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Chapter 28. Smart Grids: An Optimized Electric Power System

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Summary: Preceding chapters in *Future Energy* present exciting advances in energy production, conversion and storage, some of which were barely on the horizon when the first edition of this reference was published in 2008. Similarly, the "smart grid," which was an idea just gaining traction in 2008, reflects the most exciting paradigm change to impact the electric power system since its beginnings more than a century ago. Smart grids apply new metering, communications and control technologies and strategies to provide an optimized power system that integrates distributed energy resources and electric customer participation in maximizing power system efficiency and reliability. Smart grids will also contribute to achieving energy efficiency, conservation, power plant emissions goals. While the smart grid concept can be described relatively easily, the transition to smart power grids presents financial evaluation challenges that are unique to these new technologies and applications.

1. Chapter Scope

Smart grids apply metering, communications and control technologies to generation, transmission lines, substations, feeders (circuits), meters, and in-premise technologies. This chapter focuses on smart grid technologies and applications beginning at the substation level. Smart grid applications at the generation and transmission level have been applied for a number of years and are fundamentally different from distribution level smart gird applications because they do not engage utility customers directly; consequently this discussion is focused on the smart grid transformation expected to occur from the substation to in-premise technologies and in back-office management systems. This chapter also identifies smart grid impacts on energy efficiency, conservation and power plant emissions.

2. Traditional Power Systems

2.1. Traditional Power System Design

As illustrated in Figure 1, electric power systems have traditionally been designed to generate power at a single location, routing electricity through high voltage transmission lines to substations where voltage is stepped down and distributed over several feeders to additional transformers that step voltage down further for delivery to homes and businesses.

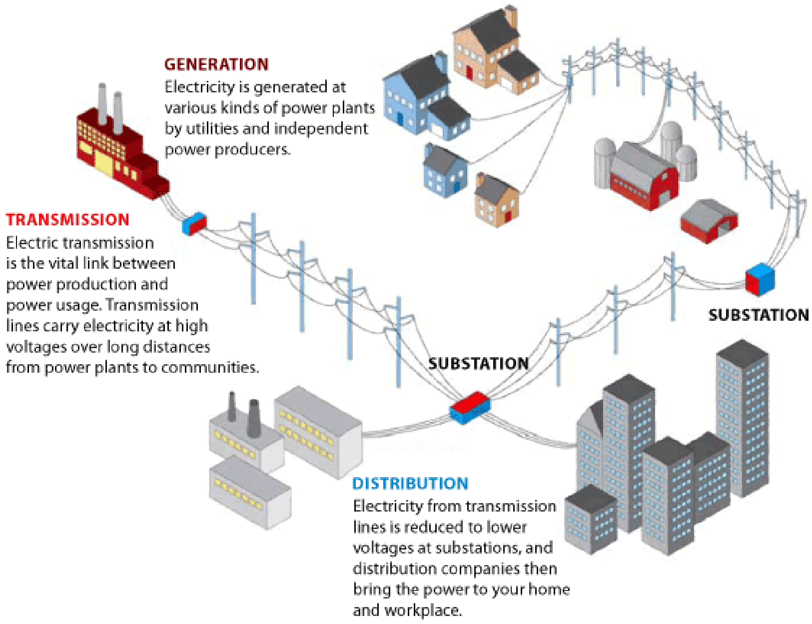

Figure 1. Traditional Power System Design.

Source: U.S. Department of Energy. "Benefits of Using Mobile Transformers and Mobile Substations for Rapidly Restoring Electric Service: A Report to the United States Congress Pursuant to Section 1816 of the Energy Policy Act of 2005." 2006.

Traditional power systems provide less information to utility operators and less control as one moves away from the generation source. Transmission lines are carefully monitored, real-time substation monitoring may or may not occur and limited metering is typically applied to distribution feeders or circuits to monitor electricity distribution voltage and other values. Some utilities can control some substation and line voltage levels and switches remotely from central stations; however, many utilities use remote equipment that senses voltages and other power characteristics and makes predefined adjustments.

Engineering calculations or models are used to determine required system characteristics and to evaluate distribution system modifications required to meet new loads or other changes in the distribution systems. Inputs to these models are periodically measured to recalibrate the models.

