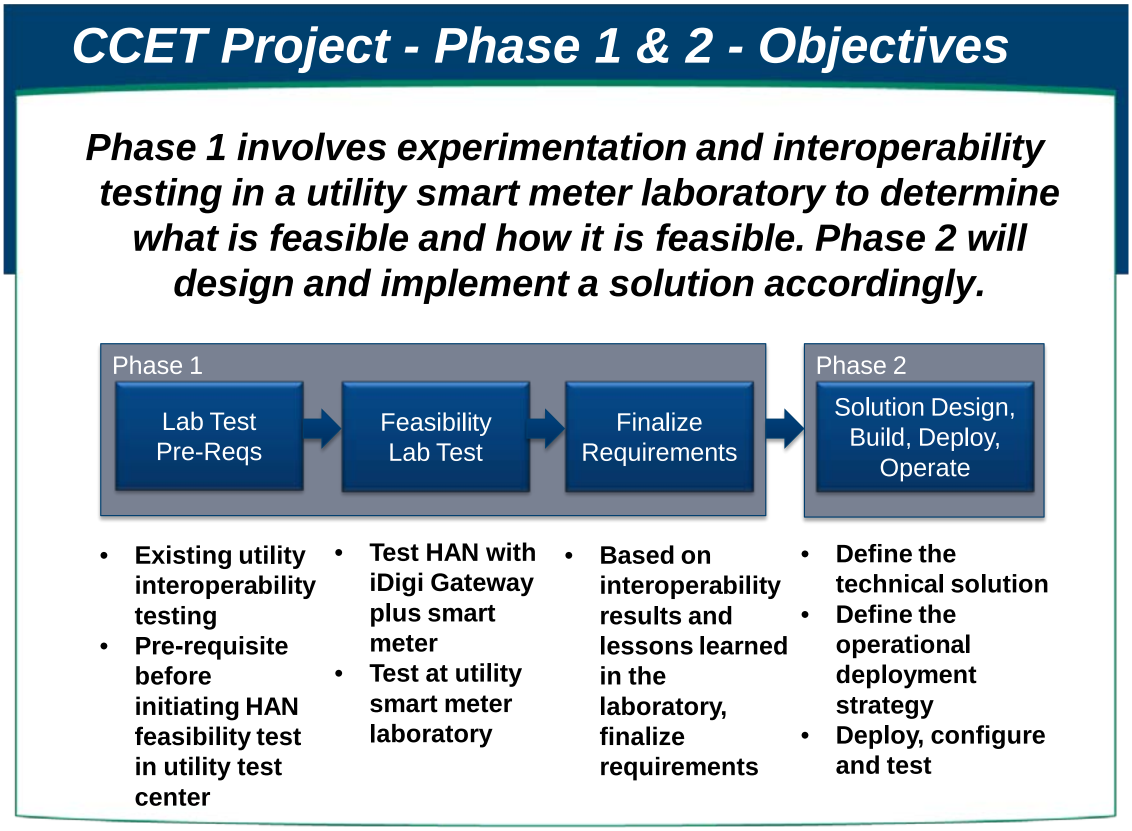


Figure 14. CCET Objectives for Phases 1 and 2

HAN Test Laboratory

The objective of this test is to determine which configuration will support communication via both paths, the Internet and the SMT/AMI network. The scope of the testing involves the following:

- SMT commands initiated from the Landis & Gyr test tool
- Vendor (Comverge) commands initiated from their back-office system at the REP via Internet
- Provision/De-provision the meter with the gateway (using SMT)
- Test interoperability between the meter and the gateway
- Test interoperability from the meter to the PCT via the gateway
- Ability to maintain connection with the vendor back-office system and the meter
- Test and discover what happens at the PCT when it receives the vendor proprietary DR command (via the Internet) as well as the SEP DR command (via the SMT)

Production Test Meter Laboratory

This second level of testing has three objectives:

- Determine if it is possible for a customer to switch out a gateway or will it require a truck roll with a trained installer
- Become familiar (hands on) with the use of the SMT HAN application programming interfaces (APIs)

- Verify work around for any identified vendor provisioning issue

The scope of this testing includes the following:

- SMT commands initiated from SMT user interface SOAP tool into SMT test environment connected to the utility production test meter laboratory
- Vendor commands initiated from back-office system via the Internet
- Tested use cases of leveraging both communication paths to support the existing DR program (Internet) and allow use of SMT communication path for DR commands
- Test work-arounds to vendor issue
- Document the combined installation/commissioning process and evaluate the potential for a customer self install

In-Home Test

The objectives of the in-home test include:

- Determine if it is reasonable to expect a customer to self-install by switching out the gateway, provisioning the devices (if necessary), and contacting the vendor for testing
- Work around any vendor DR issue
- Work around any vendor global setting configurations from previous testing

The scope and results will be documented and reported in the next iteration of this TPR.

3.5.2 Data Collection and Benefits Analysis

TXU Energy already performs DR events and will be analyzing and reporting on that data in the next TPR. Once the team validates a workable solution for the dual-path approach, the DR events will be called using both communication paths, and the results will be documented, compared and analyzed. In anticipation of Phase 2, and deployment/configuration of an appropriate dual-path solution, the team has defined its approach to reporting/validation as well as the methodology for data capture and analysis. These results are shown below.

Reporting/Validation

In order to measure and validate the success of a dual communication path, as well as for future DR reporting, TXU Energy will develop a reporting process utilizing the 15-minute interval data for customers participating in the Brighten® Conservation Program, and have a Brighten® iThermostat installed in their homes. Devices controlled via the standard communication path, the gateway, can be distinguished from devices controlled via the smart meter. Customer interval data captured before, during and after each event should provide an accurate measure of load shed during an event and allow TXU Energy to validate the success of both communication paths. The data can also be used for predicting future load shed potential.

Methodology

The following process will be developed with support from TXU Energy and other parties:

1) Identify all customers enrolled in the Brighten Conservation Program at the time of an event

   a. Data source will be the Comverge Account Status Report that is generated daily and posted to a secure file transfer protocol (SFTP) site. This report includes the identification of all iThermostat customers, number of thermostats installed, as well as the current status of their iThermostat account
   b. This will be the total population of potential DR participants
2) Identify all devices that are "online" and not opted out at the time of an individual DR event
   a. Prior to each cycling event, the team will generate a list of online devices that are controllable via the Internet
   b. All offline customers as assumed to be controllable via the smart meter
3) Record the time and duration of each control event initiated, based on customer topology
   a. Customers are broken into multiple groups in order to provide a sustained DR event, and each group can be cycled independently
   b. The team will generate a post-event report showing the start and stop times for each group cycled
4) Pull usage data for all iThermostat customers
   a. The team will pull interval data for the total population of iThermostat customers
   b. This will include data prior to, during and after each event (up to 2 hours before and after)
   c. The data will be available within 48 hours of the end of the event
5) Generate customer usage analysis to validate the following:
   a. Does meter data reflect an overall decrease during event period across customers cycled (validate event was triggered)?
   b. How many customers reflected a usage decrease, including percentage of expected customers? This will compare online versus offline customers to determine if both control event paths were successful
   c. Aggregate customer usage before, during and after each event (one hour prior to and after each event)
   d. Usage analysis including: 1) Measure total load shed during control events as well as customer averages, and 2) measure economic value based on wholesale pricing at the time of each event

3.6 Distribution-Level Battery Energy Storage System

This section covers the project plan and data collection and analysis for the distribution-level battery energy storage system (BESS) project.

3.6.1 Project Plan

A 1 MW grid connected storage battery has been installed at the Reese Technology Center to work in connection with approximately 2.6 MW of wind generation at the site. The battery will be utilized in conjunction with the wind facility to potentially supply all of the energy necessary to meet the demands of a local (Hurlwood) substation electric load. The battery and wind generation are connected such that they are only used for local capacity and do not feed back onto the transmission grid. The BESS utilizes deep-cycle Lithium Manganese Oxide (LMO) batteries designed for use in renewable energy applications. The battery is connected via a bi-directional converter through a transformer to the main grid. The energy produced by wind generation is intermittent, so the battery acts as a backup storage unit to supply power to the grid at peak demand times that often coincide with low instantaneous wind power generation. The battery is connected at the 12.47 kV medium voltage level, and it can be charged or discharged by the bi-directional converter to manage power flow into the grid.

Models for the battery, the wind turbines, and the utility network from RTC to the substation are being created in PSCAD to simulate the performance of the battery under several operating conditions such as:

- Offset load management – Charge the battery during periods of high wind and discharge the battery during the period of high load (peak load shaving).
- Ramp operation – Use the battery to supply energy when the wind speed drops rapidly, thereby countering the effective loss of the wind generation, providing time for other generation to be brought online.
- Frequency management – Discharge the battery at maximum rate to support the grid during frequency dips.

Once the system is modeled in PSCAD software, the analysis and monitoring tasks can be carried out and compared with demonstration results.

Various types of generic models available for the purpose of battery modeling have been investigated. A literature search indicates that the electrochemical polarization in Li-ion batteries leads to an inaccurate simulation of charge and discharge transients. Taking this factor into consideration, the Dual Polarization model should be effective in modeling the battery. This model will refine the description of polarization characteristics and simulate the concentration polarization and the electrochemical polarization separately.

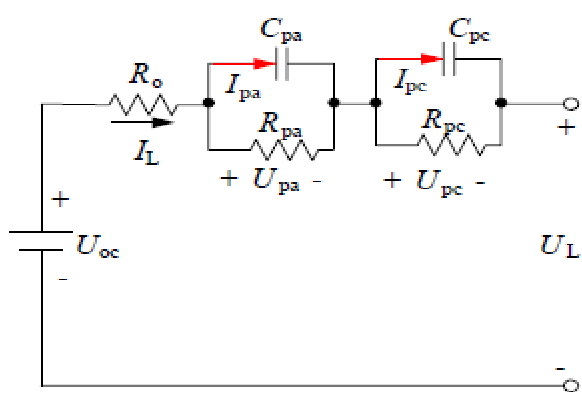


Figure 15. Basic Circuit of DP Model

The figure below shows the circuit with battery life-time and DP model as developed by Chen, et al, "Accurate Electrical Battery Model Capable of Predicting Runtime and I-V Performance". This circuit has been modeled in PSCAD to obtain a 1 MW battery.

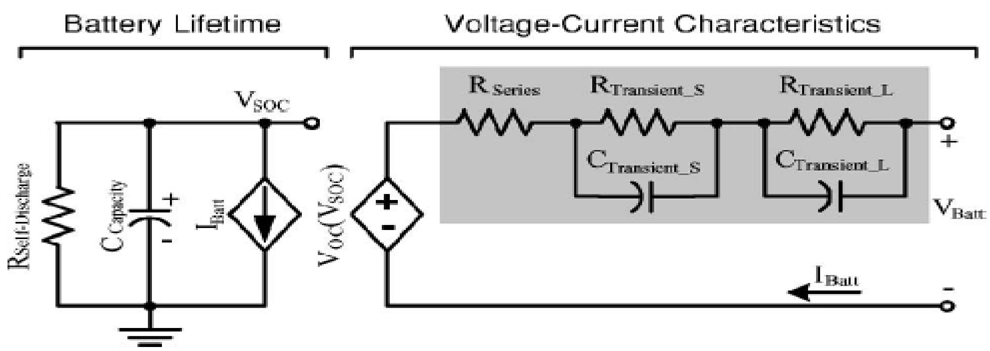


Figure 16. Accurate Battery Model Taken from Chen, et al

The basic building block of a BESS, the modules, is formed by configuring the cells in series. Two system modules are then connected in series configuration and paired with a tray level Battery Management Systems (BMS) to form a rack mountable system tray assembly. With reference to the above assembly, initially a single cell of the battery system was modeled with the voltage at 4.12 V and discharge current at 60 A as shown below. The control system model is shown in the second figure below. The battery steady state discharge operation is demonstrated in the third figure where the battery is initially charged to 4.12 V and then discharged slowly to reach the nominal voltage in one hour as shown in figure 14 below.

