From the Grid Perspective[1]

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To successfully operate and deliver its promise of a seamlessly integrated buildings-grid infrastructure, a transactive energy ecosystem requires new approaches to planning and operating the power grid. These approaches include technological advances in the area of standards, measurements, control strategy, and theories so that the essential transactive market between buildings and the grid will fully function and deliver benefits to all participants while maintaining grid stability. This paper outlines the nature of the power grid, lists challenges and barriers to the implementation of a transactive energy ecosystem, and provides concept solutions to current technological impediments.

Overview

The electric power system, commonly referred to as the grid, produces, transmits, and distributes electrical energy to end-use customers. The grid typically is classified into three main elements: generation, transmission, and distribution. Generation can consist of both bulk-power, which connects to the transmission system, and distributed generation, which connects at the distribution level near the end-use customers. Transmission consists of high voltage power lines that move bulk power over long distances from generation sites to loads. The distribution system converts high-voltage electricity from the transmission system to voltage levels that can be used by customers.

Over time, the grid has evolved into a system that uses large central station generation to produce power and the transmission and distribution (T&D) system to deliver this power to end-use customers based on a fairly predictable demand curve. This system is operated using a two-factor approach that considers economics and stability. In the United States, there are currently three major electrical grids (the Eastern Interconnect, the Western Interconnect, and the Electric Reliability Council of Texas [ERCOT]). These grids are connected by DC-DC interties with limited power transfer capabilities, but they are not synchronized with each other. Within each Interconnect, there are a number of levels of technical and regulatory infrastructures that maintain both operational stability of the grid and some type of economic dispatch or market. Both the methods to maintain system stability and market operations differ based on regional approaches to managing the grid. As new technologies, such as variable renewable energy and advanced energy management systems become more common, the grid must continue to adapt and provide customers reliable electric power at a competitive cost.

Broadly speaking, utilities raise capital to construct generation, transmission, and distribution infrastructure required to meet their obligation to serve customers in their service territory. Some utility companies may provide only one or two of these infrastructures (i.e., are not vertically integrated) in any given area, but all three infrastructures are required to generate and deliver power to a customer's meter. Each infrastructure must have sufficient capacity to deliver the maximum electric power demand (i.e., the peak demand) during the course of the year by all customers combined. This peak demand for electricity typically, but not everywhere, occurs during late afternoon or early evening time periods on the hottest summer days of the year.

Because today's power grid has no means of storing any significant amount of electricity, electric power must be generated and delivered in nearly the exact amount being consumed at any given moment in time. Each element of the grid infrastructure (a generator, a wire, a transformer, or anything else) must be sized to handle the peak demand at its location, because catastrophic damage to equipment can occur if the flow of power exceeds the rated capacity the element for too long.

The peak demand for electricity is much higher than the average level of demand at nearly every point in the power grid: the median load on the generation system is only about 75% of the peak capacity.[2] In the distribution system, the median load is even lower at about 50% of the peak capacity, because the peak demand does not occur simultaneously at every point in a power grid: for example, urban centers tend to peak in the afternoon before workers arrive home in residential suburban neighborhoods that experience peak demand in the evening. Hence the sum of the transmission system capacity is often higher than the total generation capacity, and the distribution capacity is often higher still—and the asset utilization drops

1 This report is being disseminated by the U.S. Department of Energy (DOE). As such, this document was prepared in compliance with Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554) and information quality guidelines issued by DOE.