The limited metering and communications from substations and points on feeders provide limited visibility into the current operating status of the distribution system and consequently provide only limited information on transformer loading, line losses, voltage sags and swells and other distribution system characteristics such as outage detail.

Traditional power systems face challenges integrating distributed energy resources including solar, wind and combined heat and power. Difficulty in monitoring and controlling distributed electricity generated from these sources and their intermittent nature can destabilize the grid. Increasing use of electric vehicles also contributes to concern over the ability of traditional power systems to adapt to future electricity demands.

Most traditional power systems use electromechanical meters collecting readings manually once a month providing utility customers with little detail on how or when they use electricity. While some commercial and industrial utility customers are billed for their electricity on an hourly or 15-minute basis with rates that vary by time-of-day and season, most residential customers and smaller/medium-sized commercial and industrial customers face flat or simple block rates that reflect little if any of the time-of-day and seasonal variation in the cost of providing electric service.

3. The New Smart Grid Power System Model

Smart grid technologies and applications, described in more detail in the following section, support a very different power system model than represented by the traditional power system illustrated in Figure 1. Five basic smart grid system characteristics define the new smart grid power system model

3.1. Extensive metering and communication throughout the distribution system.

Smart grids meter individual customers and individual grid equipment throughout the distribution system including transformers, switches, capacitor banks, voltage regulators and other equipment. This information is relayed back to the utility typically through a combination of communications systems.

3.2. Two-way communication and power flows

Instead of a traditional system that sends power in one direction (to the customer) and returns information in the opposite direction (back to the utility) at monthly intervals, the smart grid accommodates frequent and on-demand two-way information and power delivery.

3.3. Utility Customer Participation

Utility customer participation is one of the most important smart grid system characteristics. Not only do customers provide electric production with solar, combined heat and power and other technologies, they can actively respond to signals from the utility to reduce electricity use during peak period times or during situations where the power system is stressed.

3.4. Increased control

Smart grids increase utility control of distribution system equipment and operating characteristics and increase control of customer demand response (reduction in customer hourly loads at peak hours).

3.5. Coordination and integration

Smart grids coordinate and integrate new metering, communication, control and customer engagement technologies and strategies, leveraging technologies and programs to achieve objectives across the entire utility system.

4 Smart Grid Building Blocks

Smart grids take advantage of many of the dramatic changes in communications and solid state electronics that have occurred over the last several decades. Smart grids apply metering, communications and control strategies across the entire distribution system to optimize the delivery of electricity, integrating distributed energy resources and engaging customers with technologies and incentives to accommodate cost and efficiency considerations.

The literature on smart grid concepts and individual smart grid technologies is now voluminous and widely accessible [1] [2] [3]. Smart grid building blocks include:

4.1. AMI/smart meters

Advanced metering infrastructure (AMI) applies a communications system and solid state meters capable of remotely providing each customer's electricity use detail to the utility at 15 minute or hourly intervals. Additional information including peak electricity use, voltage and other power characteristics are also available. A variety of communications options can be used to transmit data from individual meters back to utility operations. A few of these options include public WiFi, private radio systems, and power line carrier systems that transmit information through the electric distribution system. Smart meters can also provide radio gateways into premises to control and develop information for individual appliances.

AMI/smart meters can dramatically reduce many traditional utility operating costs including meter reading, customer services, field services, collections, theft management and other functions. Service switches in the meter allow the utility to connect and disconnect customers without making a service call.

4.2. Distribution Automation: Substation and feeder metering and control

Power distribution systems include a variety of equipment such as switches, recloses, capacitor banks, voltage regulators, and transformers that are used to control power flows, voltage, power quality and other electric distribution characteristics. Existing equipment can often be retrofitted by adding communications and control capabilities. The ability to get information at the utility control room from these devices and to remotely control their functions provides utilities with an opportunity to significantly improve utility operations.

For example information from equipment on the distribution system can automatically be applied after an outage to isolate sections of the grid associated with the outage, to reroute power to minimize the number of customers impacted, to identify the problem location and dispatch field crews to correct the problem. Transformer loads can be monitored, replacing overloaded transformers before they fail. Transformer sensors can continuously monitor transformer gases to identify transformer problems before failures occur.