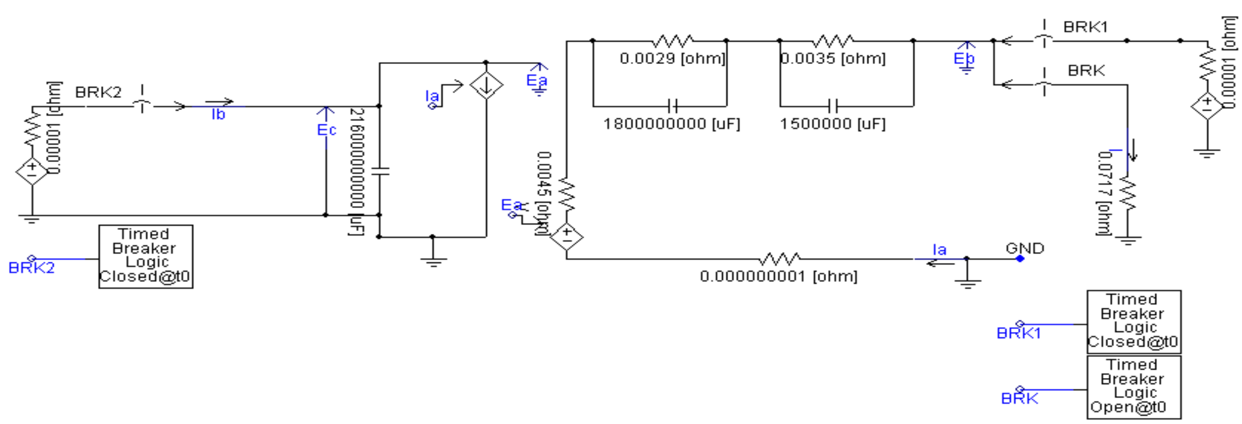


Figure 17. Battery Cell Model in PSCAD

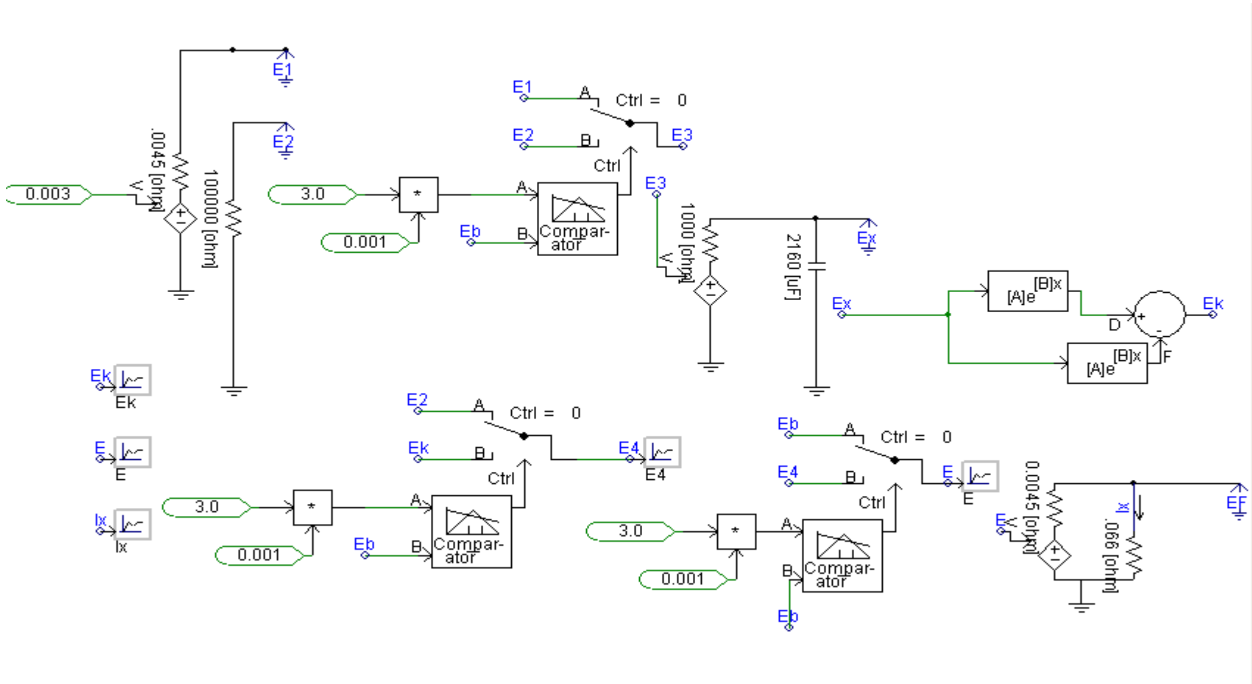


Figure 18. Controls for the Battery Cell Model in PSCAD

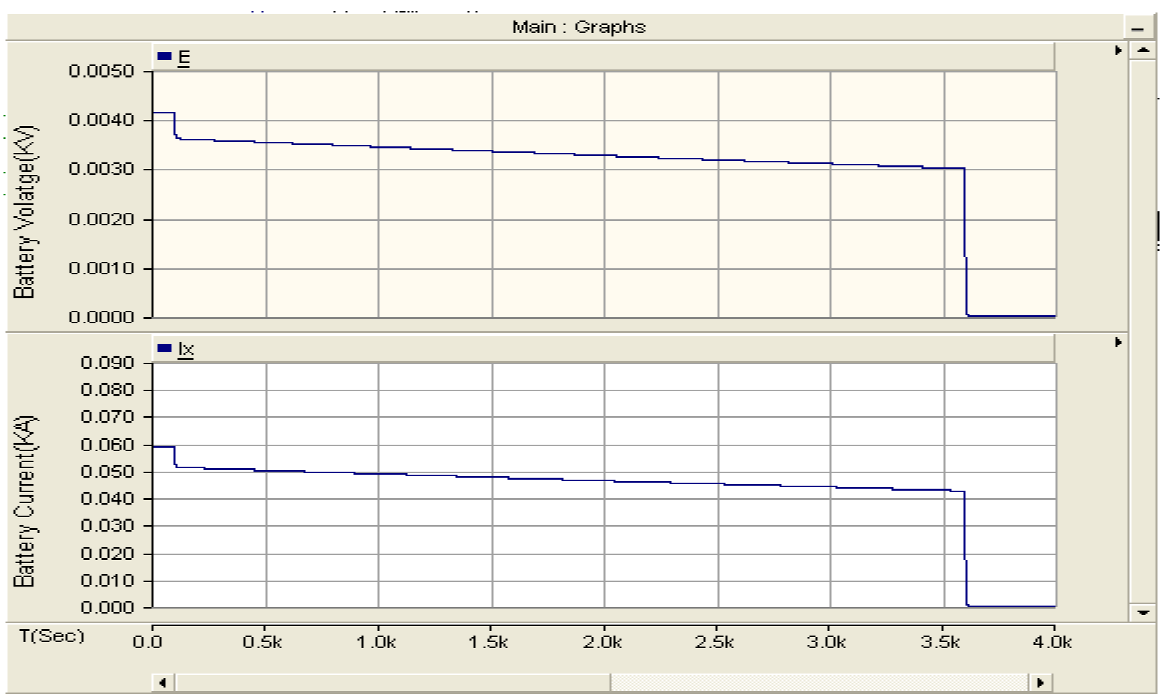


Figure 19. Output of Battery Cell Model in PSCAD

The cells are stacked in series to form a rack with 947.2 V, 60 Ah. The racks need to be stacked in parallel to obtain 947.2 V and 1200 Ah. Due to a software limitation, the simulation runs out of memory. Therefore, the individual cell size has been increased to 14.8 V and capacitor to 1080000 F to obtain the specified current of 300 A. Sixteen of these cells are stacked up in series to get a 236.8 V, 300 A tray. Four such trays are stacked in series to obtain a rack rated at 947.2 V, 300 Ah. Four racks are added in parallel to obtain the complete 947.2 V and 1200 Ah rating of the BESS system as shown below. The simulated results are shown in the figure below, and then compared and tabulated in the subsequent table.

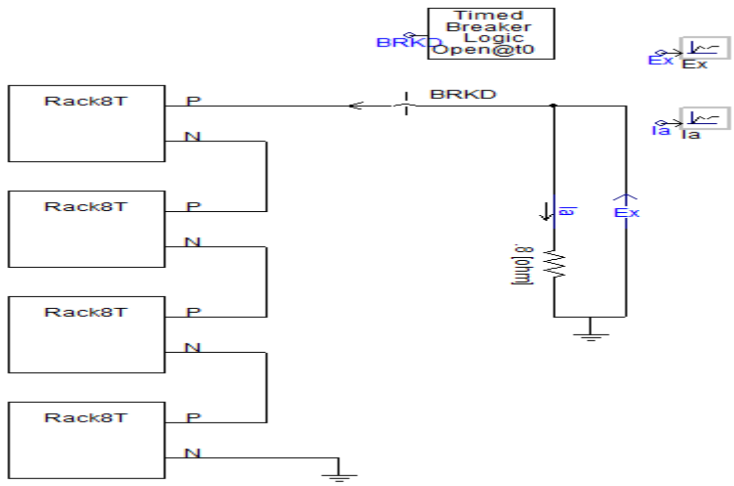


Figure 20. PSCAD Model of the BESS

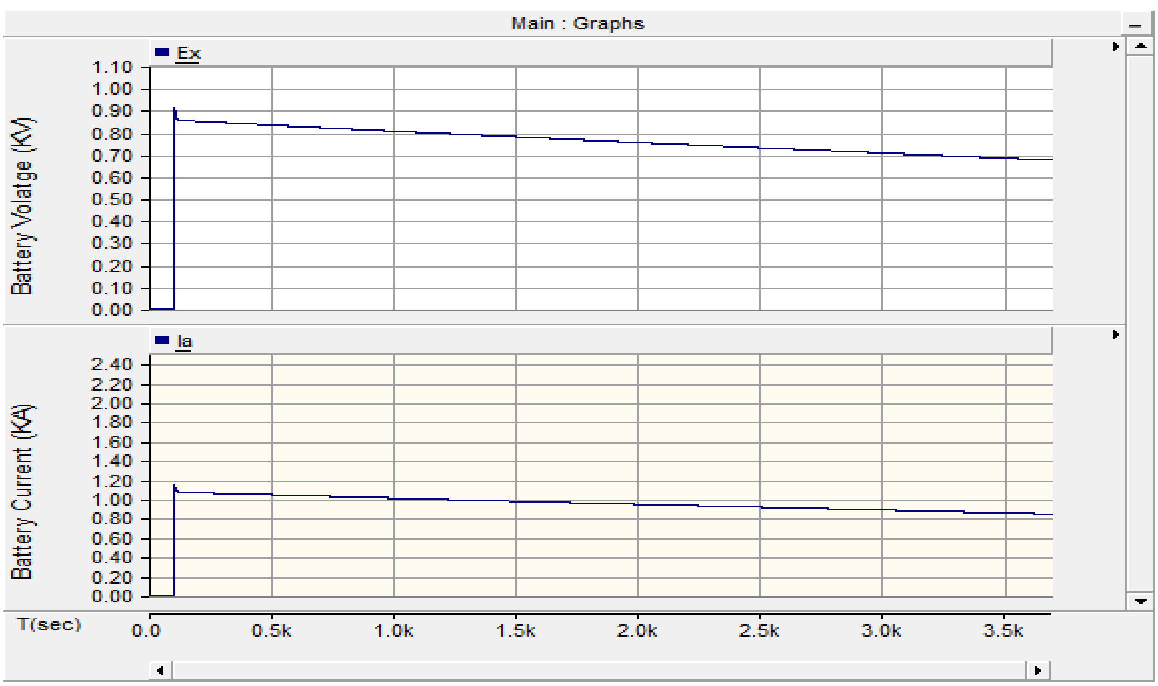


Figure 21. A Single Rack of the BESS with 913 V, 1138 Ah

Table 3. Ratings for BESS

Parameters	Practical Results	Simulated Results	Current (Ah)
Minimum voltage	768.00 V	700 V	1200
Nominal voltage	947.2	913 V	1138

3.6.2 Data Collection and Benefits Analysis

A wide array of data will be collected including daily power production, wind speed and price data for the wind turbines, as well as the parametric data for the BESS. The latter will include:

- Ramp rate and frequency for grid stabilization.
- Performance of the battery as a function of the SOC, temperature and the number of charge and discharge cycles. This also includes how well the energy flow is managed, in addition to how the transients and faults affect the battery.
- Response of the battery to steady state and transient requirements.
- Reliability of the battery as a function of performance.
- Parameters that affect the reliability of the battery such as over-current, over-voltage, under-voltage, and temperature.
- Power quality of the energy system at the connection point to the grid.

A complete analysis of power quality will be performed on the output voltage from the battery, and the inverter connecting the battery to the grid. Because the battery will be connected to the utility grid, transient analysis such as three-phase shorts, single-phase shorts and open circuit conditions cannot be performed on the system. The transient analysis will be conducted by simulating the system and injecting the faults to determine how the components will perform. Load flow and steady stated analysis will be conducted to determine the optimal flow of power in the system.

3.7 Fast Response Regulation Service with Fleet Electric Vehicles

This section covers the project plan and data collection and analysis for the fast response regulation service (FRRS) with fleet electric vehicles (EV) project. This project is still being formulated and while all parties are now in agreement, ultimately this effort must be accepted into the pilot program by ERCOT in order to be fully demonstrated.

3.7.1 Project Plan

This effort consists of design, development, integration, and deployment of technologies to utilize an existing EV fleet to deliver FRRS. The following activities will be conducted to create and ensure a successful deployment of technology:

- Identification and procurement of a utility revenue-grade meter to monitor power and grid frequency at a minimum of 32Hz.

- Development of a software aggregation control system to manage an EV fleet in accordance with FRRS parameters.
- Establishment of an interface to an existing on-site energy management system that reports EV status information.
- Establishment of a secure physical network interface to the ERCOT system in accordance with FRRS pilot requirements.
- Development of the data collection, correlation, and delivery to ERCOT of the required meter data files within one day of each frequency regulation bid period.
- Development and deployment of hardware for controlling the EV chargers within the FRRS established time frames for power responses.
- Installation and deployment of secure networking hardware for the interface between the QSE and ERCOT.
- Laboratory testing of all interfaces, using simulators, to verify communications pathways, data receipt and responses, and timing to enact FRRS power changes on the EV fleet, prior to deployment.

Success in this project will revolve around a few key data items:

- Ability to monitor grid frequency and detect deviations of .09Hz from the base 60Hz.
- Ability to implement FRRS protocol within 60 cycles (one second) of either a detected deviation or an ERCOT instruction.
- Ability to monitor and log fleet power consumption at a minimum of 32Hz during an FRRS bid period.

3.7.2 Data Collection and Benefits Analysis

This project is in the formative stage and as such is still defining the data collection methods and the data analysis methodology to support a benefits analysis of fleet EV participation in an FRRS market. These details will be provided in the next iteration of this TPR.

4. PERFORMANCE RESULTS

This section documents and summarizes results from the demonstrated technologies. As with previous sections, the information is presented by technology component. It covers topics such as:

- Operating performance and costs (capital and operations), including issues that impact performance and corrective action.
- Impact metrics and benefits analysis, including quantitative performance relative to the baseline to define delta changes in grid performance and market efficiencies.
- Stakeholder feedback including a summary of formal observations.

4.1 Synchrophasor Monitoring, Visualization, and Event Reporting

This section covers the operation of smart grid technologies and systems, including the demonstration results; impact metrics and benefits analyses; and any stakeholder feedback received to date. Additionally, where appropriate, cost data for the technologies is provided. More cost information is provided in Appendix A.

4.1.1 Operation of Smart Grid Technologies and Systems

This section primarily discusses the demonstration results for:

- PMU monitoring coverage
- baselining study
- data quality study
- lessons learned from mitigating PMU data loss
- event analyses of generation outages and wind interactions
- requirements for control room and network production upgrades
- generator model validation
- slow scan synchrophasors
- synchrophasor use cases

4.1.1.1 PMU Monitoring Coverage

At the inception of this demonstration project, the ERCOT synchrophasor network consisted of PMUs at three locations and a single PDC installed and operated by the American Electric Power (AEP), and a single PDC and Real Time Dynamics Monitoring System (RTDMS) wide area visualization system installed at ERCOT (installation was sponsored by CCET with DOE matching funding support). The demonstration proposed for this project anticipated that the three participating TDSPs (Oncor Electric, AEP, and Sharyland Utilities) would install a total of 13 additional PMUs at 13 locations on their respective transmission networks, and provide the associated synchrophasor signals to ERCOT.

During the first two years of this project, the TDSPs have identified additional locations where they could support the installation of PMUs. As of July 2013, the TDSPs have installed and are providing streaming synchrophasor data from 48 PMUs at 28 locations across ERCOT as shown in the figure below, although not all of the PMUs are directly funded by or formally part of this project, although their data feeds certainly provide measured contributions to grid performance and event evaluations. Additionally, it is expected that other ERCOT TDSPs will soon be providing data from additional PMUs being installed in their substations to ERCOT. Currently, ERCOT is anticipating receiving data from nearly 60 PMUs at 36 different locations by the end of the year.

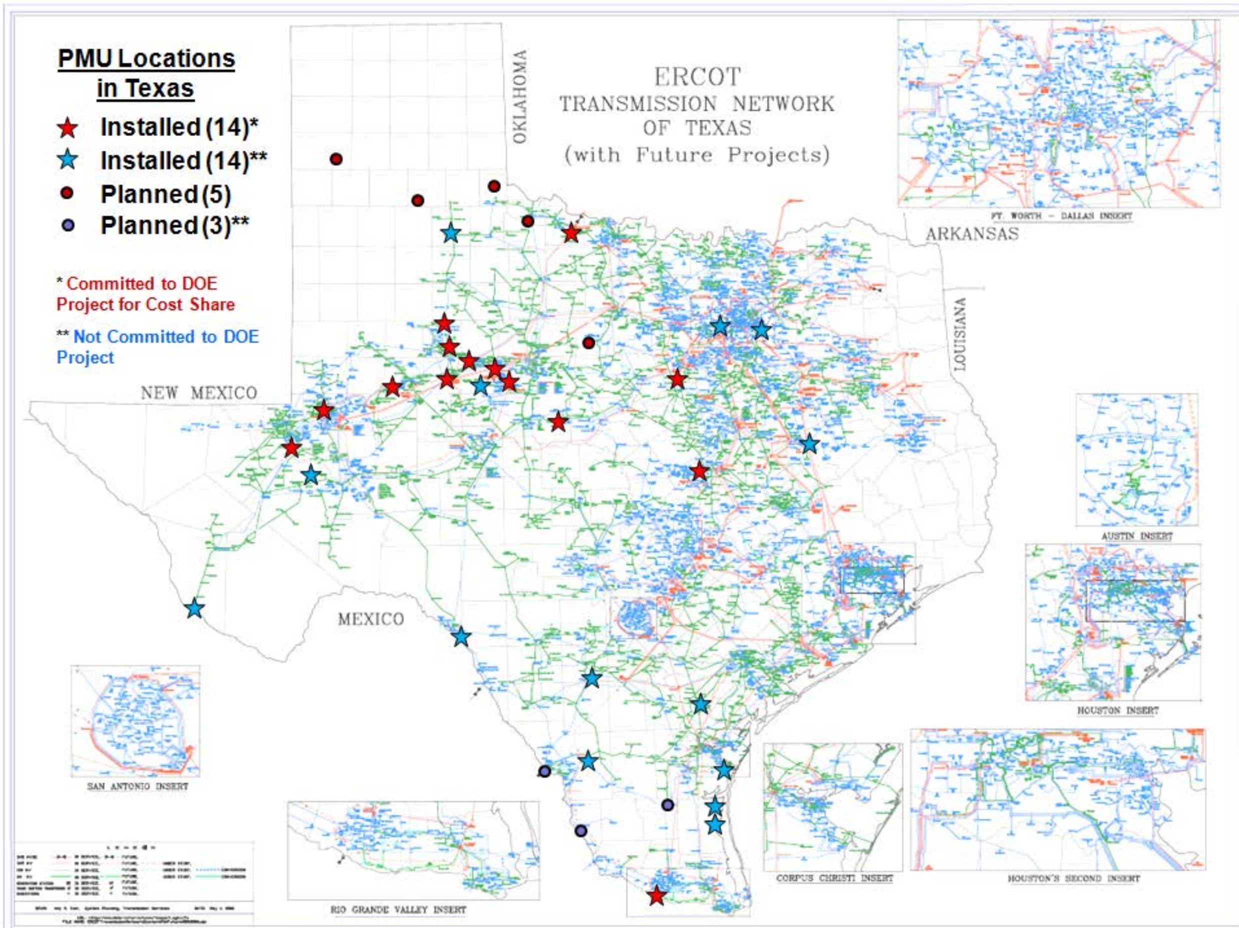


Figure 22. PMU Locations in Texas

During 2012 and the first part of 2013, the ERCOT ePDC was receiving synchrophasor data streams from two TDSP-owned PDCs (Oncor and AEP). Those in well established areas of the state have had fewer issues with communications, but it also has to do with placements of the PMUs. In rural areas, some TDSPs have had to depend on an Internet service provider to stream the data, only to learn quickly that this amount of data exceeded the capacity of those data networks. After adding new communications networks, Sharyland chose to stream its data directly from its two PMUs. This unusual data configuration has worked quite well, and enabled the addition of new PMUs without the need to first install a local PDC at the TDSP. Sharyland plans to redirect their two direct-feed PMUs into a Sharyland-owned PDC which will then supply data (including two new PMU data streams) to the ERCOT ePDC.

