Harnessing New Generation and Storage Technologies for the Grid

Successes from the Center for the Commercialization of Electric Technologies Smart Grid Demonstration Project

Introduction

Chicago may be known as the windy city, but Texas is increasingly becoming the wind-powered state. With the largest wind-generation capacity in the country and wind speeds reaching 80 miles per hour in some areas, Texas is increasingly building and operating wind turbines to power the grid. Smart grid technologies that could make wind more dispatchable were investigated by the Center for the Commercialization of Electric Technologies (CCET), located in Austin, Texas.

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CCET is a consortium of state utilities, technology companies and universities established in 2005. The project was awarded $13.5 million in American Recovery and Reinvestment Act funds, for a total project value of $27.1 million. CCET is demonstrating the technical and business feasibility of existing and new technologies that can integrate wind power into the state's grid, managed by the Electric Reliability Council of Texas (ERCOT). The project, *Discovery Across Texas*, affects 24 million customers throughout the state.

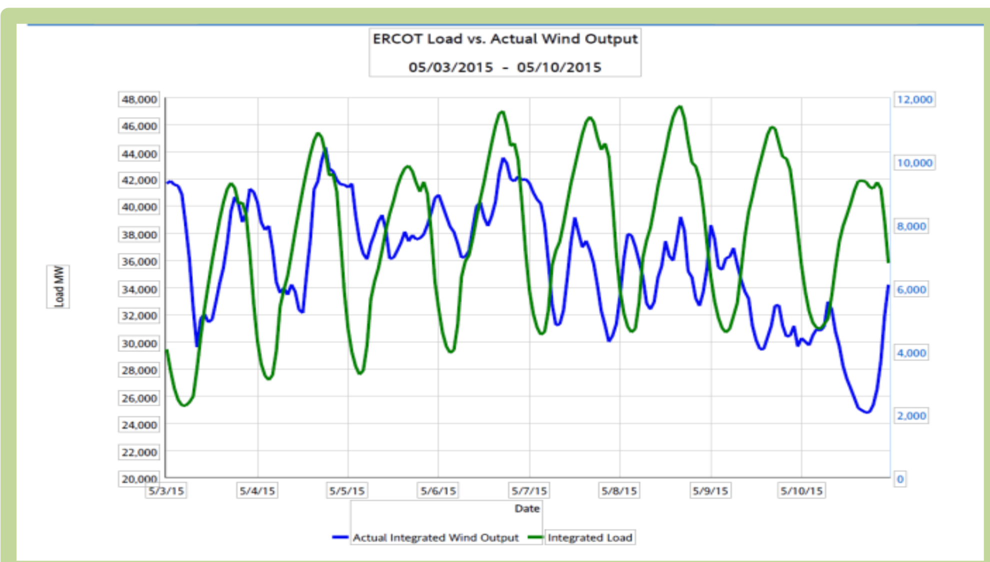

Figure 1. ERCOT load vs. wind output

In ERCOT, which serves most of Texas, wind power capacity has grown from 116 megawatts (MW) in 2000 to 13,000 MW in 2015. During 2014, wind power on average served 10.6 percent of the total ERCOT load [1]. On March

[1] ERCOT: Texas Wind Provided Nearly 11% Of Electricity For 2014, Jan. 28, 2015, http://www.nawindpower.com/e107_plugins/content/content.php?content.13868, accessed 5/13/15

29, 2015, ERCOT experienced a record for wind power supply, which reached 40.6 percent of the system load for a brief period[2]. In Figure 1, system load (green) and wind generation (blue) are shown for one typical week. The vertical axis on the right, which plots the wind output, is scaled at 25% of the vertical axis on the left, which plots the entire system load, showing that wind output is close to 25% of system load during much of the time period shown.

"In 2005, the Texas legislature made a commitment to accommodate up to 18.5 GW of wind by building out the transmission capacity to move that power to load centers in Texas," said Milton Holloway, Ph.D., CCET demonstration project principal investigator. "The transmission construction is nearing completion, and a total 19 GW of wind will soon be in place."