Smart grid metering and control capabilities also provide significantly improved Volt/VAR control on feeders compared to traditional power system practices. Utility engineers design substations, transformers and distribution circuits including voltage regulators and capacitor banks and other equipment based on engineering calculations and models. Since voltage drops with distance from the substation, voltage levels at the substation must be higher than the voltage required at the end of the feeders. Voltage drops depend on temperature and loads along the feeder and other factors. Voltage regulators and capacitor banks are used to boost voltage along the feeder and to reduce the impact of reactive power. Once designed and built, performance measurements and adjustments are conducted only periodically. However, since little information is typically available on end-of-line voltage, most systems error on the side of providing higher voltage than required, often by as much as 5 to 8 percent, to ensure sufficient end-of-line voltage. This practice wastes power, increases line losses, increases maintenance costs and increases electric costs to customers.

Volt/VAR optimization is limited by the lack of real-time visibility. Many utilities have little (or in some cases no) real-time central station information on substations, feeders and distribution equipment. Consequently, once the system is designed and installed, field visits are used to monitor individual substations and feeder equipment.

Expanded smart grid customer and distribution system metering dramatically increases opportunities to optimize the distribution system. Smart meters can typically provide 15-minute and on-call information on voltage and reactive power providing visibility into voltage at nearly every point along individual feeders. Increased metering and controllers on feeders can provide near real-time information and alerts when conditions warrant. This information can be applied with software optimization techniques to minimize energy use, peak demand and distribution system losses while ensuring minimum acceptable voltage to individual.

4.3. Communications systems

In addition to providing communications from smart meters to the utility operations center, the smart grid must deliver information from intelligent electronic devices (IEDs) throughout the distribution system including substation and feeder status data. These information channels can be accomplished in a variety of ways depending on current communications infrastructure in use at each utility. Utilities utilize a SCADA (supervisory control and data acquisition) for communications and control of basic equipment in the distribution system. SCADA system can often be expanded to handle additional smart grid information and functions and /or additional communications and control systems can be applied. For example, smart meter data may be concentrated and passed to the SCADA system at the substation to be transmitted back to the central stations.

Different smart grid technologies and applications have different bandwidth and latency (time requirements for communications) requirements; consequently, smart grid communications development requires careful planning of both near and longer-term capability needs.

4.4 Customer engagement

An AMI/smart metering and communications system can provide routine 15-minue or hourly customer electricity use data as well as information on an on-call basis not only from the customer meter to the utility but from the utility back to the customer. Information provided to the customer, typically through an internet portal, usually includes 15 minute or hourly electricity use along with information on current month usage and expenditures, estimates of the total monthly bill, and in some cases, information on electricity use of similar customers in the neighborhood.

The ability of smart grids to engage customers to reduce electricity use at peak periods is a primary benefit of smart grid investments. Utilities that pay $10/kW or even $20/kW for peak power but charge their customers rates that are averaged over a month or over several time periods in the day, can reduce power purchase or production costs by significantly more than revenue losses when they encourage customers to reduce peak electricity use.

Figure 2. Illustrates the large number of points at which utilities can engage customers with smart power systems.