2 Robert G. Pratt et al. 2003. *GridWise™: The Benefits of a Transformed Energy System.* PNNL-14396, Pacific Northwest National Laboratory (PNNL), Richland, WA. See Figure 3, page 6. Available from the PNNL website at: *http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14396.pdf*

accordingly. In fact, fully 10% of our generation capacity is used only to meet the load during the top 5% of hours of the year (~400 hours), and 25% of our grid's distribution capacity exists only to serve peak load for these same 400 hours.[3]

Because over 70% of the nation's current total use of electricity (3856 billion Kilowatt-hours) is consumed by 117 million households and 5.5 million commercial buildings,[4] integrating them with the grid is critical to reducing peak loads and keeping associated infrastructure costs down. Moreover, most of the projected load growth predicted by the DOE/Energy Information Administration (EIA) through 2040 is driven by buildings, which in turn will drive projected capacity expansions.[5] Many smart grid applications are designed to minimize peak demand.[6] Primary among them today is traditional demand response (DR), but as costs come down, distributed generation and storage (both electric and thermal) also may make important contributions, as will transactive energy approaches as described in the companion Introduction and Vision paper. The Federal Energy Regulatory Commission (FERC) estimates that the DR resource contribution from all U.S. DR programs will be almost 72,000 megawatts (MW), or about 9.2% of U.S. peak demand.[7]

Utilities have employed simple forms of DR mostly in the form of interruptible contracts, which are utilized almost exclusively in emergencies, and direct load control. Opportunities that can be exploited involve (1) vastly expanding the number of customers and types of end uses engaged, (2) expanding the range of grid benefits derived by utilizing the smart grid's communication technologies to signal customers, (3) metering technologies to gauge their response, and (4) creative rate-making to devise incentives for that response.

As a corollary to their obligation to serve their customers, utilities have an obligation to provide 'reasonable and customary' levels of reliability to customers. In the United States, this level of reliability is very high compared with much of the world beyond the developed nations that are our most direct economic competitors. However, even this level of reliability has significant consequences for customers and the nation's economy.

Smart grid approaches that improve the transmission grid's ability to prevent and limit widespread outages are a major part of the broader grid agenda, but also are critical in light of the stress that will be caused by the introduction of massive amounts of renewable generation over the coming decades. These approaches involve better sensing (especially through phasor measurement units [PMUs]), better analytics of grid stability and security (focused on high speed computation), and better control (eventually extending to automated wide-area control and remedial action schemes). Eventually, with the convergence of reliability improvements at both the transmission and distribution levels, the dream of a highly robust 'self-healing' grid can be realized.

The future grid will provide a seamless, cost-effective electricity system, from generation to end-use, with the flexibility to accommodate all clean energy sources and capacity requirements. However, the challenge of addressing variable resources is part of a larger grid modernization agenda that must address many other profound changes in the nation's infrastructure, such as growing use of natural gas, increased consideration of distributed generation, limited ability to expand the transmission system, and measures to add flexibility to the system, including energy storage. This system will allow for significant scale-up of clean energy, universal access to consumer participation and choice, holistically designed solutions, two-way flows of energy and information, and reliability, security, and resiliency.

Smart technologies involving advanced sensors, communications networks, and controls offer a key strategy for accomplishing the future grid. These smart technologies can benefit the grid by providing responses from building loads to:

- Reduce electricity production costs and costs for generation and T&D system infrastructure that can meet peaks loads
- Help balance the bulk grid by providing ancillary services that support the integration of energy from renewable resources at scale
- Support distribution systems in the management of voltage, including fluctuations that may be induced by the integration of distributed solar photovoltaic (PV) power at scale
- Provide a 'safety net' for the power grid in the event of an emergency to reduce the likelihood of blackouts, and to decrease the time needed to recover from disruptions and outages.

One way to increase grid flexibility is to develop and enable efficient, secure, and reliable transaction-based energy services markets, integrating energy supplies, demand, and related services. This approach harnesses millions of small, distributed assets such as DR in buildings, distributed generation and storage, and electric vehicles (EVs) to provide valuable grid services.

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[3] E. Lightner and R.G. Pratt. 2004. *GridWise - Bringing the Electricity System into the Information Age*. Presented Dec. 2, 2004 at the First International Conference on the Integration of Renewable Energy and Distributed Energy Resources, Brussels, Belgium.