Seven technologies (summarized in Table 1) were picked in response to the changing mix of generation in Texas. Synchrophasors increase wide area situational awareness of the grid. To protect these data gathering assets and their communications, vendors Intel/McAfee[3] deployed cyber security protection schemes. Together with the fleet V2G effort, these three research areas improved system frequency control.

Demand management allows system load to adapt to wind and solar generation output. The Smart Meter Texas (SMT) Portal, together with advanced metering infrastructure (AMI), increased the reliability of residential response to calls for demand reduction. Combined with a time of use (TOU) pricing experiment to encourage increased loads at night when wind generation is at its peak, the load was shaped more closely to the wind generation profile.

A 1 MW, 1 MWh battery on a distribution circuit provided insights into how wind generated power can be made dispatchable. Regarding solar power, problems such as harmonic distortion due to solar generation on the distribution system were monitored to assess the risks to consumer appliances and utility transformers.

Technology implemented	Benefit
Synchrophasors	System frequency control
Security Fabric	Protect critical synchrophasor assets
Utility-Scale Battery on a Distribution Network	Dispatchable wind power
Solar Monitoring	Maintaining power quality
Time of use pricing	Demand management
SMT Portal and Demand Response	Communication over AMI
Frequency Regulation using V2G	System frequency control

Table 1. Project Implemented Technologies and Benefits

Improving Grid Reliability with Synchrophasors

Wind power is a renewable and clean source of energy, but it is variable and intermittent, with limited predictability and periods of little wind. CCET is demonstrating, however, that new monitoring technologies can help manage wind power's effects on the grid. CCET's demonstration

[1] Wind generation output in ERCOT tops 10,000 MW, breaks record, March 28, 2014, http://www.ercot.com/news/press_releases/show/26611, accessed 5/13/15

[2] Wind generation output in ERCOT tops 10,000 MW, breaks record, March 28, 2014, http://www.ercot.com/news/press_releases/show/26611, accessed 5/13/15

[3] McAfee, Cyber Secure Synchrophasor Security Fabric, http://smartamerica.org/teams/cyber-secure-synchrophasor-security-fabric/, accessed 6/9/15

project used synchrophasor technology to measure power characteristics in real time. Also known as phasor measurement units, or PMUs, synchrophasors measure the grid's voltage phase to inform utilities about the state of the electric grid. By time-stamping each measurement, synchrophasors enable utilities to compare measurements from different times and locations, thereby tracking power flows in real time, which can be useful for increasing reliability, in particular preventing blackouts.

> "Through the collaborative efforts of CCET with active participation of ERCOT and Texas utilities, CCET leveraged ARRA funding and now Texas is positioned to be among the first in the nation to use synchrophaser technology as an operator tool to improve grid reliability."

As of November 2014, utilities[4] had installed and are providing streaming synchrophasor data from 83 PMUs at 35 locations to the ERCOT real-time dynamics monitoring system (RTDMS). These efforts also attracted the attention of other utilities across Texas who began planning for deployment of additional PMUs. As of October 2014, ERCOT anticipated receiving streaming data from 94 PMUs[5] at 46 different locations during the first quarter of 2015. This extensive network now provides robust monitoring coverage[6] of the ERCOT grid and offers other benefits through new technology applications[7].

Synchrophasor systems are destined to become control-room tools for grid management and, therefore, will need to be protected from cyber-attacks under a presidential executive order known as critical infrastructure protection. This order was updated as Executive Order 13636[8] in February, 2013. CCET partners have developed and tested a security fabric product for use in synchrophasor systems.

"Through the collaborative efforts of CCET with active participation of ERCOT and Texas utilities, CCET leveraged ARRA funding, and now Texas is positioned to be among the first in the nation to use synchrophaser technology as an operator tool to improve grid reliability," Holloway said.

By quickly pinpointing potential grid issues, synchrophasor technology helps utilities take corrective actions to protect the grid, thereby improving the reliability of wind energy and the grid as a whole.

In addition, researchers demonstrated that, after an energy oscillation, they could use synchrophasor data to trace the problem back to the originating generator. In the future, PMUs may even be able to trace these oscillations in near real-time.