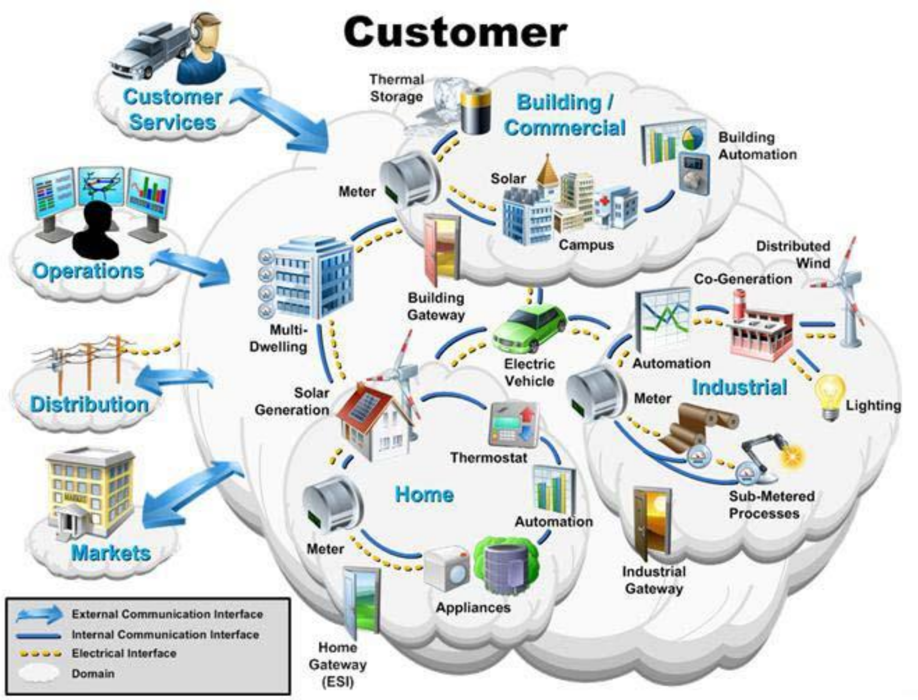

Figure 2. Illustration of Two Way Power and Information Flows.

Source: NIST Special Publication 1108, NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0, Office of the National Coordinator for Smart Grid Interoperability, January 2010
U.S. Department of Commerce, National Institute of Standards and Technology.

Smart grid customer engagement programs can be categorized as follows:

4.41. Information programs

These programs provide information to utility customers on their energy use compared to previous time periods and to comparable customers in their neighborhoods. Empirical evidence suggests that these programs can save as much as 3-5 percent in electricity use.

4.42. Pricing programs

Utilities are using various pricing incentive programs such as critical peak pricing that applies higher prices during peak hours and peak time rebates that provide payments to customers who reduce electricity over peak periods. Time-of-use rates are frequently used where three or four time periods in the day are identified and customers pay different electric rates depending on the cost of providing power in those time periods.

4.43. In-premise technologies

In-premise technologies such as programmable communicating thermostats (PCT) provide utility control and promote customer participation. PCTs are thermostats that the utility can reset to lower temperature setting in the summer to reduce air conditioning loads. Utility customers can reduce thermostat settings even lower, or over-ride the utility setting to opt out of the demand response event. Information sent back to the utility confirms participation in the program and results in bonus payments or a confirmation of program participation. These technology-based programs can reduce electricity use for participating customers by as much as 30 – 35 percent when paired with incentive pricing programs. [4]

Direct load control has been used for years by utilities to reduce peak period impacts of air conditioners, electric space heating, swimming pool pumps and water heaters; however, the smart grid infrastructure reduces the cost of implementing these applications and provides continuous information on individual customer peak demand impacts.

4.5 Distributed Energy Resources (DER), Electric Hybrid Vehicles (EHV), etc.

While relatively unimportant for most utilities at present, distributed energy resources will continue to transform the electric power system. The advanced monitoring and control of feeders with DER provide the utility with information and control options required to accommodate the increasing saturation of DER and electric hybrid vehicles (EHV). Stability issues monitoring and adapting to EHV demands requires smart grid system metering and controls. While DER creates control challenges for the utility, it also reduces peak period energy use and depending on the DER technology, can reduce future electric distribution capacity requirements.

5. A Summary of Smart Grid Financial Benefits

Two primary financial drivers that help explain utility smart grid interests.

5.1. Reducing power purchase and production costs

Electric power is provided with a combination of generating assets including

- High capital cost- low operating cost base-load units run continuously and include hydroelectric, coal and nuclear plants. These power plants provide the most economical source of electricity.
- Intermediate units run most of the time and include combined cycle natural gas plants that produce electricity at a higher cost than base-load units.
- Peaking units such as natural gas turbines that have low capital cost, relative to base load units and high operating costs; electricity produced by these plants is much more expensive, in part because they are dispatched infrequently. Some peaking units may run as little as 100 hours per year.

Use of these different generating units is illustrated in Figure 3.