[4] DOE/EIA estimate for 2011. See *http://www.eia.gov/energyexplained/index.cfm?page=electricity_use*

[5] DOE/EIA, Annual Energy Outlook 2014 Early Release, Reference Case. See the EIA AEO table browser at *http://www.eia.gov/oiaf/aeo/tablebrowser/*

[6] EIA data on peak demand is available at *http://www.eia.gov/tools/faqs/faq.cfm?id=100&t=3*

[7] Federal Energy Regulatory Commission. 2012. *Assessment of Demand Response and Advanced Metering Staff Report*. Washington, DC. Available at *www.ferc.gov/legal/staff-reports/12-20-12-demand-response.pdf*

There are several ongoing demonstrations that are exploring how to meet the challenge of increased renewable penetration and how to use new loads to support system reliability. To demonstrate better approaches to manage wind reliability, improve wind generation capacity, and enhance buildings load response, the Center for Commercialization of Electronic Technologies and stakeholders such as ERCOT, the Electric Power Research Institute (EPRI), and Centerpoint are conducting a project funded in part by the American Recovery and Reinvestment Act of 2009 (ARRA) at several locations in Texas. The demonstration includes a "Smart Meter Texas" control portal to help match intermittent large-scale wind generation to load, and also a state-of-the-art Smart Grid community with the latest high-efficiency construction, smart demand response appliances, energy storage, and distributed generation smart grid technologies.[8]

At the same time, in the Pacific Northwest, Battelle Memorial Institute, Bonneville Power Administration, and 11 utilities are conducting a five-year smart grid demonstration project, 50% funded by ARRA, to develop a single integrated smart grid incentive-signaling approach for electricity users. The Pacific Northwest has a significant amount of wind power (~7 gigawatts [GW])[9], and swings in available wind can be as high as ~250 megawatts in a five-minute period,[10] posing challenges to grid operation. The demonstration is one of a few pioneering transactive energy and transactive controls projects, testing and validating its ability to continuously coordinate the responses of smart grid assets, including buildings, to meet a wide range of operational objectives and engage distributed control so that wind integration problems are mitigated.[11]

Challenges and Barriers

Challenges

We have identified four general challenges facing the grid that can be addressed from better integration of renewables, buildings, and EVs:

1. Reducing peak loads through transactive energy approaches, including DR, energy efficiency, and contributions from distributed storage and generation can reduce investments in new infrastructure
2. Providing ancillary services that are necessary to keep the grid in supply/demand balance, in real time, to maintain frequency and voltage within standard ranges, and that provide adequate reserve capacity to withstand contingencies involving the loss of any asset in the system
3. Increasing reliability by providing alternative, flexible, actively-managed alternatives to simply building more infrastructure to supply needed levels of reliability for an economy increasingly dependent on electricity
4. Managing voltage better at the distribution level to realize the energy-efficiency potential of conservation voltage reduction and accommodate high penetration of photovoltaic renewables connected to the distribution system.

Typically, these challenges are addressed at a system level for grid operations. On the other hand, buildings usually optimize energy use and address challenges within the building envelope. By managing their loads in response to the needs of the grid, buildings also can provide system-wide benefits, and as more variable generation is added to the grid, the value of grid-responsive buildings will only increase.

The challenge is to ensure that these building assets provide the smooth, stable, and predictable response required, when they are primarily owned and operated by customers or third parties rather than directly controlled by grid operators. The purpose of a transaction-based control approach is to seamlessly integrate distributed assets into a collaborative, incentive-based network that, in the context of grid operations, functions as a virtual control system. This approach will enable and motivate entities to transact and deliver energy services to the grid at the lowest possible cost using distributed control approaches.