At ERCOT, the ePDC and RTDMS had been running on servers in ERCOT's test environment while the operational support capabilities were evaluated. In early 2013, planning began for the installation of production grade servers and associated hardware. This migration was completed in September 2013.

At TTU, the ePDC and RTDMS systems have been installed and running since May 2013. Their synchrophasor network, which is in the SPP region (not ERCOT), currently consists of two stable PMU installs with high data availability and two additional installs with very low data availability. The two high data availability PMUs are located on the TTU campus and at a Lyntegar-owned substation in Lynn County. The two low availability PMUs are both located at the Reese Technology Center and connected over a 900 MHz encrypted Ethernet radio link to the ePDC. The cause of the low availability is poor signal strength negatively impacted by line-of-sight problems. These two radio links will be redirected to the battery installation where they will be tied to the fiber optic network in late 2013. The battery is much closer to the PMUs and has excellent line-of-site to both locations. An additional 3-6 PMUs are planned to be added to this network by early 2014.

4.1.1.2 Baselining Study

In order to both validate the accuracy of the synchrophasor data being delivered to ERCOT, and to begin the process of establishing alert and alarm levels which can be used to inform the grid operators of emerging conditions on the system, a baselining study was initiated. The study evaluated both synchrophasor data and about 16,000 state estimator cases from the ERCOT energy management system (EMS) for the year 2012.

The synchrophasor data included all the PMUs that were installed and providing data to ERCOT (some were added during 2012, and thus covered only a portion of the year). The synchrophasor data was down-sampled from the nominal data rate of 30 samples per second to one sample per second to streamline the analysis.

The baselining analysis included a clustering study that identified PMU locations where the voltages and voltage angles moved in unison with nearby PMUs, as a means of identifying unique monitoring regions within the ERCOT grid. A total of six regions were identified, and similarly performing PMUs were thus clustered. The clustering study also compared the voltage magnitude and angles as measured by the synchrophasor network with the same metrics from the state estimator study results to validate the comparability of the two data monitoring systems.

The baselining analysis next analyzed, for the entire calendar year 2012, the ranges of voltage magnitude, voltage angles relative to a reference substation, and voltage angle differences (pairs) between PMUs in different regional clusters. This analysis was done for each of the anticipated 42 substations that are expected to ultimately have PMUs providing synchrophasor data to the ERCOT control center. The analysis also identified maximum and minimum values for each of the study metrics. Results from this baselining analysis were presented to the project team; however, because the ERCOT grid is changing significantly with the addition of new 345 kV CREZ circuits that will dramatically alter the characteristics of the grid, it was determined that the experience-based operating limits that might be determined from this baselining study (based on the 2012 grid configuration) would not be reasonable limits based on the expanded ERCOT grid (including the new CREZ lines). Thus, it was determined to perform an update of the study based on the first six months of 2013. The update study is just starting.

4.1.1.3 Data Quality Study

In order for ERCOT to achieve a production quality phasor monitoring system that can be relied upon in real-time operations, three conditions must be met: 1) the data must be flowing reliably from the PMU to the grid operator's console, 2) the data must be valid, and 3) the data must be monitoring the critical locations (right places). In early 2013, an analysis of the overall synchrophasor data flow and data quality was initiated to address this first condition, and to identify improvements that might be needed to successfully achieve the first condition.

The goals of the study were to:

- Identify nodes in the phasor network that might be affecting data availability (dropout).
- Classify identified dropout issues by severity and frequency.
- Determine likely causes of data dropouts at identified locations.
- Propose solutions to help eliminate identified data availability problems.

While the initial study results concluded that all the sub-second synchrophasor data was reliably being delivered from each of the TDSPs into the ERCOT ePDC and RTDMS databases, there were gaps in some of the second-average and minute-average data that was also being saved in the RTDMS database. An incompatibility between the data and the database storage routines was identified and corrected in early July. A review of the data base consistency is scheduled to confirm that this has corrected all of the identified issues from the initial study, and then it will be reexamined.

4.1.1.4 Lessons Learned from Mitigating PMU Data Loss

During the first two years of this project, the synchrophasor data volume has increased from 3 PMUs reporting at the outset to 48 PMUs reporting as of July 2013 (of which 41 are being used for operations monitoring). Since September 2011, daily reporting statistics have been tracked for each of the PMUs. As indicated in the summary plot below, which presents monthly average values through August 2013, early in the project when new PMUs were added, their availability and data quality was initially low but improved rapidly. As the participants have gained experience adding PMUs in their respective networks, the initial reporting performance of the newer PMUs has started higher and improved more rapidly.

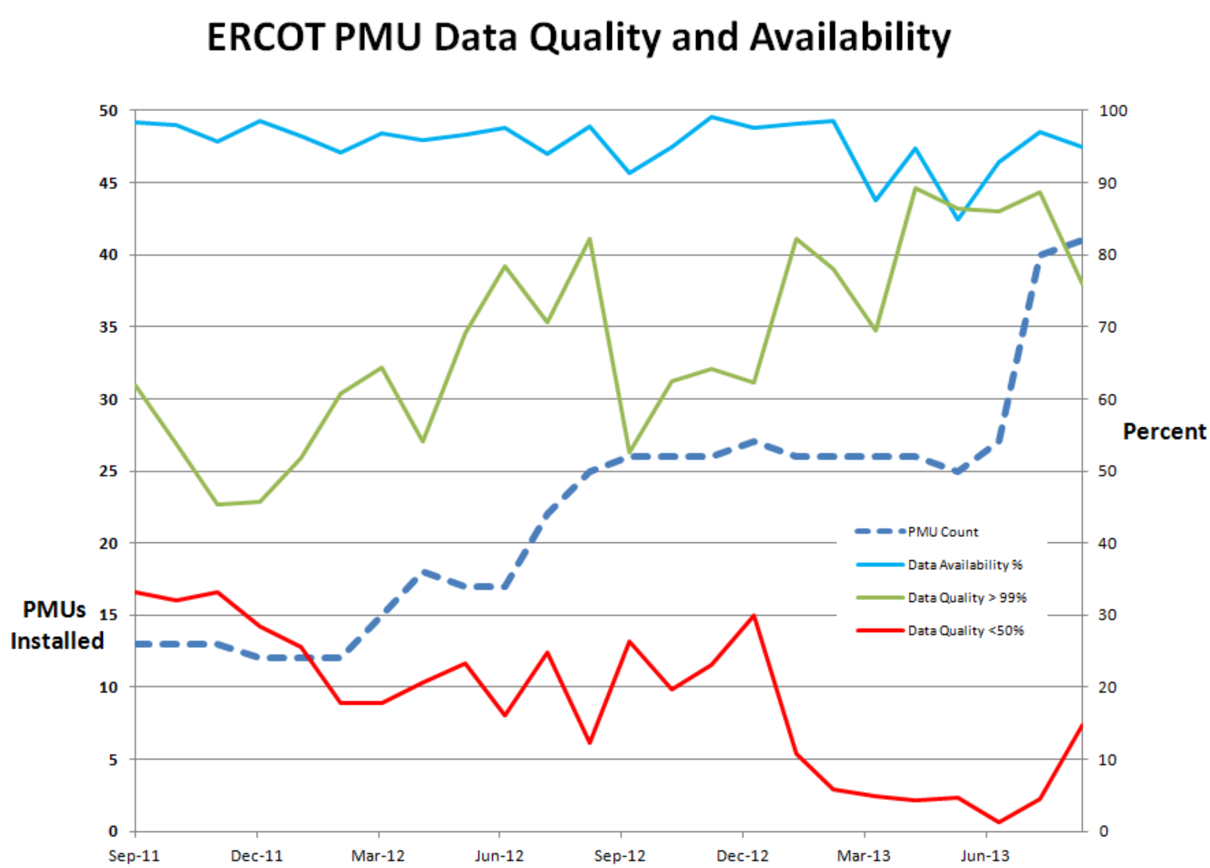


Figure 23. ERCOT PMU Data Quality and Availability

The most common challenges to achieving high overall PMU data quality have been securing a reliable communications channel between the PMU and the TDSP PDC, and getting a good time stamp signal into the PDC. As is characteristic for most utilities in North America, the ERCOT grid is represented by both legacy TDSP communications networks, and newer, more robust communications paths. Where PMUs were relying on the legacy communications networks, some tuning of the network was needed in order to improve the overall reliability of the PMU data stream. In three cases, it was not possible to achieve the necessary bandwidth and communications reliability to support the PMU data stream, so those PMUs were removed from the data network.

Sharyland initially attempted to utilize a wireless carrier for the first link of their PMU data stream from one of their substations. The wireless carrier disconnected the data stream after only a few days of operation, and refused to provide service to Sharyland – the carrier was not anticipating the volume of data represented by the PMU data stream. To complete the communications link to their substation, Sharyland had a hard-wire communications line installed.

Two PMU signals in the AEP PMU data stream are being provided voluntarily by their respective generation plant owners. Unfortunately, since providing PMU data is not high on the plant owners’ priorities, these units are not being adequately supported, so the data quality from these PMUs is lower than desired, and the signals are not as useful as they might otherwise be.

On one occasion, a network card on a co-located ERCOT-owned switching device, in the AEP facility where AEP's T-1 connection interconnected with the ERCOT wide area network, was causing random delays in transmission, causing the AEP PMU data stream to drop out for short periods of time. Diagnostic testing by both AEP and ERCOT validated that connections to their respective ports on the network switch were working properly, but testing across the switch was not performed. After several weeks of poor performance, an onsite technician removed and reseated the network card, duplicating the problem. The network card was replaced, and the intermittent data dropouts ceased. In this case, neither organization was sufficiently aware of the interface configuration to be able to test across the switch as part of their routine diagnostic testing.

4.1.1.5 Event Analysis of Generation Outages

The ERCOT RTDMS system automatically captures event files when significant generation is lost (e.g., loss of a unit 400 MW or greater). These event files are then analyzed to assess the overall performance of the grid, including frequency dip and initial inertial frequency recovery, to compare against the interconnection frequency bias, voltage dips (location and magnitude), and angle swings across the grid. These results are being accumulated and tabulated, together with grid configuration metrics such as total amount of generation on-line, mix of generation on-line, level of wind production, etc. Statistical analysis of these event metrics will be used to identify performance trends.

Additionally, on several occasions, minor sustained oscillations have been detected on the ERCOT grid. Using the synchrophasor data, these oscillations are evaluated with respect to location of the strongest signal (find the PMU closest to the source), the frequency and damping characteristics of the oscillation, and any identified interactions with other generation. The results are then tabulated, together with grid configuration metrics such as total amount of generation on-line, mix of generation, level of wind production, etc. In most of these cases, the source of the oscillations could be identified and confirmed through communications with the respective generation owners. In each case where a specific generator could be identified, the oscillations were confirmed to have been caused by incorrect settings in one of the generator control systems. This demonstrates the capability of the PMU monitoring system to be able to identify improperly performing control systems, and to enable the grid operators to contact the generation owners to effect corrective changes in the control settings. While this is not yet being accomplished in real time, the technology demonstrates the potential for being able to perform these analyses in near real time.

As additional PMUs are added to the ERCOT grid, the ability to detect, locate, and diagnose control-system caused oscillations will improve.

4.1.1.6 Event Analysis of Wind Interactions

While a major element of this demonstration project is focused on identifying interactions between wind generation and the ERCOT grid, and demonstrating improved capability to manage the grid with large amounts of wind generation operating, this first phase of the demonstration project has been focusing on expanding the PMU monitoring network and upgrading the computer network and hardware to support wide-area monitoring and visualization of the ERCOT grid using synchrophasors. At the same time, additional transmission has been under construction as part of the Competitive Renewable Energy Zones (CREZ) transmission expansion program to support the projected expansion in wind generation. The planned projects are expected to improve or add nearly 7,000 circuit miles of transmission lines and more than 17,000 megavolt amperes (MVA) of capacity to the grid. A significant portion of the CREZ transmission expansion has already been completed and placed into operation, and additional transmission lines are expected to be completed by the end of 2013. Finally, the construction of new wind generation has been underway across Texas.

At the beginning of 2010, there was 10,069 MW of wind generation installed on the ERCOT grid, and the peak wind production was recorded at 7,016 MW (June 2010). By the end of 2012, wind generation had increased to 12,667 MW installed, and in mid-February, 2013, the peak wind production had increased to 9,481 MW, supplying nearly 28% of the system load for a brief period. Wind generation is forecast to increase to more than 18,500 MW installed.

Analysis of the recorded synchrophasor data for 2012 and 2013 is underway to examine potential interactions between wind generation and the ERCOT grid. Initial analysis has identified low-level oscillations in the range of 5.0 – 5.5 Hz which are detectible at substations near the large wind generation areas in ERCOT. These oscillations are likely driven by control systems, as the frequencies are too high for typical electromechanical oscillations. It has also been observed that the oscillatory frequencies differ by region. More analysis is required to identify the grid conditions under which these oscillations appear, and whether they have the potential to interact with other generation. This study is just beginning.

4.1.1.7 Requirements for Control Room and Network Production Upgrades

During 2012 and early 2013, the minimum requirements for the computer and communications infrastructure needed to support the use of synchrophasor-based wide-area monitoring and visualization in the ERCOT control room were developed. Several possible configurations were examined, ranging from a single-instance implementation on production grade servers, to a fully redundant implementation complete with staging and test environments. In early 2013, ERCOT decided to proceed with a single-instance implementation on production grade servers, with an associated network configuration. An illustration of the planned network configuration is shown below. EPG has supplied an upgraded version of the RTDMS wide-area monitoring and visualization system, and has assisted ERCOT in configuring that version on the test system, in preparation for installation on the new production grade hardware. The new hardware was delivered in late July 2013 and the initial install of the software began in August.

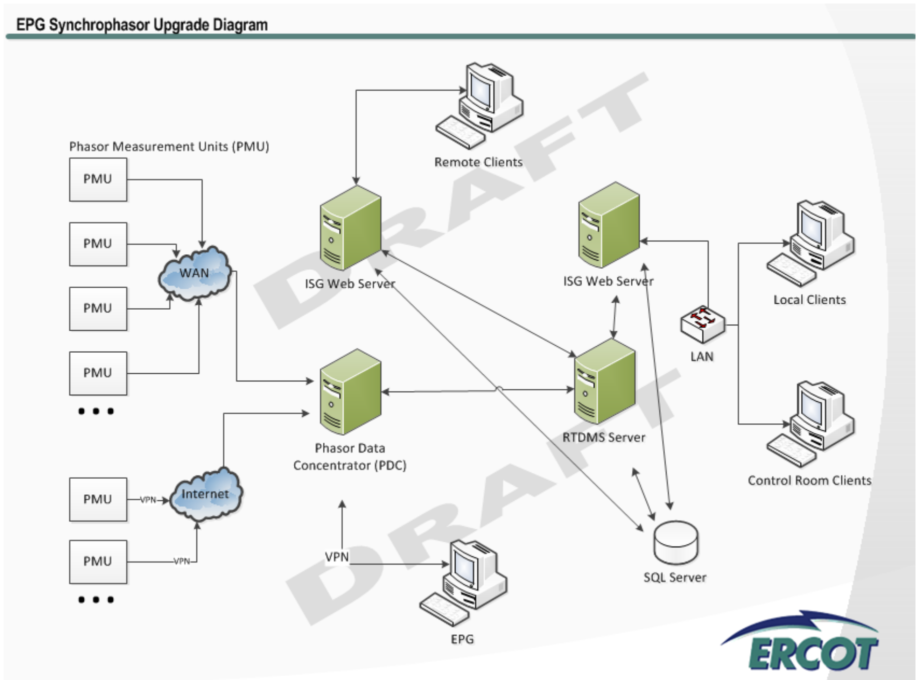


Figure 24. Synchrophasor Upgrade Diagram

Operator training for both ERCOT and the TDSP operators is now scheduled for late September.

4.1.1.8 Generator Model Validation

Synchrophasor data can potentially be used to aid grid planners in validating the generator models upon which their dynamic simulation studies rely. Through CCET-sponsored research on behalf of ERCOT, researchers at the University of Texas at Arlington (UTA) developed algorithms that have the potential of directly validating the parameters that describe individual generators connected to the ERCOT grid by using synchrophasor data collected where the generator interconnects the grid. As part of this demonstration project, EPG, working in collaboration with UTA, are implementing the generator parameter model validation algorithms into its off-line analysis tool, Phasor Grid Dynamics Analyzer. The algorithms will then be tested with both simulated data and recorded synchrophasor data, to the extent possible, in order to demonstrate the potential for the algorithms to assist grid planners in validating their dynamic models.