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[4] CCET participating utilities are:
American Electric Power, Oncor, Sharyland Utilities, Golden Spread Electric Coop, South Plains Electric Cooperative, TXU Energy

[5] Adams, John, ERCOT Use Of Synchrophasors For Operations Support At Ercot, October 23, 2014, accessed 6/23/15

[6] NASPI, ERCOT Data Mining For Oscillations from Wind Generators, March 24, 2015

[7] Early analysis of ERCOT synchrophasor data available from Grady, Mack, Experience with Synchrophasor Analysis and Applications in Electric Power Systems, http://web.ecs.baylor.edu/faculty/grady/_20130919_Mack_Grady_SEL_Niagara_Falls_Sept_19_2013.pdf, Sept. 19, 2013, accessed 6/3/15

[8] Executive Order 13636: Improving Critical Infrastructure Cybersecurity, https://www.dhs.gov/sites/default/files/publications/dhs-eo13636-analytic-report-cybersecurity-incentives-study.pdf, accessed 6/23/15

Integrating Renewable Energy into Future Smart Grid Communities

The problem of wind intermittency can be addressed with energy storage. CCET demonstrated the use of battery storage to improve wind-power grid integration, installing a battery system in Lubbock, TX with 1 MW of power and 1 MWh of energy capacity (See Fig. 2). That unit is being used to optimize the reliability of the grid by complementing the intermittency of wind, storing power during high wind and providing power during low wind conditions. A detailed analysis of the system (see Table 2) showed a benefit-to-cost ratio of 1.16 for a 20 year net present value calculation. Benefits included reduction in electricity costs due to reduced demand charges; power quality improvements in both voltage and frequency; and reduction in environmental emissions.

Benefit Category	Value (in $K)
Reduced electricity costs	2,309.6
Improved power quality	594.9
Emissions savings	546.6
Total Benefits	3,451.1
Total Costs	2,960
Benefit/Cost Ratio	**1.16**

Table 2. Battery Cost Benefits to Grid

CCET's future community demonstration also is comparing solar-powered neighborhoods to nearby neighborhoods without solar power to learn more about the impact of renewable power on the grid, particularly in months where the load is low due to reduced need for heating and cooling. Because renewable power is often generated locally, it can cancel a portion of the local load. This is important because the uncancelled resistive loading can also have a damping effect, due to absorption of energy. Low load conditions together with locally generated renewable power [9] can distort the harmonic nature of the power, possibly affecting power quality. For this analysis, researchers are using data from home-monitoring devices installed by transmission and distribution service providers and researchers in two neighborhoods, one in Houston and another in Austin. Ideas for mitigation of these power quality effects, including injecting reactive power into distributed generation sites, are under consideration by the researchers.

Figure 2. CCET 1 MW battery stack, showing cooling system at top

Another key aspect of the future community is variable electric pricing designed to measure the willingness of consumers to change behavior and

[9] The project determined that photovoltaic inverters conforming to industry standards do not appreciably distort voltage or current.

shift some home activities to times when electricity is cheaper. This project is one of the first in the country to offer night time wind-enhanced pricing, which is significantly cheaper than daytime pricing since wind often blows stronger at night. For the wind enhancement pricing trial, the night-time electric rate for the Pricing Group was lowered to $0.0265 per kWh from 10 p.m. – 6 a.m. on all days during those months. To make the experimental pricing revenue neutral, there was an offsetting surcharge of approximately $0.02 per kWh on the participants' energy consumption during all other hours of those five months. During non-wind months, consumption was statistically the same for the experimental and control groups. There was a small rebound effect during the summer, possibly due to PEV owners charging during the afternoon because of an increase in evening activities in summer. Some participants stated that they charged for convenience during daytime hours because the wind pricing scheme was not in effect during the summer. During the wind tariff months, the pricing group used an average of 4% less electricity overall, a small but statistically significant amount, considering the PEV loads are the most sensible to shift to late evening or overnight hours for most homeowners.