Technical Barriers

Technical barriers to achieving the transactive energy vision consist principally of technologies and standard requirements to communicate between the electric power system and buildings. Most significant of the technical barriers are requirements for secure, open protocols to ensure safe operations of buildings and the larger grid. The grid manages stability of the system by providing centralized dispatch and a short-term control signal (i.e., an automated generator control [AGC] system frequency) and control of the connected generation in a centralized control approach. In this method, only large generation resources respond to keep the system stable. Currently, there is a deficiency in the ability to share performance information or to transact load and energy services within a building and with other surrounding facilities or electric distribution systems that could influence the operations of the larger grid. Specific technical barriers include:

- A framework for revealing and expressing actual real-time grid operational needs in terms of value is needed for distributed assets requirements. Traditional vertically integrated utilities typically do not express these values in any form that enable

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[8] Smart Grid.gov website: *http://www.smartgrid.gov/project/ccet_technology_solutions_wind_integration*

[9] 4.5 GW in BPA's balancing Authority *http://www.bpa.gov/Projects/Initiatives/Wind/Pages/default.aspx* and 2.6 GW outside it, for a total of 7.1 GW. Personal communication with R. Melton, PNNL, 7 October 2013.

[10] Terry Oliver, Chief Technology Innovation Office, BPA, "Pacific Northwest Smart Grid Demonstration: Project Overview." Presentation at Buildings-To-Grid Technical meeting, December 12-13, 2012, at National Renewable Energy Laboratory (NREL).

[11] SmartGrid.Gov website: *http://www.smartgrid.gov/project/battelle_memorial_institute_pacific_northwest_division_smart_grid_demonstration_project*

such assets to participate in a transactive fashion. Even where independent system operator (ISO) energy markets are present, only the wholesale values are expressed; distribution-level values are ignored, and markets for ancillary services that enable participation by distributed assets are immature.

- Protocols and standards are needed to communicate these multiple value streams and the associated transactions.
- Signaling mechanisms are needed to engender the desired response. Advanced metering infrastructure network bandwidths are generally inadequate for communicating dynamically varying retail rates or incentives (e.g., rebates) for energy response at hourly or sub-hourly time scales. For regulation and spinning reserve services, a radio broadcast may be required to engage distributed assets because the low latency required (4 seconds). Such broadcasts do not exist.
- Measurement and verification techniques are required to properly reward participation by distributed assets. Overcoming this barrier will be particularly challenging where no baseline consumption can be readily established, or where response on 4 second time scales is required.
- Feedback mechanisms are needed to establish precision control, particularly as distributed assets become plentiful, but today these assets do not provide such feedback in the form of their intended response.
- Device-level control strategies are needed so distributed assets can optimize their available response and their earned incentives.
- Control theory needs to be developed to prove that stability can be achieved from such distributed control systems.

Technical Opportunities

Deploying a transactive energy approach to grid operations will require:

- Advanced controls for these assets that achieve multiple grid objectives in response to signals such as prices or incentives, while serving the needs and desires of their owners in an automated fashion
- An open, secure, scalable, self-organizing information architecture that expresses and communicates these values and allows distributed, third-party assets to transact for these energy services in real time.

Solutions need to be aligned with the nation's renewable energy and energy efficiency goals. In the area of renewable resources, opportunities include:

- Increasing the penetration of renewables by reducing the impact of any additional ancillary services required
- Increasing the penetration of wind, central solar by reducing the need for new transmission lines to deliver power from the generators to urban load centers
- Increasing the penetration of distributed PV by reducing integration costs at the distribution system and at the customer premise.

For energy efficiency in buildings, opportunities include:

- Keeping electric bills low by reducing peak loads with transactive energy approaches and demand response, reducing costs for ancillary services, reducing costs for maintain and improving reliability, all of which reduce costs that utilities must recover through rates
- Earning billing credits and rebates for providing peak-load management, ancillary services, and voltage support, and by using grid-friendly appliances and equipment
- Achieving energy efficiency and conservation by leveraging smart grid data and smart building systems to identify energy efficiency opportunities for retrofits when replacing equipment and appliances, by automating performance diagnostics, by additional conservation voltage reduction, and by better integration of energy efficiency as a grid strategy
- Increasing the energy efficiency benefits at the buildings/grid intersection via conservation voltage reduction.

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