The need for accurate generator dynamic modeling was highlighted in late 2011 during a scheduled transmission outage for maintenance. During the outage planning, ERCOT simulated the grid conditions that would be present during the outage and concluded that the wind generation connected to the portion of the grid where the outage would occur would remain stable; however, after removing the transmission line from service, severe voltage oscillations were experienced by the wind generator, resulting in loss of the generation. Utilizing the synchrophasor data recorded during the event, ERCOT planners were able to determine that the performance of the wind generation predicted by the dynamic outage planning studies did not match the actual performance of the wind generation. Changes to the dynamic model parameters were provided by the generation owner and incorporated into the ERCOT models. While ERCOT may be confident that this generator model is now accurate, there are hundreds of other generators that could be unintentionally misrepresented in ERCOT's dynamic studies. Utilizing synchrophasor data to validate predicted grid performance offers the potential of avoiding unexpected outages due to inaccurately modeled generation and load.

4.1.1.9 Slow Scan Synchrophasors

The Oncor Energy Management System includes the capability to capture time-stamped voltage magnitude and voltage angle (synchrophasor) data in their substation Remote Terminal Units (RTUs), and to deliver that synchrophasor data into their Transmission Management System (TMS). Oncor has begun to implement this feature, bringing time-stamped data into their TMS at a rate of three samples per minute. This slow scan data is then delivered into the Oncor PI Historian using the Inter-Control Center Communications Protocol (ICCP). A Visual Studio Web service is used to process the data for display to the user. These displays include phase angles across transmission lines, phase angles between selected locations, phase angles relative to a selected location, and system stress using a relative phase angle dial indication. An illustration of the relative phase angle dial is shown below.

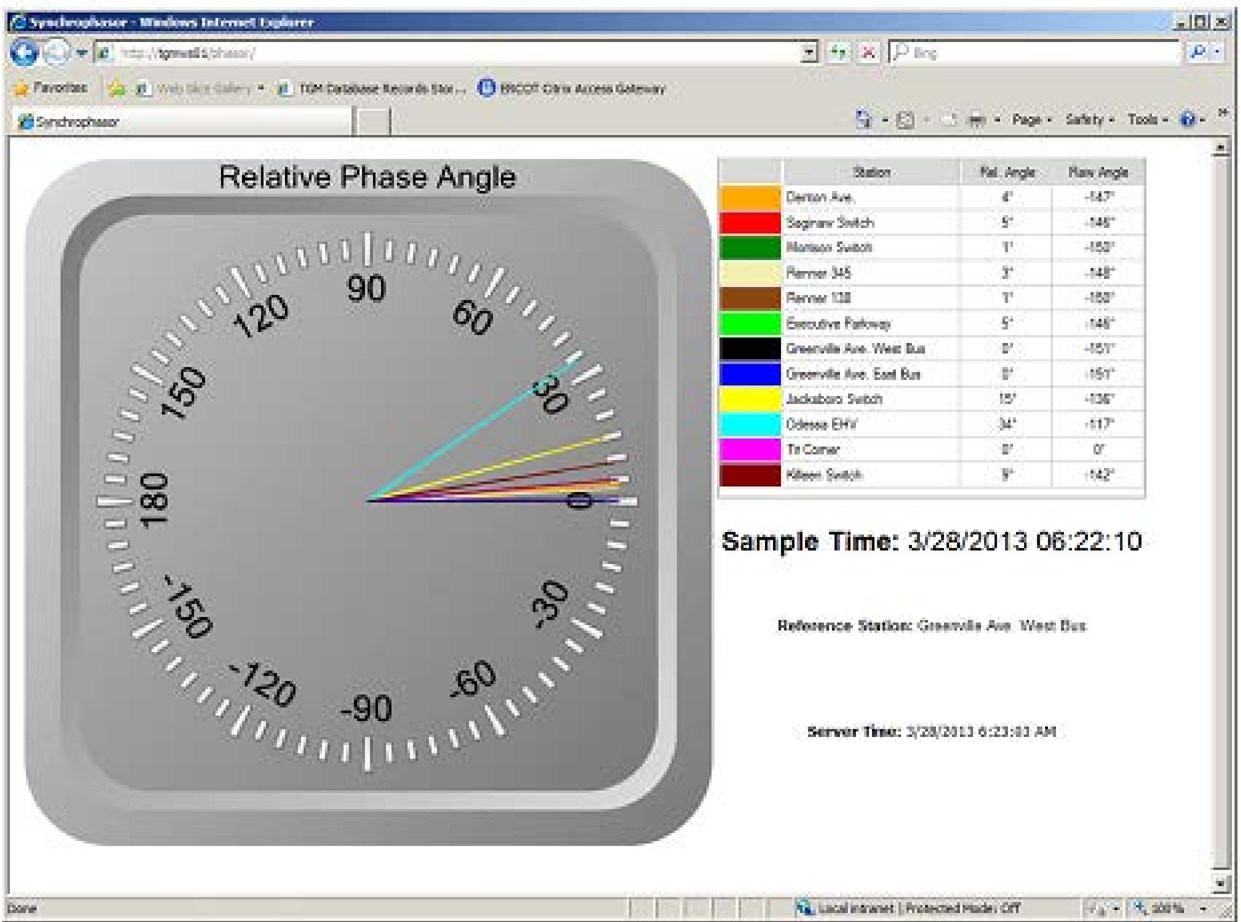


Figure 25. Relative Phase Angle Dial Illustration

Oncor is in the process of enabling this capability at more locations, stabilizing the data collection process, analyzing the data to establish alarm and notification limits, and developing a training program and operational procedures for deployment into the operational environment.

The key benefit of leveraging this slow scan synchrophasor data is the ability to monitor a significantly larger portion of the Oncor grid because the slow scan rate and limited data packet size make it possible to enable this capability at essentially every Oncor substation which is already using synchrophasor-enabled protective relays. The slow scan data cannot, however, be used to inform the operators about oscillatory events, nor can it be used to assist in validating dynamic generator models.

This slow scan data can potentially also be made available to ERCOT via the existing ICCP data link between Oncor and ERCOT. It has not yet been determined whether this expanded capability will be useful to ERCOT, in conjunction with the high speed synchrophasor data already being collected and displayed, or if this slow scan approach can be applied at other TDSPs.

4.1.1.10 Synchrophasor Use Cases

While the deployment of PMUs for this demonstration program was based on availability (PMUs were installed where the communications capability was sufficient, and the location was desirable for monitoring), part of the project plan includes developing PMU location selection principles and criteria that can be used to site future PMUs. In support of this objective, the project team has developed a set of 15 synchrophasor use cases. These use cases describe the proposed grid operations application for the data, the type of data that would be required to support the use case, and whether streaming data is required. The use cases are summarized below.

Use Case	Grid Scope	Streaming 30 samples/sec	Slow Speed 3 samples/min	Local Event Capture
High Stress Across System (High Phase Angle) Observed	Wide Area	Yes	Yes	
Small Signal Stability – Damping is Low	Wide Area	Yes		
Small Signal Stability – Emerging Oscillation Observed	Wide Area	`Yes		
Voltage Oscillation Observed	Regional	Yes		
Voltage Instability Monitoring (real-time P-V or Q-V curve)	Regional	Yes		
Detection of Subsynchronous Interactions (Not necessarily resonance, just below 60 Hz)	Local Regional	Yes		
Integrate PMU Data Into State Estimator	Wide Area	Yes	Yes	
System Disturbance – Capture and Interpretation	Regional	Yes	Yes, not high resolution	Yes
Generator Parameter Determination	Local	Yes		Yes
Major Load Parameter Determination	Local	Yes		Yes
PMU-Based Fault Location	Local Regional	Yes		Yes
Phase Angle Across Breaker for Reclosing Action		Yes	Yes	
Subsynchronous Resonance Identification and Mitigation (PGRR027)	Regional	Yes		
Transmission Characteristics Determination	Regional	Yes		Yes
Dynamic Transmission Line Ratings using PMU monitoring	Regional	Yes		

The team plans to develop a PMU location selection criteria based, in part, on these use cases.

4.1.2 Impact Metrics and Benefits Analysis

The anticipated benefits of development and deployment of a synchrophasor network in the ERCOT grid are focused around improving the grid operators' ability to manage large amounts of wind generation. Benefits could include:

- Identification of emerging grid conditions which, if not properly mitigated, lead to loss of generation or load
- Identification and correction of undesirable generation interactions, such as oscillations
- Identification of discrepancies between measured and predicted grid response to events, including frequency bias and dynamic response, generator dynamic response, and load dynamic response.

Benefits identified to date (and described above) have included detection and identification of undesirable performance of generator control systems, and generator dynamic modeling discrepancies (differences between predicted and actual performance). While loss of generation occurred in at least two of these identified events, the generation lost was the source of the discrepancy, and no customer load was lost. Thus, quantification of benefits, such as mitigation costs or economic loss, is a challenge at this time.

4.1.3 Stakeholder Feedback

For this initial TPR, there are no observations from stakeholders on the impact of this project.

4.2 Synchrophasor Security Fabric

This section covers the operation of smart grid technologies and systems, including the demonstration results; impact metrics and benefits analyses; and any stakeholder feedback received to date.

4.2.1 Operation of Smart Grid Technologies and Systems

The functional goal of the Security Fabric demonstration is to demonstrate delivery of a synchronized PMU data stream over a secure communications framework for the Internet Protocol (IP) interconnection between two locations: a Security Fabric-enabled ePDC at the Reese Technology Center connected to the Independent System Operator's ePDC (represented by an ePDC located at TTU). The functional goal of this demonstration for data visualization security is to enable an RTDMS client and RTDMS server with Security Fabric to provide secure data visualization for the TTU synchrophasor system.

The first phase of this demonstration is the establishment of a synchrophasor network at Reese Technology Center and TTU. For this first phase, the ePDCs at Reese and TTU are both in place and operational. The RTDMS is operational at TTU, along with an RTDMS Client, which provides the wide-area monitoring and visualization capabilities. Phasor Archivers (to store the synchrophasor data stream) are installed and operational. Two PMUs are currently delivering data to the Reese Technology Center, and two additional PMUs are in place but have communication issues which are expected to be resolved by October 2013. This will represent the baseline system against which the performance of the Security Fabric-enabled system will be compared beginning later this fall when the additional Security Fabric-enabled components are installed at TTU.

4.2.2 Impact Metrics and Benefits Analysis

The Security Fabric is being designed to address all seven of the NIST-IR 7628 security guidelines. The approach will integrate the best of breed commercial technologies to operate in parallel with the synchrophasor applications. The approach is designed to be compatible with standard IT processes, and is designed for interoperability. The approach leverages the silicon capability of server hardware in secure identification/authentication, together with partitioned servers and virtual machines running the application software. While the Security Fabric will have some "knowledge" about the application it is protecting (such as which devices the application will be expected to communicate with), the application will not need to be modified in order to be protected by the Security Fabric. In achieving this design goal, the Security Fabric will be extensible to cover other critical operating functions that demand cyber security protection. The specific metrics to be captured and reported are unique to this project, and will be defined as ongoing laboratory testing and device integration continues.

The benefit of the Security Fabric approach is to provide data transport security for an IP connection between two locations without the need to make special modifications to the applications that will be communicating across the connection, and without materially affecting the performance between the applications. Success in this demonstration will enhance the deployment and use of synchrophasor applications inside the operating control rooms of independent system operators by eliminating concerns about the security of the data being delivered from the TDSPs. When the project commences in earnest, later this year or in early 2014, the benefits will be defined, validated and documented in the next increment of this TPR.

4.2.3 Stakeholder Feedback

For this initial TPR, there are no observations from stakeholders on the impact of this project.

4.3 Residential Circuit Monitoring

This section covers the operation of smart grid technologies and systems, including the demonstration results; impact metrics and benefits analyses; and any stakeholder feedback received to date.

4.3.1 Operation of Smart Grid Technologies and Systems

Data collection from the circuit monitors began in July 2013. Preliminary analysis of the data shows that the Harmony community (equipped with solar) has a higher voltage Total Harmonic Distortion (THD). On average, the THD is peaking at 4.12 %. The Legends Ranch community (no solar) has a THD that peaks at 3.07 %. The IEEE 519 standard for Harmonic Limits recommends the THD remain under 5%.

A second observation is that the line voltages are slightly higher at the Harmony community than the Legends Ranch community. The former has an average 20,606 volts with a peak of 20,870 volts. The latter has an average of 20,469 volts with a peak of 20,630 volts.

4.3.2 Impact Metrics and Benefits Analysis

The specific metrics and benefits analysis for this project will be defined in the next increment of this TPR.

4.3.3 Stakeholder Feedback

For this initial TPR, there are no observations from stakeholders on the impact of this project.

4.4 Residential TOU Pricing Trial

This section covers the operation of smart grid technologies and systems, including the demonstration results; impact metrics and benefits analyses; and any stakeholder feedback received to date.

4.4.1 Operation of Smart Grid Technologies and Systems

The following sections describe the TOU pricing trial observations and analysis results noted thus far in this project.

The original goal was to call a maximum number of monthly critical peak events each month according to the table below. It defines each month along with the minimum threshold temperature and the maximum number of events to be called in that month; however, the summer of 2013 proved to be "cooler" than forecasted, so the threshold for August was lowered to 103^{0}F

Table 4. Revised Thresholds for Calling Peak Days

Month	Threshold Temperature (^{0}F)	Maximum Monthly Peak Events
June	102	3
July	103	4
August	~~105~~ 103	5
September	102	3

TOU Pricing Incentive Account Analysis

Pecan Street performed preliminary analysis on the performance of pricing incentives as detailed in Section 3.4.1. The data set is total adjustment credit earned from March 1, 2013 to August 1, 2013 for 56 out of the 62 TOU participant accounts. The data for the remaining six accounts need further validation and are not included in this analysis. The figure below shows the adjustment credit earnings distribution.

There are initial indications towards a positive shift in behavior in terms of adjustment credit earned by the 56 TOU participants. 93% of participants had positive earnings and 73% had earnings up to $40. The maximum adjustment credit earned to date is $83, and five participants (7%) currently have deductions on their incentive account. The average credit earned is $22.

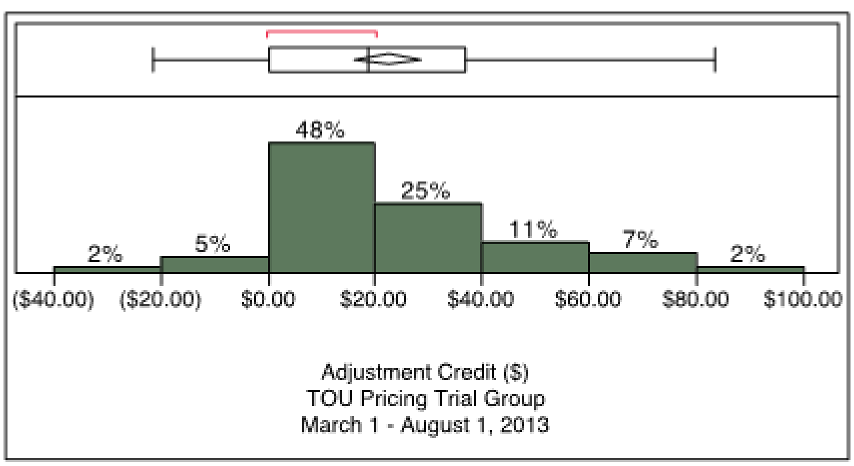


Figure 26. Adjustment Credit Earnings Distribution

Wind Enhancement TOU Pricing Analysis

Frontier Associates analyzed the pattern of daily overall consumption and the individually sub-metered consumption for electric car charging, kitchen appliances and laundry from February 2013 (when data collection began) to June 2013. Observations are described below.

As shown in the figures below, in March (and April to May), in the hours indicated by blue shading, the TOU pricing group (blue line) tended to shift their energy usage to the overnight hours (10 p.m. to 6 a.m.) when reduced overnight wind enhancement pricing was in effect. As expected, this behavior of shifted usage is absent in June (and February) when there is no discounted overnight pricing. The following figures are hourly consumption profiles for March (a “wind” month) and June (a “non-wind” month). For March, note the ‘bump’ after 10 p.m. (22:00) and the elevated usage (versus control group) from midnight (0:00) to 6 a.m.