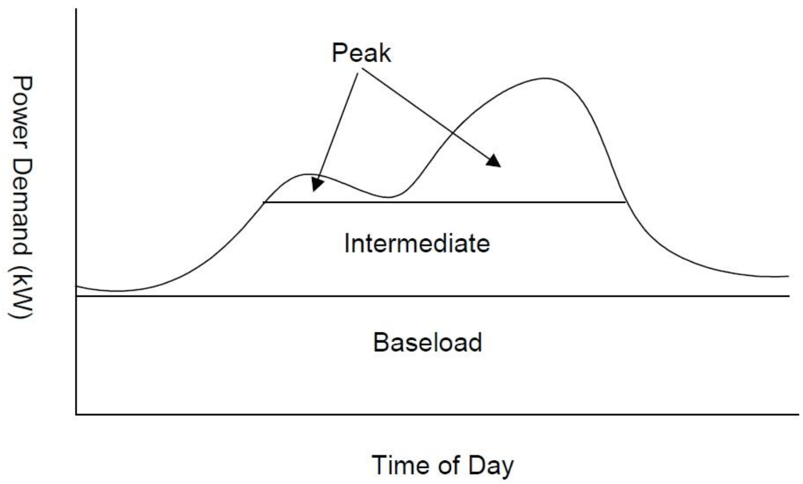

Figure 3 Baseload, Intermediate and Peaking Generating Capacity

Electric utilities or generating authorities, dispatch individual power plants in such a way that total generation cost is minimized with base-load units running most of the time, intermediate units running when power demands rise above those that can be supplied by base-load units and peaking units run only to meet peak period demands. The cost of providing the next kW of electricity at any time depends on the marginal cost associated with generation from the units providing that power. In competitive wholesale markets, the price of marginal power at peak period times can be driven to prices that are as much as 20 times or more the off-peak period. For example in the Texas electricity market the 2013 price cap is $5/kW (US) whereas off-peak rates tend to be closer to $0.25(US). For comparison, running a 5,000 watt electric dryer for 1 hour in peak periods will incur wholesale cost of approximately $25(US) while the cost is only $1.25 (US) to run the dryer for 1 hour during off-peak periods.

However, most electric customers, especially residential customers pay rates that do not reflect variations in costs that occur across hours of the day or seasons of the year. Monthly rates that apply total monthly kWh consumption to a $/kWh rate are common. Consequently, utility customer electricity use during peak hours costs utilities much more in power supply costs than the revenue derived from customers for those hours.

The ability of smart grids to measure hourly kW use provides utilities with the opportunity to provide demand response programs using customer incentives to reduce electricity use during peak periods. In addition to reducing wholesale power costs, demand response also reduces stress on the distribution system and delays investments in future generation, transmission and distribution capacity.

5.2 Reducing electric utility operating expenses

Traditional electric utilities spend large sums for meter reading, customer services, field services, collections, theft management and other functions, many of which are nearly eliminated with smart grid systems. For example, meters are read, connected and disconnected, evaluated for theft and other activities all through software administered in the utility back office. Outages are more accurately identified reducing costs of restoring power. Much of the traditional utility field inspection and maintenance is avoided.

6. Challenges in evaluating smart grid investments

6.1. Smart grid costs are substantial

Smart grid investment costs are considerable and vary substantially by utility. A review of more than 100 pilot programs found costs of only an AMI/smart meter system ranged from $81 to $532 per meter with an average of $221 [5]. A 2012 Electric Power Research Institute (EPRI) report estimates per meter costs of $1,800 to $2,400 for economically justified, fully deployed, smart grid investments, including AMI/smart meters and distribution investments but excluding transmission investments [6].

The size of smart grid investments makes embarking on a smart grid initiative rather daunting. Undertaking only an AMI/smart meter system at the average reported cost means that a utility with 100,000 meters can expect to spend $22.1 million (US); using the lower EPRI estimate of $1,800 per meter for a fully deployed system amounts to $180 million (US).

The EPRI study also reported benefit cost ratios ranging from 2.8 to 6.0 making these investments quite attractive; however, it is difficult for most board members, council members and others making the final investment decision to intuitively grasp the comparison of costs and benefits for such a complex investment.

6.2. Analysis challenges

Many utilities are reluctant to embark on a smart grid investment strategy to take advantage of smart grid technologies, in part, because evaluating the smart grid business case is more complicated and different in several fundamental ways compared to traditional utility capital expenditure decisions. For example, smart grid investments often involve many more department inputs. An AMI system requires changes in meter reading, billing, customer service, field services, IT (information technology), meter maintenance and so on. Perhaps more importantly, many of the evaluations associated with smart grid investments reflect different analysis that has not been performed by most utilities in the past and requires new tools or individuals with different skill sets.