Also, the project performed a critical peak pricing (CPP) experiment during defined peak hours on no more than 15 designated "critical peak" days during June through September from 4-7 PM. The CPP price was $0.64 per kWh. To make the experimental pricing revenue neutral, there was an offsetting discount of approximately $0.016 per kWh on energy consumption during all non-peak hours of CPP event days. Sixty-two trial partcipants experienced 12 and 15 CPP days called in 2013 and 2014, respectively. In 2013, the average load reduction per customer per event was 0.44 kW (15.3% of load), whereas in 2014 it was 0.17 kW (6.15% of load). The drop in second year savings was partly due to persistence of the lifestyle changes made in 2013 and to a lesser extent due to customer fatigue. Further analysis showed that 40% of the CPP power reductions were due to heating, ventilation and air conditioning (HVAC) behavior changes and 22% was due to PEV charging changes. For pricing group members without PEVs, the relative contribution of HVAC jumped to 57%. A significant amount of the other power reductions came from laundry and kitchen appliances.

Pricing Group members with electric vehicles (EVs) saved about 65% more energy during CPP events on average than those without. The detailed 2013 energy use changes are depicted in Figure 3.

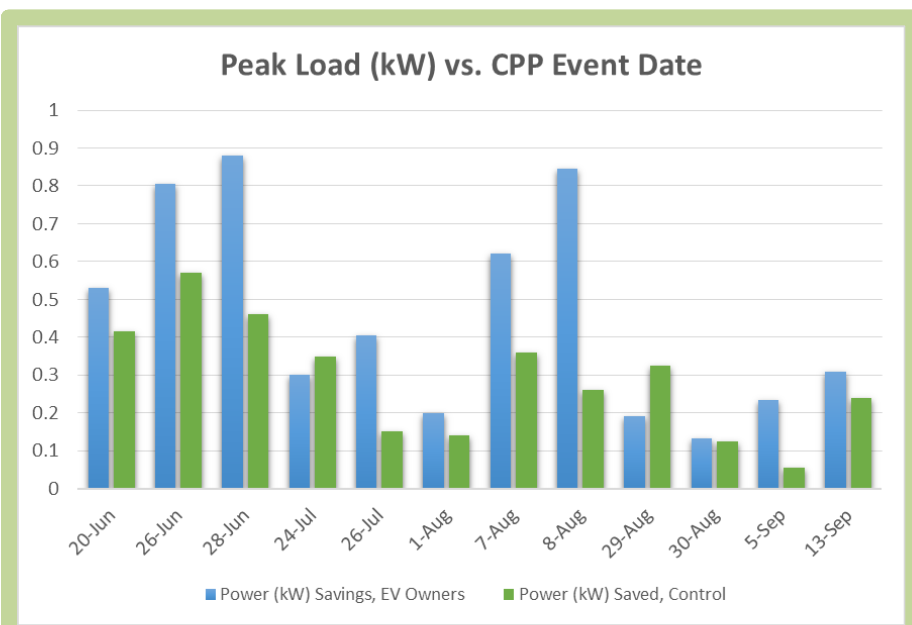

Figure 3. Reduction in Peak Load, by PEV ownership, 2013

Smart Meter Texas Portal Demonstrates Demand Response

Historically for the TXU Energy program only 55% of participants in DR progams were remotely accessed and power cycled, partly because of communication connectivity problems. In light of this history, to increase participation, CCET did a proof of concept, demonstrating that the existing Smart Meter Texas (SMT) Portal[10], managed by a consortium of electric utilities, can provide an alternate communication path for demand response signals. Leveraging the portal, a smart meter can relay the signal to the programmable communicating thermostat (PCT) and home gateway directly, enabling the consumer to participate in demand response .

"The jury is still out on the best communication technologies joined with customer smart devices and utility smart meters to realize the full benefits of demand response," Holloway said. "CCET and our partners have demonstrated the technical viability of joining smart metering system capabilities with Internet-based systems to improve the reliability of direct load control demand response in the competitive market of ERCOT." Economically, the value proposition for the SMT portal is $27 to $89 per customer per year, with payback of 4-10 years given a $300 cost for a gateway and PCT.