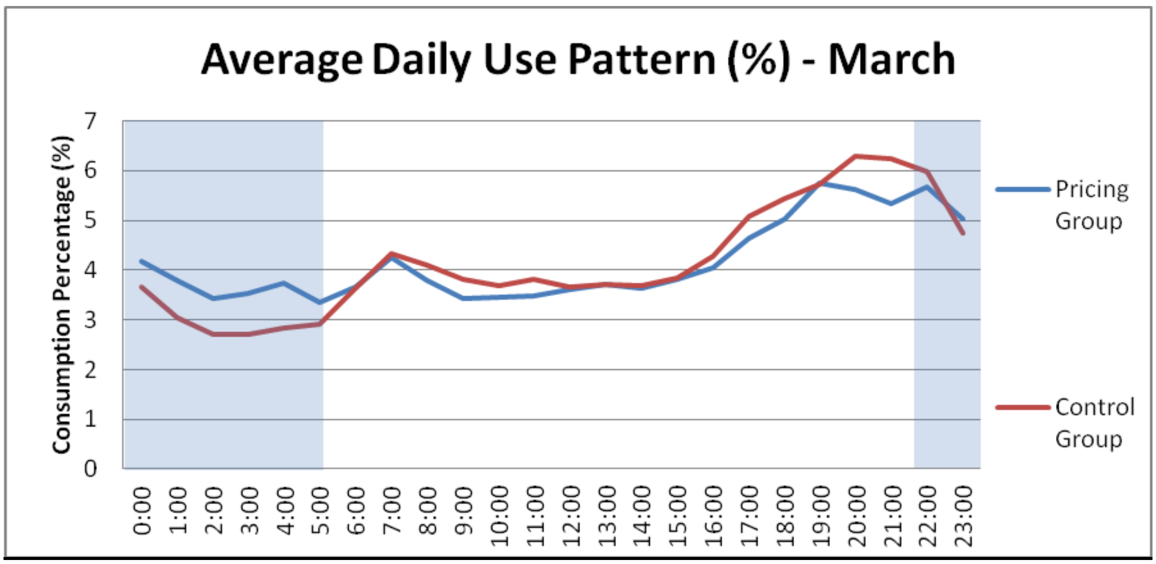


Figure 27. March 2013 Overall Hourly Usage Profile in Percentage

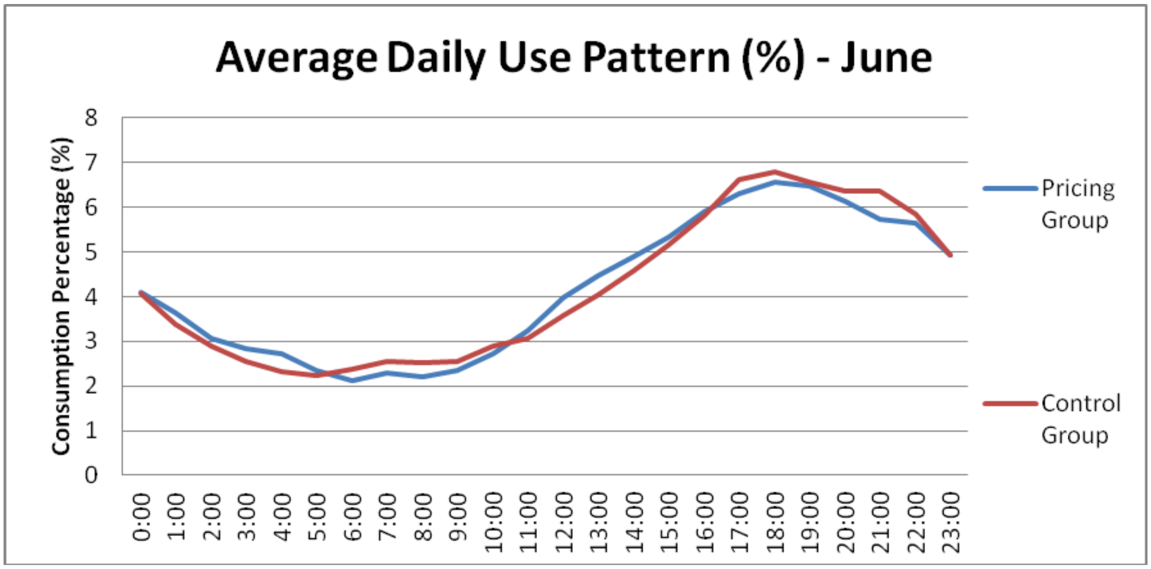


Figure 28. June 2013 Overall Hourly Usage Profile in Percentage

Reviewing the individual circuit consumption profiles, the greatest shift is for "electric car charging". Comparing the figures below for "wind" months versus the month of June (a "non-wind" month), it is notable that the TOU pricing group (blue line) is diligent in charging their cars after 10 p.m. only when there is a pricing incentive. Since only a small number (4) of the control group own electric vehicles, conclusions are being withheld for now on control group behavior with respect to vehicle charging. This will be a topic for survey questions to help better understand the exhibited behavior.

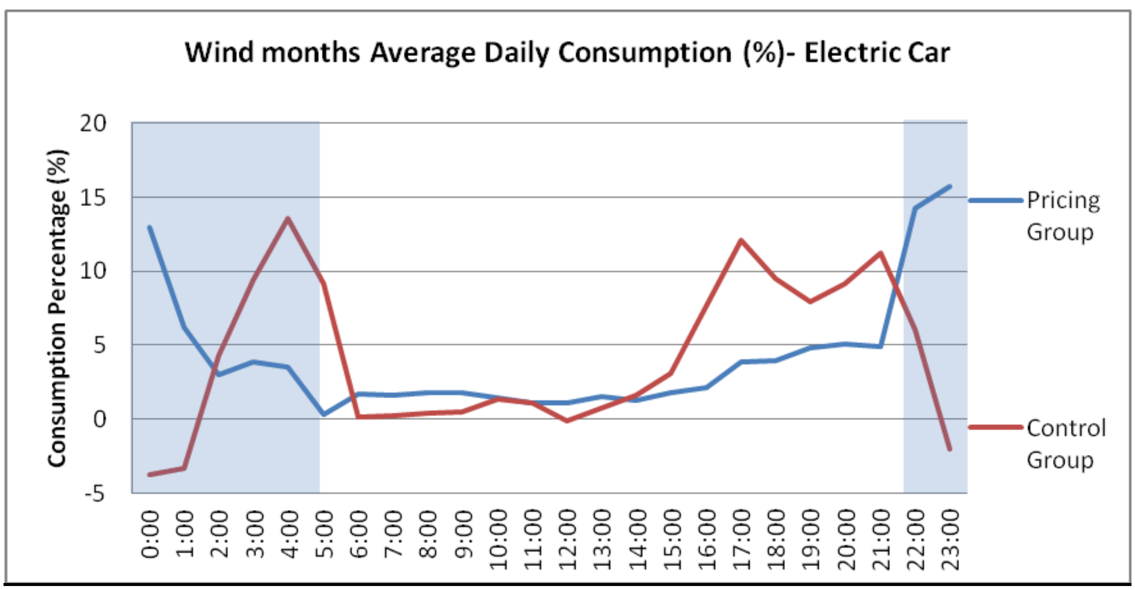


Figure 29. March to May 2013 Average Daily Electric Car Usage Pattern in Percentage

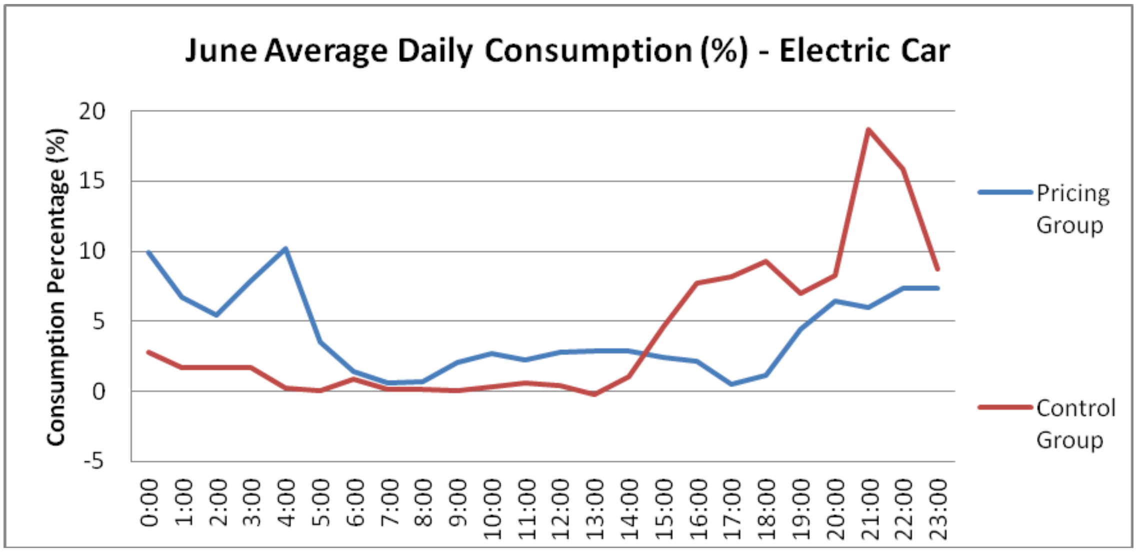


Figure 30. June 2013 Average Daily Electric Car Usage Pattern in Percentage

For laundry-related consumption, the results noted a slight usage shift toward the overnight hours during the "wind months". However, as anticipated, there was no shift noted for kitchen appliance usage as the less expensive wind enhancement pricing didn't begin until 10 p.m.

Critical Peak Pricing Event Analysis

As of early September, 11 CPP days have been called. It is interesting to note that participant response in reducing peak load is much better on some CPP days than on others. For example, the two graphs below show hourly load profiles on 26 June and 1 August for comparison. The first, 26 June, is an example of a strong response (heavy black line) in reducing load during the peak pricing hours (shaded band), while the second graph, 1 August, indicates virtually no response. The other non-bolded lines on each graph are for the immediately preceding (4) weekdays – baseline days – representing behavior without peak pricing.

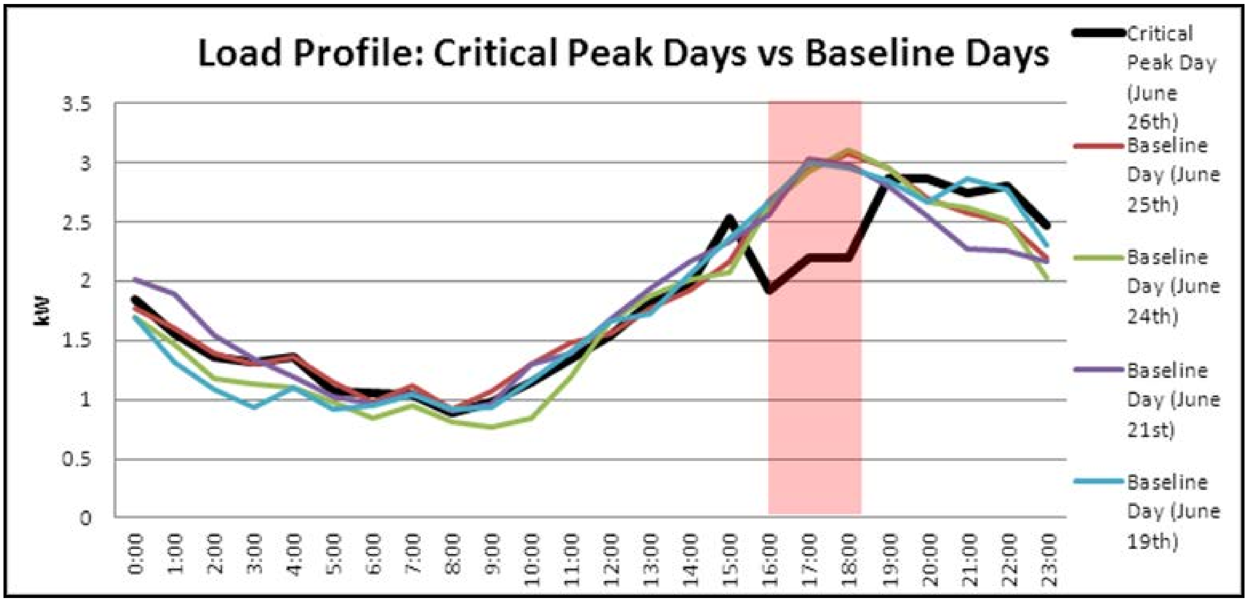


Figure 31. Second Critical Peak Day (26 June) Load Pattern Comparison

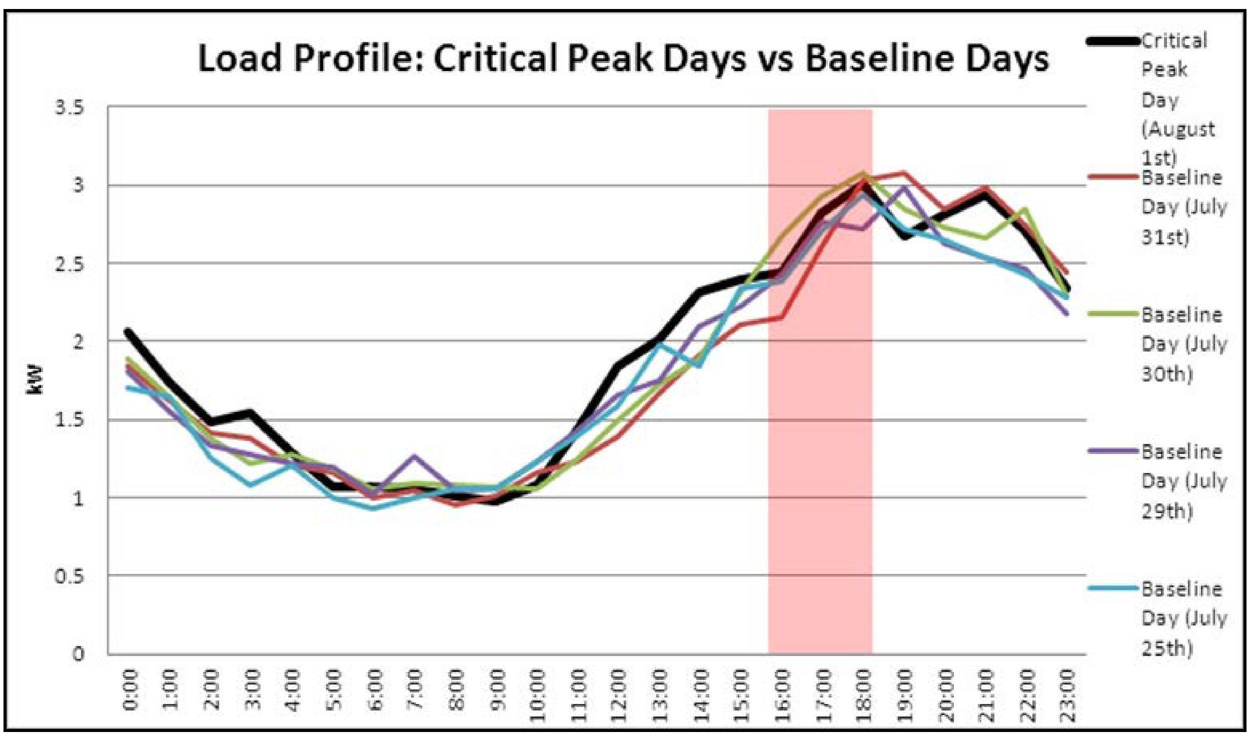


Figure 32. Sixth Critical Peak Day (1 August) Load Pattern Comparison

Two methods, explained below, have been applied to estimate the kW savings for peak day versus baseline days. The first method is called the “Day Matching Method” and uses raw kW data without weather adjustment. The second “weather adjusted” method is more meaningful and representative of participant behavior.

In the “Day Matching Method”, the kW savings is calculated as the difference between the average whole-house load (kW) during the 4 p.m. – 7 p.m. hours on a CPP day versus the “baseline kW”, defined as the average kW for the same hours of the immediately preceding four non-CPP weekdays. The following example shows the kW savings calculation for the 20 June CPP day. Note that 14 June was not included in the baseline average because it was an unseasonably cool day.

Table 5. Example of Critical Peak Pricing Day kW Savings Calculation (Day Matching Method)

Day	Baseline Period kW	CPP kW	kW savings
20-Jun		2.099958789	
19-Jun	2.89702902		
18-Jun	2.35090962		
17-Jun	2.884796772		
14-Jun	~~2.0854566~~*		
Average	2.71091180	2.099958789	0.61095301

o Not used in average (unseasonably cool day)

Using this method, the estimated kW savings for the first 11 CPP days are tabulated below.