For example, consider the evaluation of financial costs and benefits associated with demand response (DR) programs. The majority of DR financial benefits are associated with avoided system peak period power costs. Utilities who produce more electricity than they use can typically sell excess power in the market, so regardless of whether a utility produces or buys its power, the market price of power at peak period hours typically determines the value of each kW saved with the demand response programs.

Utility system peak period DR load reductions are composed of demand response impacts from individual customers in segments such as residential single family dwelling units, commercial office buildings and so on. Programs focus on one or more end-uses such as residential air conditioning, residential pool pumps, office building lighting, and office building backup-generation and so on. Different end-uses provide different DR potential as indicated in Figure 4 which illustrates office building end-use hourly electricity use diversity in northern California.

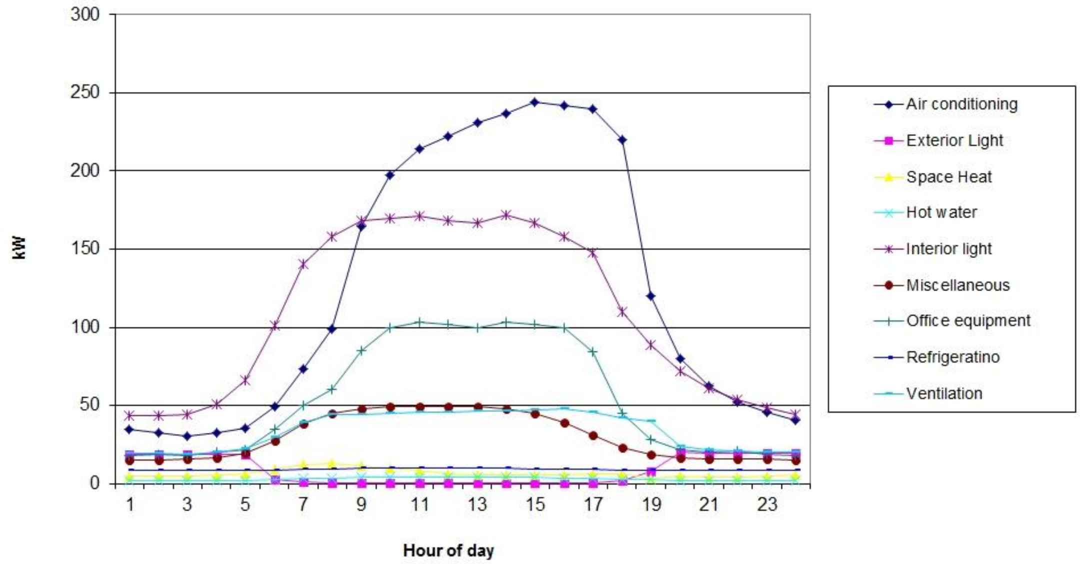

Figure 4. End-use Electricity Use Diversity in A Northern California Office Building on an August Week-day

Source: Jackson, J. Energy Budgets at Risk (EBaR): A Risk Management Approach to Energy Purchase and Efficiency Choices (2008)

Within each customer segment, diversity also exists across individual customers reflecting variations in building age, equipment age and usage characteristics and other factors as illustrated in Figure 5. These hourly loads are normalized (hourly kW divided by total daily kW) to compare difference in load shapes.