Electric Vehicles Leverage Cheap Wind Power

The frequency regulation market is for a so-called "ancillary service" that allows electricity generators, storage facilities and some aggregated loads to bid to provide services. Frequency regulation aims to maintain the electric grid frequency close to 60 Hz. Providers of this type of service guarantee the ability to ramp production up or down to maintain the balance of generation and load on the grid, which affects the frequency. This project demonstrated the capability of addressing frequency regulation through the use of aggregated electric vehicle (EV) fleets to provide fast response, a technology referred to as Vehicle-to-Grid (V2G). In contrast to a large utility scale battery costing millions of dollars, electric vehicles while idle can provide frequency regulation to the utility at little extra cost. The CCET solution used the National Instruments suite of components, including a CompactRIO data acquisition (DAQ) computer, with associated voltage, current, and relay modules. This DAQ monitored the electrical distribution circuit to each EV charging station. To satisfy ERCOT data collection requirements, the meter was required to measure grid conditions at a minimum of 32 times per second or better; the meter successfully measured frequency at 40 times per second, detecting deviations of 0.01 Hz from the desired frequency near 60 Hz. For instance, the fleet could contribute to keeping the frequency between 59.98 and 59.99 Hz if that was good for the grid. Keeping with system requirements for market participation, the fleet responded within one second or less with 95-100% of obligated power and the system successfully deployed to each frequency event within 450-600 ms 100% of the time. The solution was technically successful at the system architecture level and at the individual meter level.

Of direct interest to CCET was the profit potential of participation in the market. The project was not successful in the market due to participation costs that cancelled out any financial benefits. These included making a secure network connection to

[10] Smart Meter Texas website, https://www.smartmetertexas.com/CAP/public/residential/residential_faq.html, accessed 6/12/15

the ERCOT system, records management, and the control hardware. For example, control hardware costs were under $20,000 versus over $100,000 that would have been spent on individual power meters or redesigning the electrical panel box. The project showed that EVs operating in a V2G mode can be used with the grid in a manner that *would* increase wind energy dispatchability at a cost that could be recouped in scenarios where frequency regulation costs are high enough. These prices per 100 kWh fluctuated from lows of $0.50 in 2013 to over $8.00 in early 2014. The cost of 100 kWh of wholesale electricity is approximately $5, based on a cost of $50 per MWh. Frequency regulation is the recycling[11] of energy, not net energy transfer, so it makes sense that it costs less per kWh on average than energy delivery. It is typically more costly when loads are relatively high (daytime peak) or low (nighttime low)[12] on the grid. The frequency regulation benefit of EVs is in addition to the benefits EVs provide by loading the grid at night. Therefore, the experimental wind pricing and the V2G experiment can be seen as complementary investigations into how EVs help grid reliability.

Next Steps

CCET will leverage the lessons learned from the Discovery Across Texas project and that of other demonstration projects across the nation to develop new projects to help inform the Texas market about the challenges and opportunities of new technologies. CCET will help develop new applications for synchrophasor technologies, deliver the promises of demand response and investigate the potential benefits and costs of improved visibility into the distribution systems of the grid. As battery and electric vehicle technologies progress, and market regulations are updated, the technologies demonstrated by CCET during this project will play an increasing role in maintaining electric grid reliability and cost-effective delivery of electricity.

Further Reading

For more information about CCET's demonstration project, read its interim technology performance report, published on the SmartGrid.gov website. A more detailed description of SGDP can also be found at SmartGrid.gov.

Under the American Recovery and Reinvestment Act of 2009, the U.S. Department of Energy and the electricity industry have jointly invested over $1.5 billion in 32 cost-shared Smart Grid Demonstration Program projects to modernize the electric grid, strengthen cybersecurity, demonstrate energy storage, improve interoperability, and collect an unprecedented level of data on smart transmission, distribution operations and customer behavior.

[11] Lazarewicz, M.L. ; Beacon Power Corp., Wilmington, MA ; Rojas, A., Grid frequency regulation by recycling electrical energy in flywheels, IEEE conference publication, 2004, http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1373235&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D1373235

[12] Kirby, B., Frequency Regulation Basics and Trends, Oak Ridge National Laboratory, 2004, http://ferc.gov/EventCalendar/Files/20100526085937-Kirby,%20Frequency%20Regulation%20Basics%20and%20Trends.pdf