Table 6. Estimated kW Savings for First 11 CPP Days

Date	***Event***	***Daily High***	***kW savings***
6/20/2013	1	97°F	0.610953010
6/26/2013	2	102°F	0.754866082
6/28/2013	3	105°F	0.678640836
7/24/2013	4	97°F	0.253308756
7/26/2013	5	100°F	0.186928027
8/01/2013	6	103°F	- 0.061693708
8/07/2013	7	105°F	0.392144498
8/08/2013	8	104°F	0.396105151
8/29/2013	9	101°F	0.100243563
8/30/2013	10	103°F	- 0.129503337
9/05/2013	11	100°F	0.289931967

As noted in the last column of the table above, demand reduction (kW savings) per event is irregular and appears to generally trend downward over time.

Because it is known that temperatures on baseline days (4 days immediately prior to the peak day) are generally, by definition, lower than on peak days, Frontier also used a second alternative analysis methodology – fixed effects panel data analysis – to produce “weather adjusted” results, thus accounting for this “baseline temperature penalty” in the savings calculation. It was also suspected that there may be a “bounce over” in energy use to the hour preceding (pre-cooling) and following (recovery) the peak period, so those hours were also included in the analysis. The panel data analysis segregates the weather effects from the behavior change during the peak event, giving more representative results. Since hourly weather data is downloaded from a National Oceanic and Atmospheric Administration (NOAA) database that is updated monthly, Frontier has to date been able to calculate “weather adjusted” kW savings for only the first 5 events through 31 July, as tabulated below:

Table 7. Weather Adjusted kW Savings for First Five Events

Date	*Event*	*Daily High*	*kW savings*
6/20/2013	1	97°F	0.4777
6/26/2013	2	102°F	0.7797
6/28/2013	3	105°F	0.8121
7/24/2013	4	97°F	0.3605
7/26/2013	5	100°F	0.3592

As noted in the table, the estimated weather adjusted kW savings are generally greater (and more meaningful) than using raw data as they are more representative of participant pricing response. This will be the preferred method of analysis going forward.

Pricing response peak reduction will be monitored, and survey questions will be utilized to correlate participant behavior to results.

4.4.2 Impact Metrics and Benefits Analysis

The metrics and benefits analysis will be detailed in the next increment of the TPR.

4.4.3 Stakeholder Feedback

For this initial TPR, there are no observations from stakeholders on the impact of this project.

4.5 Residential Demand Response

This section covers the operation of smart grid technologies and systems, including the demonstration results; impact metrics and benefits analyses; and any stakeholder feedback received to date.

4.5.1 Operation of Smart Grid Technologies and Systems

The use of broadband networks to deliver the DR signals to in-home devices has not achieved a high percentage of success, thus limiting the economic benefits of performing residential DR. The proposed solution is to also transmit the DR signals across the AMS networks, through the smart meter to the in-home devices. There are potential technical hurdles to be resolved so that the HAN devices can accept signals through two different communication networks; however, once resolved, the improved success rate of these DR efforts could significantly contribute to reducing electric load across the grid when needed.

The team started Phase 1 with the equipment configuration most widely deployed in the field, but early testing revealed the following.

- Initial configuration focused on those devices widely deployed (White Rogers PCTs).
- Testing revealed that the initial configuration would not support SEP protocols and is not upgradable over the air.
- Not economically feasible to roll a truck.

The team then conducted a workshop to evaluate alternative approaches to resolve the issues. The team decided to repeat Phase 1 and continue with the dual path approach but switch configuration to a new product (Carrier PCT) that had been deployed more recently. The approach is outlined in the figure below, and is followed by details on the various testing to date.

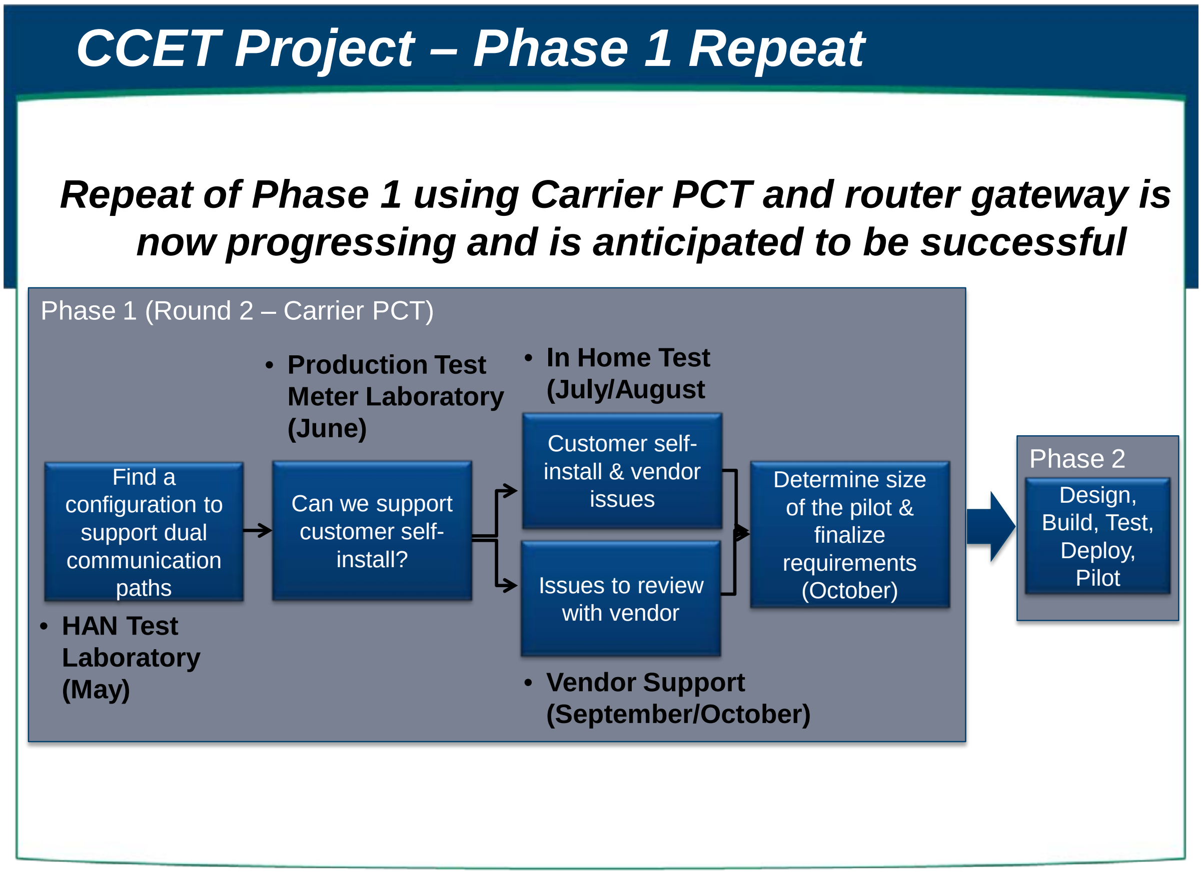


Figure 33. Repeat of Phase 1

HAN Test Laboratory

The objective of this test was to determine which configuration would support communication via both paths, the Internet and the SMT/AMI network. The scope of the testing involved the following:

- SMT commands initiated from the Landis & Gyr test tool
- Vendor (Comverge) commands initiated from their back-office system at the REP via Internet
- Provision/De-provision the meter with the gateway (using SMT)
- Test interoperability between the meter and the gateway
- Test interoperability from the meter to the PCT via the gateway
- Ability to maintain connection with the vendor back-office system and the meter
- Test and discover what happens at the PCT when it receives the vendor proprietary DR command (via the Internet) as well as the SEP DR command (via the SMT)

The results of the testing revealed the following:

- Of eight possible combinations of gateway configuration and HAN network configuration, one configuration accomplished a “partial pass”
- One configuration supported the necessary communication via the new SMT /AMI path and provided partial communication via the existing vendor/Internet path

- Defined three issues to review with the vendor to determine potential for full pass
  - DR command via vendor system – issue with provisioning process – tested a work around
  - Telemetry data from the PCT to the vendor back-office system – used for validation and also customer-rich experience
  - Vendor framework global settings based on router type – different from the production environment settings
- Raised the question of whether or not the combined installation /commissioning process could be addressed by a customer performing a self-install to avoid a costly truck roll

Production Test Meter Laboratory

This second level of testing had three objectives:

- Determine if it is possible for a customer to switch out the gateway or will it require a truck roll with a trained installer
- Become familiar (hands on) with the use of the SMT HAN application programming interfaces (APIs)
- Verify work around for previously identified vendor provisioning issue

The scope of this testing included the following:

- SMT commands initiated from SMT user interface SOAP tool into SMT test environment connected to the utility production test meter laboratory
- Vendor commands initiated from back-office system via the Internet
- Tested use cases of leveraging both communication paths to support the existing DR program (Internet) and allow use of SMT communication path for DR commands
- Test work-arounds to vendor issue
- Document the combined installation/commissioning process and evaluate the potential for a customer self install

The findings of the testing were:

- Testing could not be completed. The vendor back-office test system experienced an outage for a week
- Fully satisfied second objective. The team gained first-hand experience using SMT APIs
- Partially satisfied first objective. The team evaluated approaches for a hybrid install process (call center supported installation process to be tested in the field)
- Surfaced suggestions for improving process via firmware changes
- Team decided to repeat the test, but felt fairly confident that all issues were resolved or could be worked around. The repeat of the test would be conducted at the home of a “friendly” (TXU Energy employee) home

In-Home Test

The objectives of the in-home test include:

- Determine if it is reasonable to expect a customer to self-install by switching out the gateway, provisioning the devices (if necessary), and contacting the vendor for testing

- Work around vendor DR issue from previous testing
- Work around vendor global setting configurations from previous testing

The scope and results will be documented and reported in the next iteration of this TPR.

4.5.2 Impact Metrics and Benefits Analysis

The architecture and components for the dual-path DR configuration are still undergoing field testing so there are no metrics yet to analyze. They will be included in the next iteration of the TPR.

4.5.3 Stakeholder Feedback

For this initial TPR, there are no observations from stakeholders on the impact of this project.

4.6 Distribution-Level Battery Energy Storage System

This section covers the operation of smart grid technologies and systems, including the demonstration results; impact metrics and benefits analyses; and any stakeholder feedback received to date.

4.6.1 Operation of Smart Grid Technologies and Systems

There are two primary sets of data that will be analyzed: wind turbine related data and BESS related data. Since the BESS was just deployed to and installed at the Reese Technology Center in August 2013, there really is little data of value to be analyzed at this time. Those results will be included in the next increment of this TPR. However, some months of data have been collected and analyzed related to wind power and those are included below:

Wind power related data

Nine months of daily power production, wind speed and price data has been collected and analyzed from the Alstom wind turbine at the Reese Technology Center as of June 2013. The figures below show daily average data of the power sent to the Hurlwood substation in kW, the (Alstom) turbine production, and the locational margin pricing (LMP) for the months of April, May, and June 2013. The power production and cost analysis is done to provide a baseline for the performance of economic dispatch analysis to determine optimal battery charge/discharge schedules.

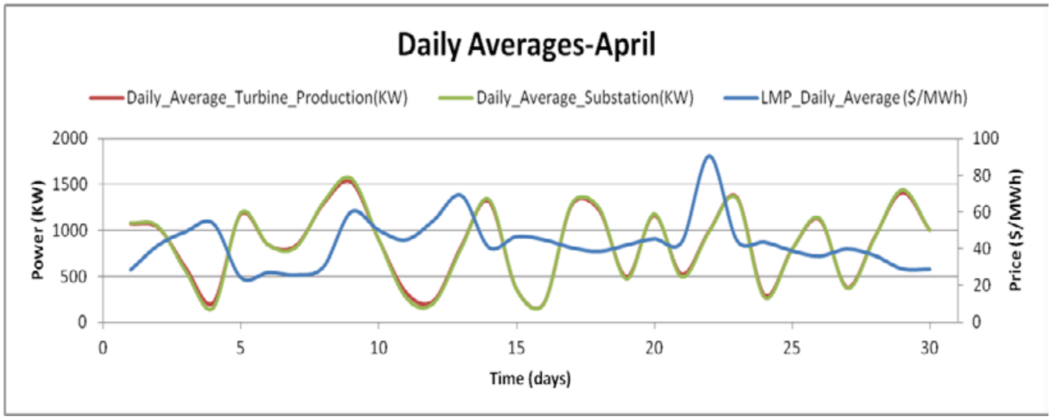


Figure 34. Daily Averages for April 2013

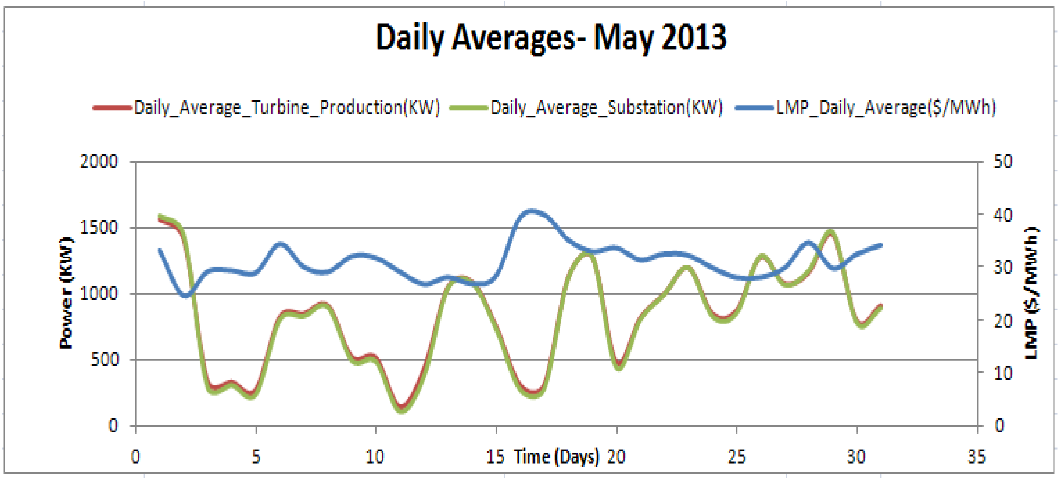


Figure 35. Daily Averages for May 2013

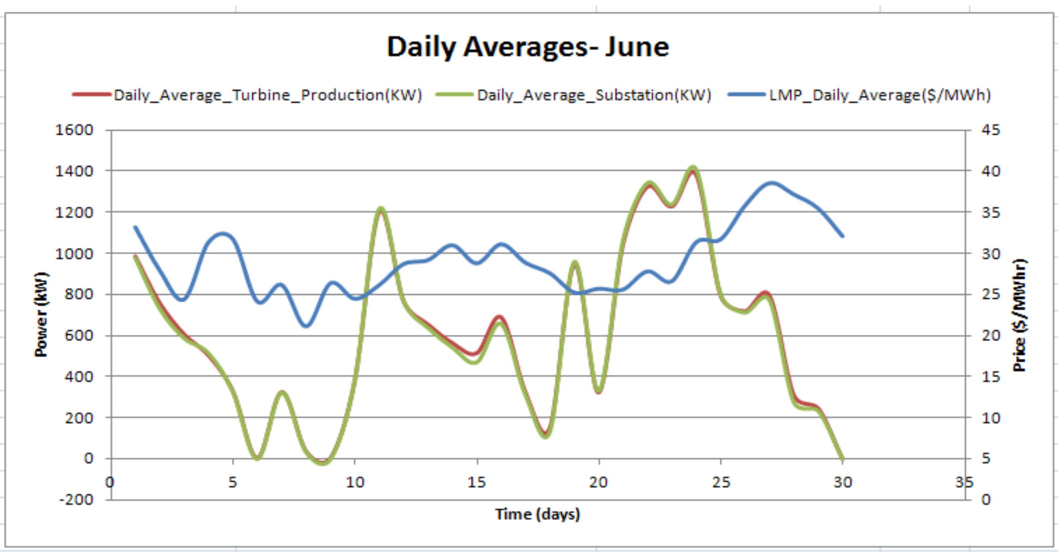


Figure 36. Daily Averages for June 2013

Beginning in July 2013, the SWiFT turbines became operational and data became available. The following data analysis is similar to that shown above, but shows separate graphs for the Alstom daily averages and the SWiFT daily averages for the months of July and August. These depict the daily average power produced and delivered to the Hurlwood Substation.