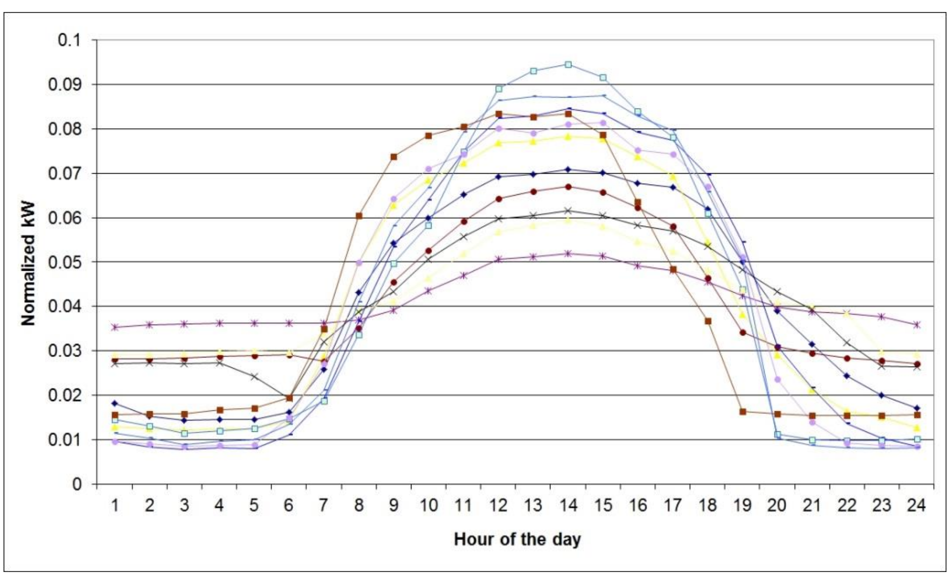

Figure 5. Northern California Office Building Electricity Use Diversity on an August Week-day

Source: Jackson, J. Energy Budgets at Risk (EBaR): A Risk Management Approach to Energy Purchase and Efficiency Choices (2008)

Total DR program impacts depend which customers participate in which programs and the extent of that participation across the entire utility service area. Predicting participation rates and DR hourly load impacts for the various programs reflects a new challenge for most utilities and requires knowledge of marketing and customer engagement as well as information on hourly DR response impacts of various end-use equipment under alternative program designs.

Many utilities have only total system hourly loads data and monthly billing data without any customer class or end-use detail and assume that information required to assess specific demand response programs is simply unavailable. However, customer-segment end-use loads can be developed for individual utilities using monthly billing data, systems load data and commercially available hourly load databases to develop reliable estimates of demand response and other programs that impact customer loads such as conservation voltage reduction (CVR).

6.3. Smart Grid Research Consortium business case evaluation recommendations
The Smart Grid Research Consortium was established at Texas A&M University in 2010 to provide assistance to small and medium size electric utilities in addressing these smart grid cost/benefit financial analysis challenges. The Consortium, which transitioned to an independent research and consulting organization in 2011, conducted research and worked with utilities and equipment manufacturers over a two-year period to develop a comprehensive quantitative financial analysis framework to assess individual smart grid business cases. The Consortium has completed smart grid financial analysis at 17 US utilities

Based on its research and applications experience the Consortium has developed eight recommendations for smart grid business case analysis including:

1. Apply a quantitative framework that supports scenario and what-if-analysis
2. Conduct comprehensive analysis including AMI/smart meters, distribution automation including conservation voltage reduction and customer engagement including demand response, pricing and other customer-centered programs, even if initial investment focus is narrowed to one or two of these areas
3. Reflect interdependencies across technologies and applications
4. Develop and apply hourly load models for individual customer classes and end-uses to forecast future hourly loads and to reflect system load impacts of demand response programs and conservation voltage reductions
5. Calculate future costs and benefits for at least 15 years
6. Apply internal rate of return (IRR), net present value and provide quarterly costs and benefits detail

7. Consider alternative scenarios with respect to investment focus, priorities, what-if analysis of different future wholesale and technologies prices and scenario analysis to evaluate various input uncertainties
8. Present results for executive management with concise intuitive, summary financial analysis presentations

6.4. Framing financial analysis results

The last item in the Consortium's list of recommendation is especially important. Utility decision-making varies by utility type; however, major investment decisions are typically put before a board of directors, city council or another group where individuals may not have the background to feel comfortable with some of the more nuanced financial analysis results presented in traditional investment decision-making.

Cumulative discounted net benefit is an appealing presentation of project financial considerations in that it displays costs and benefits on a timeline that shows how benefits offset costs over time.

Figure 5 shows a cumulative discounted net benefit chart from a Consortium business case analysis. The chart shows cumulative financial benefits minus cumulative costs on a quarterly basis through the year 2030.