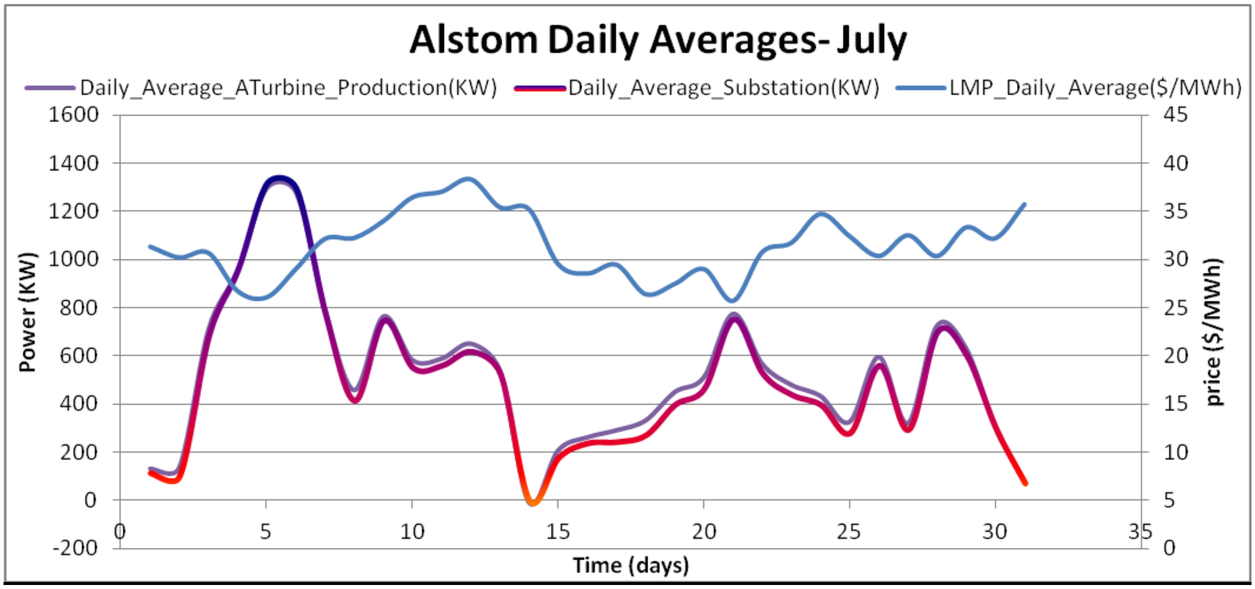


Figure 37. Alstom Turbine Daily Average Power during July 2013

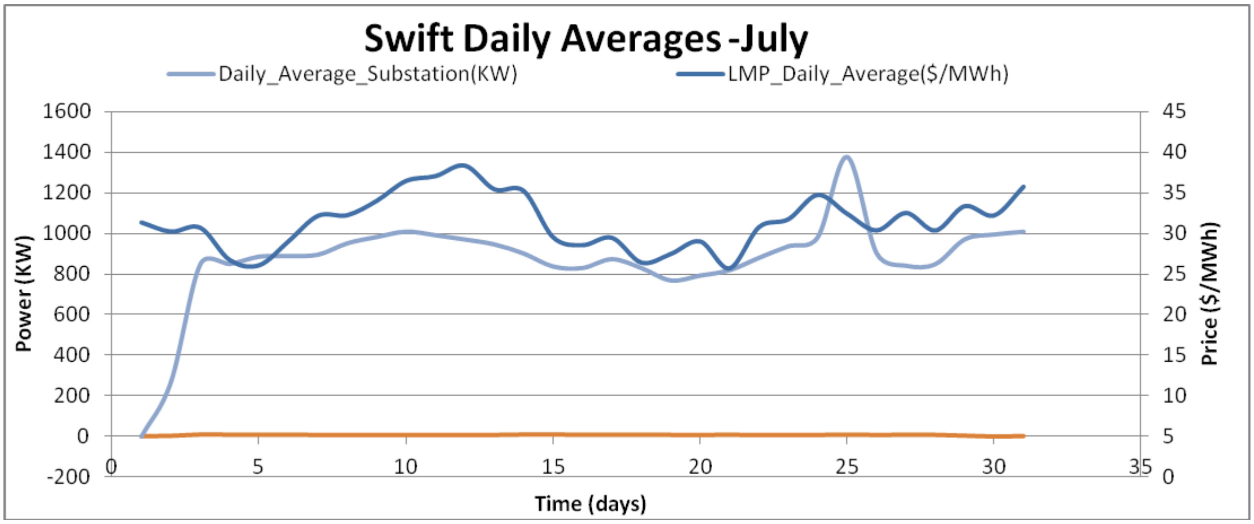


Figure 38. SWiFT Turbine Daily Average Power during July 2013

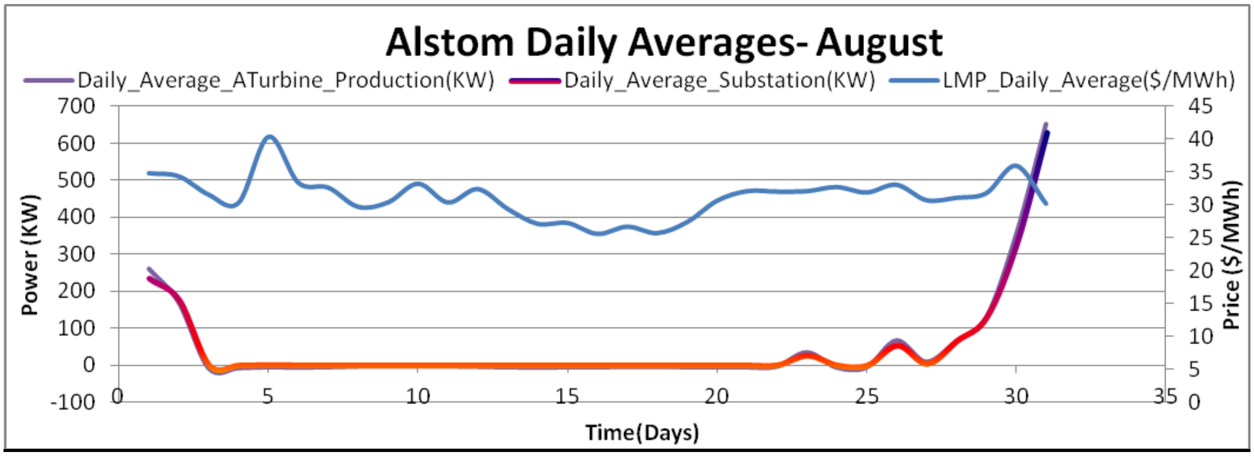


Figure 39. Alstom Turbine Daily Average Power during August 2013

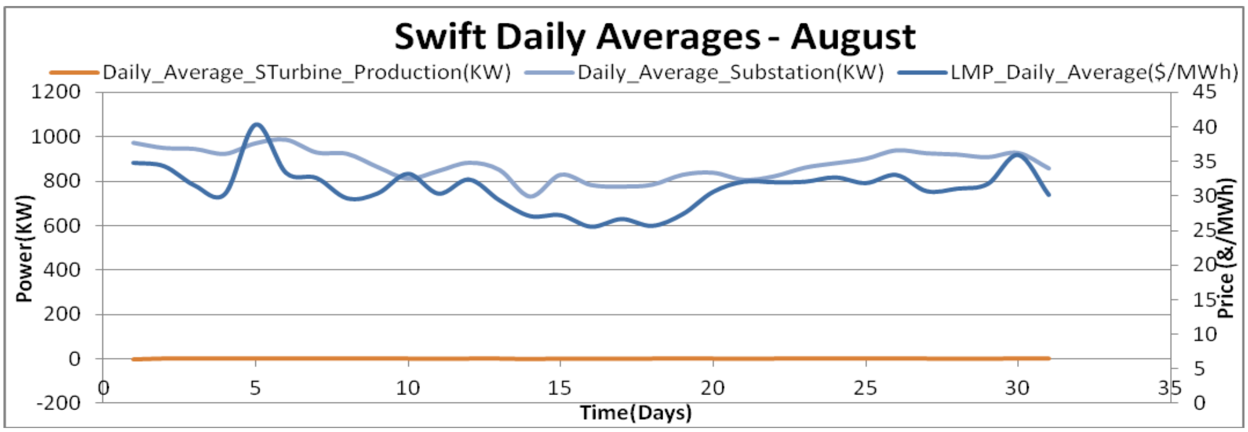


Figure 40. SWiFT Turbine Daily Average Power during August 2013

The final two graphs compare the daily averages between Alstom and SWiFT production for July and August 2013.

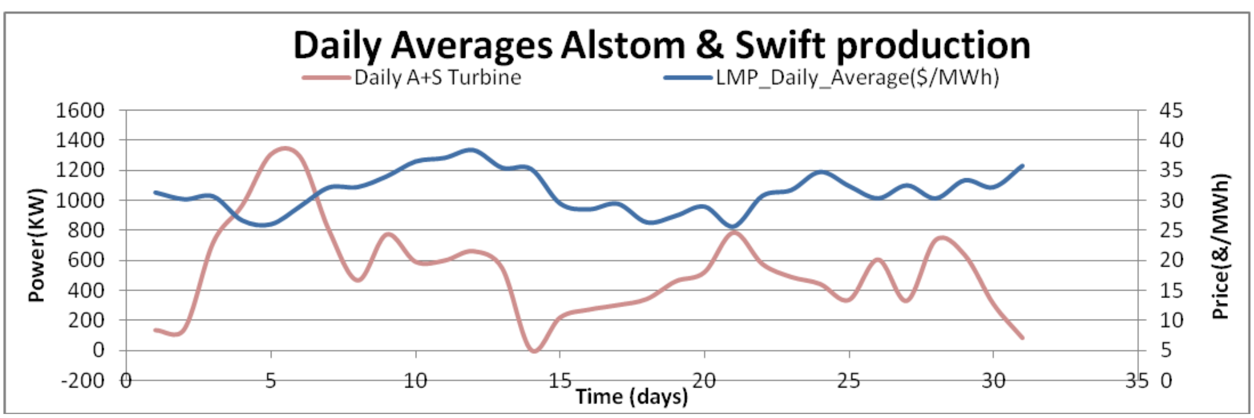


Figure 41. Daily Average Power Production for the Alstom and SWiFT Turbines – July 2013

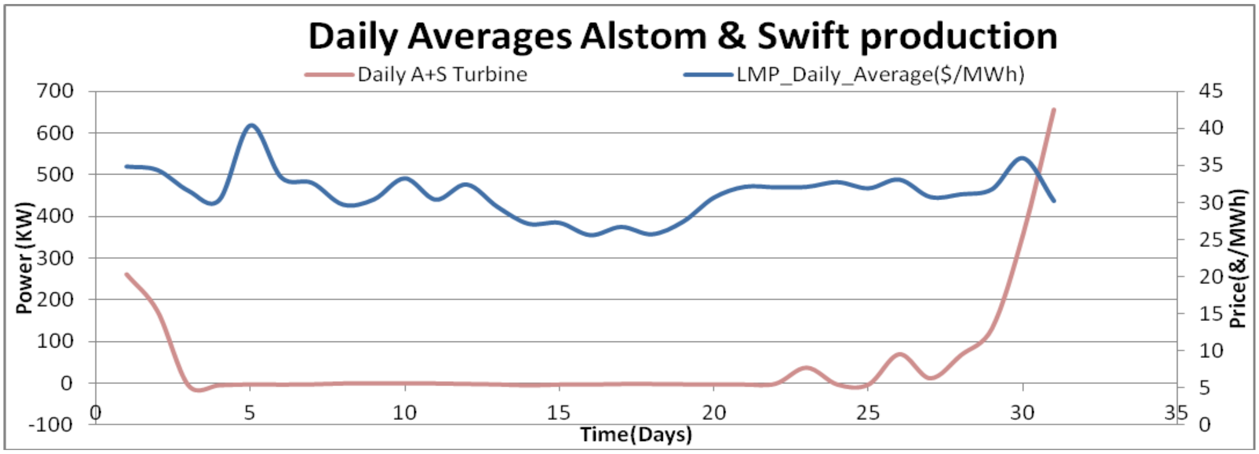


Figure 42. Daily Average Power Production for the Alstom and SWiFT Turbines – August 2013

4.6.2 Impact Metrics and Benefits Analysis

The metrics and benefits will be defined in the next increment of the TPR.

4.6.3 Stakeholder Feedback

For this initial TPR, there are no observations from stakeholders on the impact of this project.

4.7 Fast Response Regulation Service with Fleet Electric Vehicles

This section covers the operation of smart grid technologies and systems, including the demonstration results; impact metrics and benefits analyses; and any stakeholder feedback received to date.

4.7.1 Operation of Smart Grid Technologies and Systems

The specific technologies and systems for this FRRS effort are still being defined. These details will be provided in the next increment of the TPR.

4.7.2 Impact Metrics and Benefits Analysis

As this project is still being formulated, the specific metrics and benefits have not been defined. This section provides some insight into what those metrics and benefits might be. They will primarily revolve around two key concepts: 1) ability to participate in FRRS according to the rules outlined by ERCOT, and 2) the economic benefits realized from using an EV fleet for FRRS. The anticipated items to be included in the future impact metrics and benefits analysis include:

- Power response to FRRS signals. This metric will measure the EV fleet response to an FRRS signal based on an appropriate power level and maintaining that power level for the defined time period without significant deviation.
- Frequency deviation detection. This metric will involve capturing frequency from the grid at 32Hz sampling rates and the detection of deviations at a resolution of 0.01Hz.

- Time to implement FRRS signal. Participation in the ERCOT FRRS pilot requires implementation at either the specified power level or at full offered power with 60 cycles (1 second) of either notification via ERCOT signal or detection of frequency deviation through power line monitoring. This metric will capture the implementation time.
- Percent of successful deployments in offering period. This metric will indicate the success rate for meeting deployment obligations during the offering period (1 hour). The metric will combine the ability to implement within 60 cycles and the ability to sustain deployment to within 95% - 110% of obligated capacity, both of which are required for successful response.
- Percent of successful deployments during pilot. This metric will compare the results of responding to all of the offering periods during the pilot.
- Economic impact or benefit to fleet owner. This metric will compare the revenue generated through participation in FRRS versus any penalties that would have been assessed by ERCOT as a result of unsuccessful deployments. This metric will be compiled for each offering period, and for the pilot period.

Ultimately, the economic benefit to the fleet owner will be defined based on not only potential revenue but also considering the costs to configure a fleet for participation and any operational impacts as a result of participation in the FRRS offerings.

4.7.3 Stakeholder Feedback

For this initial TPR, there are no observations from stakeholders on the impact of this project.

5. CONTACTS

This section lists key CCET team member and DOE contacts for the project.

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6. ACRONYMS

The table below defines the acronyms used in this TPR.

AEP	American Electric Power
AMS	Advanced Meter(ing) System
BESS	Battery Energy Storage System
CCET	Center for the Commercialization of Electric Technologies
CPP	Critical Peak Pricing
DG	Distributed Generation
DOE	Department of Energy
DR	Demand Response
DST	Discovery at Spring Trails
EID	Energy Internet Demonstration
EPG	Electric Power Group
ERCOT	Electric Reliability Council of Texas
ETT	Electric Transmission of Texas
EV	Electric Vehicle
FRRS	Fast Response Regulation Service
GNIRE	Group NIRE (National Institute for Renewable Energy)
GSEC	Golden Spread Electric Cooperative
HAN	Home Area Network
HEM	Home Energy Management
IEEE	Institute of Electrical and Electronics Engineers
IRB	Internal Review Board
ISO	Independent System Operator
LMO	Lithium Manganese Oxide
LR	Legends Ranch
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration

PDC	Phasor Data Concentrator
PEV	Plug-in Electric Vehicle
PGDA	Phasor Grid Dynamics Analyzer
PI	Principal Investigator
PM	Project Manager
PMO	Project Management Office
PMU	Phasor Measurement Unit
PV	Solar Photovoltaic
QSE	Qualified Scheduling Entity
REP	Retail Electric Provider
RTC	Reese Technology Center
RTDMS	Real-Time Dynamics Monitoring System
SGCT	Smart Grid Computational Tool
SGRDP	Smart Grid Regional Demonstration Project
SMT	Smart Meter Texas
SPEC	South Plains Electric Cooperative
SPP	Southwest Power Pool
SwRI	Southwest Research Institute
SWiFT	Scaled Wind Farm Technology
TBR	To Be Reviewed
TBD	To Be Determined
TDSP	Transmission and Distribution Service Provider
THD_v	Total Harmonic Distortion (voltage)
THD_i	Total Harmonic Distortion (current)
TOU	Time Of Use
TPR	Technology Performance Report
TTU	Texas Tech University
WiSE	Wind and Science Engineering

A. BUILD METRICS APPENDIX

This appendix provides the most recent build metrics (equipment totals and cost) data that was provided to the DOE.

Customer Systems Assets - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

Implemented Customer Systems	Units	Project	System
In-Home display: devices installed	#	0	15,000
Direct Load Control Devices: devices installed	#	0.0	0.0
Programmable Communicating Thermostats: devices installed	#	1,385	40,000
Smart Appliances: devices installed	#	0	0
Energy Management Devices/Systems: devices installed	#	0.0	0.0
Other Devices installed	#	0	0
Other Devices installed	#	0	0
Other Devices installed	#	0	0

Web Portal	Units	Project	System
Web portal: Is portal in production?	yes/ no	☐	☒
Customers with access	#		6,603,495
Customers with active accounts	#		38,646

Customer System Descriptions

	Project	System
In-Home Displays	CCET is leveraging the customer systems within the Pecan Street demonstration project, so these systems will be reported as part of the Pecan Street metrics.	In addition to the customers of Pecan Street, a number of retail electric providers in Texas are providing their customers with IHDs.

Customer System Descriptions

	Project	System
Direct Load Control Devices		
Programmable Communicating Thermostats	CCET is utilizing PCTs (and gateways) that TXU Energy has installed in customer homes, and they will be participating in demand response experiments.	TXU Energy, other retail electric providers, and some utilities are deploying PCTs.
Smart Appliances	CCET is leveraging the customer systems within the Pecan Street demonstration project, so these systems will be reported as part of the Pecan Street metrics.	Same as project.
Energy Mgmt Systems	CCET is leveraging the customer systems within the Pecan Street demonstration project, so these systems will be reported as part of the Pecan Street metrics.	Same as project.
Web Portal	For the pricing trial, PSI has created a web portal so that customers can view their pricing trial accounts.	The Smart Meter Texas is a portal jointly funded and developed by four major utilities in Texas that is available to all of their customers who have a smart meter. The customers can view their 15-minute meter data and historical usage data. They can also provision home area network devices to receive signals through
Home Area Network	CCET is leveraging the customer systems within the Pecan Street demonstration project, so these systems will be reported as part of the Pecan Street metrics.	Same as project.

Customer System Descriptions

	Project	System
Other Device		
Other Device		
Other Device		
Additional Project Descriptions		

Customer System Installed Costs

	Units	Project Funded	Cost Share
Back Office Systems	$	0	0
Web Portals	$	47,000	0
In-Home Displays	$	0	0
Direct Load Control Devices	$	0	0
Smart Appliances	$	0	0
Programmable Communicating Thermostats	$	0	801,000
Cost of other devices installed	$	0	0

Customer System Installed Costs	Units	Project Funded	Cost Share
Cost of other devices installed	$	0	0
Cost of other devices installed	$	0	0
Other Costs	$	0	0

Other Cost Description

Pricing Programs - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

Implemented Rate Plans	Units	Project	System
Flat Rate: is the pricing program available?	yes/ no	☐	☒
Flat Rate: number of customers with access	#		
Flat Rate: number of customers enrolled	#		
Flat Rate with Critical Peak Pricing: is the pricing program available?	yes/ no	☐	☒
Flat Rate with Critical Peak Pricing: number of customers with access	#		
Flat Rate with Critical Peak Pricing: number of customers enrolled	#		
Flat Rate with Peak-Time Rebate: is the pricing program available?	yes/ no	☐	☐
Flat Rate with Peak-Time Rebate: number of customers with access	#		
Flat Rate with Peak-Time Rebate: number of customers enrolled	#		
Tiered Rate: is the pricing program available?	yes/ no	☐	☒
Tiered Rate: number of customers with access	#		
Tiered Rate: number of customers enrolled	#		
Tiered Rate with Critical Peak Pricing: is the pricing program available?	yes/ no	☐	☐
Tiered Rate with Critical Peak Pricing: number of customers with access	#		
Tiered Rate with Critical Peak Pricing: number of customers enrolled	#		
Tiered Rate with Peak-Time Rebate: is the pricing program available?	yes/ no	☐	☐
Tiered Rate with Peak-Time Rebate: number of customers with access	#		
Tiered Rate with Peak-Time Rebate: number of customers enrolled	#		
Time of Use Rate: is the pricing program available?	yes/ no	☐	☒
Time of Use Rate: number of customers with access	#		

Implemented Rate Plans	Units	Project	System
Time of Use Rate: number of customers enrolled	#		
Time of Use Rate with Critical Peak Pricing: is the pricing program available?	yes/ no	☐	☒
Time of Use Rate with Critical Peak Pricing: number of customers with access	#		
Time of Use Rate with Critical Peak Pricing: number of customers enrolled	#		
Time of Use Rate with Peak-Time Rebate: is the pricing program available?	yes/ no	☐	☒
Time of Use Rate with Peak-Time Rebate: number of customers with access	#		
Time of Use Rate with Peak-Time Rebate: number of customers enrolled	#		
Real-time Pricing: is the pricing program available?	yes/ no	☐	☐
Real-time Pricing: number of customers with access	#		
Real-time Pricing: number of customers enrolled	#		
Real-time Pricing with Critical Peak Pricing: is the pricing program available?	yes/ no	☐	☐
Real-time Pricing with Critical Peak Pricing: number of customers with access	#		
Real-time Pricing with Critical Peak Pricing: number of customers enrolled	#		
Real-time Pricing with Peak-Time Rebate: is the pricing program available?	yes/ no	☐	☐
Real-time Pricing with Peak-Time Rebate: number of customers with access	#		
Real-time Pricing with Peak-Time Rebate: number of customers enrolled	#		
Variable Peak Pricing: is the pricing program available?	yes/ no	☐	☐
Variable Peak Pricing: number of customers with access	#		
Variable Peak Pricing: number of customers enrolled	#		
Pre-pay Pricing: is the pricing program available?	yes/ no	☐	☒
Pre-pay Pricing: number of customers with access	#		
Pre-pay Pricing: number of customers enrolled	#		
Net Metering: is the pricing program available?	yes/ no	☐	☐

Implemented Rate Plans

Implemented Rate Plans		Units		Project	System
Net Metering: number of customers with access		#			
Net Metering: number of customers enrolled		#			
Other program available	Tiered + Wind Enhancement + CPP	yes/	no	☒	☒
Other programs: number of customers with access		#		60	60
Other programs: number of customers enrolled		#		60	60
Other program available		yes/	no	☐	☐
Other programs: number of customers with access		#			
Other programs: number of customers enrolled		#			
Other program available		yes/	no	☐	☐
Other programs: number of customers with access		#			
Other programs: number of customers enrolled		#			
Rate Decoupling: is implemented?		yes/	no	☐	

Rate Plan Descriptions

	Project	System
Flat Rate		Flat rate pricing is available to all customers in the service area if they select a retail electric provider that offers it.
Flat Rate with Critical Peak Pricing		Flat rate with CP pricing is available to all customers in the service area if they select a retail electric provider that offers it.

Rate Plan Descriptions

	Project	System
Flat Rate with Peak Time Rebate		
Tiered Rate		Austin Energy, the utility that supports the Pecan Street, uses a tiered rate billing system.
Tiered Rate with Critical Peak Pricing		
Tiered Rate with Peak Time Rebate		
Time of Use Rate		TOU pricing is available to all customers in this service area if they select a retail electric provider that offers it.
Time of Use Rate with Critical Peak Pricing		TOU with CP pricing is available to all customers in the service area if they select a retail electric provider that offers it.

Rate Plan Descriptions

	Project	System
Time of Use Rate with Peak Time Rebate		TOU with PTR pricing is available to all customers in the service area if they select a retail electric provider that offers it.
Real-Time Rate		
Real-time Rate with Critical Peak Pricing		
Real-time Rate with Peak Time Rebate		
Variable Peak Pricing		
Pre-paid Rate		Pre-paid pricing is available to all customers in this service area.

Rate Plan Descriptions

	Project	System
Net Metering Rate		
Other program Tiered + Wind Enhancement	In 2013, the project began pricing experiments which include this rate plan. It includes a slight revision of the Austin Energy tiered system along with a wind enhancement component for the winter shoulder months (5) and a critical peak price component during the summer months (4).	Same as project.
Other program		
Other program		
Additional Project Descriptions		

Distributed Energy Resources - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

Distributed Energy Resources	Units	Project	System
Distributed generation: number of units	#	1	1
Distributed generation: installed capacity	kW	1,670	1,670
Distributed generation: total energy delivered	* kWh	719	719
Energy storage: number of units	#	0	0
Energy storage: installed capacity	kW	0.0	0.0
Energy storage: total energy delivered	* kWh	0.0	0.0
Plug-in electric vehicles charging points: number of units	#	0	0
Plug-in electric vehicles charging points: installed capacity	kW	0.0	0.0
Plug-in electric vehicles charging points: total energy delivered	* kWh	0.0	0.0
DER/DG interconnection equipment: number of units	#		

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

Distributed Energy Resource Descriptions

	Project	System
Distributed Generation Interface Description	CCET is leveraging DER systems within the Pecan Street demonstration project, but these systems will be reported as part of the Pecan Street metrics. CCET is also leveraging wind energy from one turbine at the Reese Technology Center.	In addition to the one wind turbine that is supporting the CCET project, three more smaller wind turbines were recently installed and commissioned at the Reese Technology Center as part of a Sandia National Labs effort. Once they are energized, their specifics will be included in the system metrics.

Additional Project Descriptions

Group NIRE is facilitating the deployment and testing of various wind turbine technologies at the Reese Technology Center. These commitments, including the supporting infrastructure, are being offered as cost share to the CCET project. Efforts to date include an installed 1.67MW Alstom wind turbine, underground and above ground distribution lines, and other supporting infrastructure.

Distributed Energy Resources' Installed Costs	Units	Project Funded	Cost Share
DER Interface Control Systems	$	0	0
Communications Equipment	$	0	0
DER/DG Interconnection Equipment	$	0	0
Renewable DER	$	0	5,042,828
Distributed Generation Equipment	$	0	0
Stationary Electric Storage Equipment	$	0	0
PEVs and Charging Stations	$	0	0
Other Costs	$	0	0

Other Cost Description

Electric Distribution System Assets - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

Implemented Distribution Devices	Units	Project	System
Portion of system with SCADA	%	0	100
Portion of system with Distribution Automation (DA)	%	0	100
Automated Feeder Switches: number of devices installed	#	0	0
Automated Capacitors: number of devices installed	#	0.0	0.0
Automated Regulators: number of devices installed	#	0	0
Feeder Monitors: number of devices installed	#	6	6
Remote Fault Indicators: number of devices installed	#	0.0	0.0
Transformer Monitors (line): number of devices installed	#	0	0
Smart Relays: number of devices installed	#	0	0
Fault Current Limiter: number of devices installed	#	0	0
Other devices installed	#	0	0
Other devices installed	#	0	0
Other devices installed	#	0	0

DA Applications in Operation	Units	Project	System
Fault Location, Isolation, and Service Restoration (FLISR): is this application in operation?	yes/ no	☐	☐
Voltage Optimization: is this application in operation?	yes/ no	☐	☐
Feeder Peak Load Management: is this application in operation?	yes/ no	☐	☐
Microgrids: is this application in operation?	yes/ no	☐	☐
Other DA Application: is this application in operation?	yes/ no	☐	☐

Distribution Management System Integration

	Units	Project	System
AMI: is integration complete?	yes/ no	☐	☐
Outage Management System: is integration complete?	yes/ no	☐	☐
Transmission Management System: is integration complete?	yes/ no	☐	☐
Distributed Energy Resources: is integration complete?	yes/ no	☐	☐
Other Systems: is integration complete?	yes/ no	☐	☐

Distribution Device Description

	Project	System
SCADA	The project is not funding or leveraging funding of the SCADA system	Same as project.
Portion of system with SCADA	The project is not funding or leveraging funding of the SCADA system	Same as project.
Portion of system with DA	The project is not funding or leveraging funding of the DA system	Same as project.
DA devices	The project is not funding or leveraging funding of the DA system	Same as project.

Distribution Device Description

	Project	System
DA communications network	The project is not funding or leveraging funding of the DA system	Same as project.
Other device		
Other device		
Other device		

Distribution Application Descriptions

	Project	System
FLISR	The project is not funding or leveraging funding of the FLISR system	Same as project.

Voltage Optimization	The project is not funding or leveraging funding of any voltage optimization system	Same as project.
Feeder Peak Load Management	The project is not funding or leveraging funding of any feeder peak load management system	Same as project.
Microgrids	The project is not funding or leveraging funding of any microgrid development.	Same as project.
Other DA Applications	The project is not funding or leveraging funding of any other DA applications.	Same as project.

Distribution Management Integration Descriptions

	Project	System
AMI	The project is not funding or leveraging funding of the AMI system	Same as project.
Outage Management	The project is not funding or leveraging funding of the OM system	Same as project.

Distribution Management Integration Descriptions

	Project	System
Transmission Management	The project is not funding or leveraging funding of the transmission management system	Same as project.
DER Systems	The project is not funding or leveraging funding of the DER system	Same as project.
Distribution Management System	The project is not funding or leveraging funding of the DM system	Same as project.
Other Systems	The project is not funding or leveraging funding of any other utility system	Same as project.
Additional Project Descriptions		

Distribution Systems Installed Costs

	Units	Project Funded	Cost Share
Back Office Systems	$	0	0
Distribution Management System	$	0	0
Communications Equipment and SCADA	$	0	0

Distribution Systems Installed Costs	Units	Project Funded	Cost Share
Feeder Monitor/Indicator	$	0	89,128
Substation Monitors	$	0	0
Automated Feeder Switches	$	0	0
Capacitor Automation Equipment	$	0	0
Regulator Automation Equipment	$	0	0
Fault Current Limiter Equipment	$	0	0
Cost of other devices installed	$	0	0
Cost of other devices installed	$	0	0
Cost of other devices installed	$	0	0
Other Costs	$	0	0

Other Cost Description

Electrical Transmission System Assets - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

Implemented Transmission Devices	Units	Project	System
Portion of system covered by Phasor Measurement Units (PMUs)	%	22.98	66.53
Portion of system covered by PMUs by end of project	%		75
PMUs: number of extra high voltage (EHV) and above installed and operational	#	15	51
PMUs: number of below EHV installed and operational	#	4	4
Phasor Data Concentrators (PDC)	#	4	6
Dynamic Capability Rating System (DCRS) - Transmission Lines	#	0.0	0.0
Dynamic Capability Rating System (DCRS) - Station Transformers	#	0	0
DCRS - Other Devices	#	0	0
Substation Automation — Other devices installed	#	1	1
Other devices installed	#	0	0
Other devices installed	#	0	0

Transmission Applications in Operation	Units	Project	System
Angle/Frequency Monitoring	yes/ no	☒	☒
Post-mortem Analysis (including compliance monitoring)	yes/ no	☐	☐
Voltage Stability Monitoring	yes/ no	☒	☒
Thermal Overload Monitoring	yes/ no	☐	☐
Improved State Estimation	yes/ no	☐	☐
Steady-state Model Benchmarking	yes/ no	☐	☐
DG/IPP Applications	yes/ no	☐	☐
Power System Restoration	yes/ no	☐	☐

Transmission Device and Application Descriptions

	Project	System
PMUs EHV and Above	ERCOT currently has 55 PMUs installed in its service territory. The project cost share covers 19 of the PMUs.	There are plans to add at least 7 more PMUs to the ERCOT region and potentially an equivalent number in the SPP region of Texas, but these will be part of the larger PMU system.
PMUs Below EHV	TTU has installed a network of 4 PMUs which includes 2 on campus and two monitoring the distribution network at the Reese Technology Center.	Same as project.
PDCs	ERCOT has a PDC and three reporting utilities each have a PDC. TTU has installed two PDCs, one on its campus and one at the neighboring Reese Technology Center (about 8 miles away).	Same as project.
Communications Network	The utilities may consider upgrades of their communications networks in the future.	Same as project.
Advanced Applications	The real-time dynamics monitoring system (RTDMS) is being enhanced as part of the project. The EPG phasor grid dynamics analyzer (PGDA) is also in use for offline event analysis. ERCOT and some utilities have the RTDMS and PGDA applications.	Same as project.
DCRS - Other Device	There are no plans to install any other DCRS.	Same as project.

Other device Substation Automation	Pecan Street is upgrading one of its substations to support the homes in its community, and that effort is being provided as cost share to the CCET project.	Same as project.
Other device		
Other device		
Additional Project Descriptions		

Transmission Systems Installed Costs	Units	Project Funded	Cost Share
Back Office Systems	$	0	0
Advanced Applications	$	465,352	249,505
Dynamic Rating System	$	0	0
Communications Equipment	$	0	313,806
PDC	$	13,424	80,195
PMU	$	0	953,432
Line Monitoring Equipment	$	0	0
Cost of other devices installed — Substation Automation	$	0	4,449,432
Cost of other devices installed	$	0	0

Transmission Systems Installed Costs

	Units	Project Funded	Cost Share
Cost of other devices installed	$	0	0
Other Costs	$	0	0

Other Cost Description