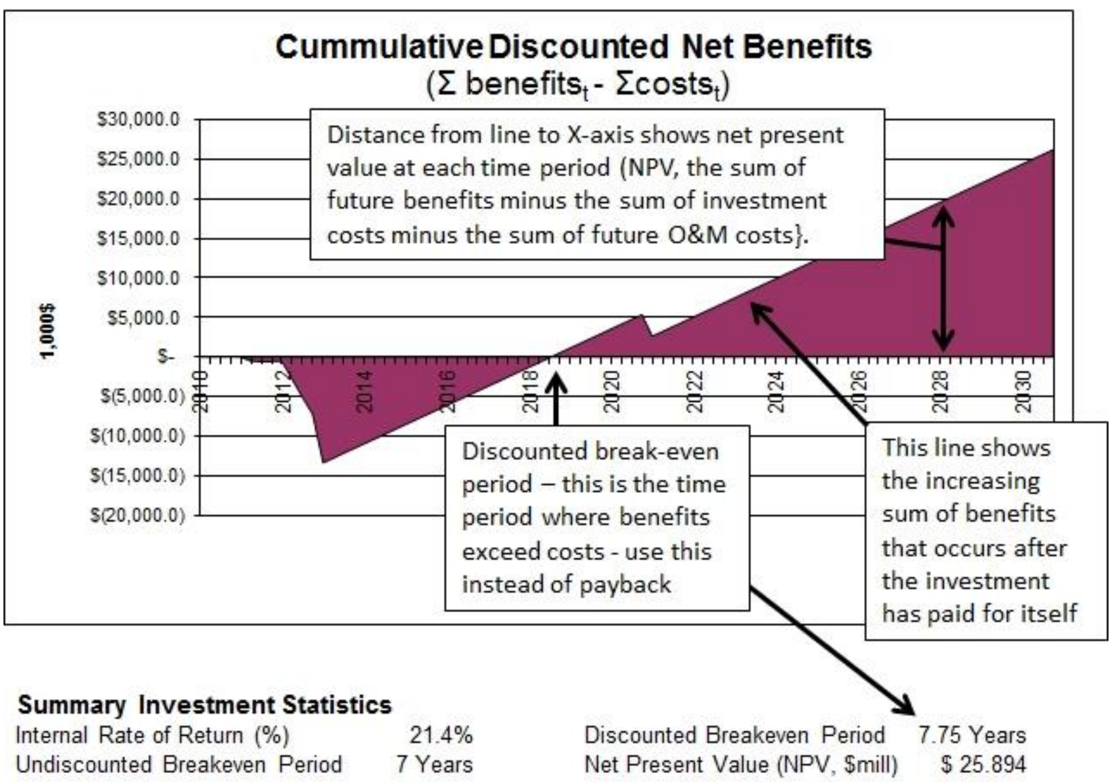

Figure 6. Cumulative Discounted Net Benefit Chart.

Source: Smart Grid Research Consortium, Orlando, Florida June 30, 2013.

7. Other Smart Grid Issues

Smart grid topics cover a wide variety of technologies and applications beyond those described above. The following additional topics are important in the development of smart grids:

7.1 Interoperability and cyber security

Communications networks provide the backbone of smart grids conveying information from customer meters and equipment throughout the distribution system back to the utility. Depending on the communications systems being used, these data may be concentrated and/or relayed four or five times before they reach the utility. In addition, appliance data within each facility must be transmitted to the meter and passed along as well. The ability of equipment from different manufacturers to communicate with one another and to communicate with different kinds of equipment to transfer information is important in ensuring a smoothly functioning communications and information system.

In addition, each communication link is subject to security threats. Both interoperability and cyber security have been a serious concern and have received a great deal of attention over the last several years [7]

7.2. Privacy

With all of the information streaming from utility customer facilities, it is no wonder that privacy has become a concern. 15-minute electric load profiles can reveal much about each facility ranging from when the facility is occupied to what appliances are being used. The question of how these data may be used and who has a right to these data has not been resolved though there appears to be a presumption that electric usage data is personal and cannot be shared without permission of the utility customer.

7.3 Regulatory issues

Who pays and who benefits is the perennial regulatory issue for investor-owned utilities (IOUs) . For many smart grid applications this is not an issue; however, Volt/VAR optimization is a good example of where regulatory issues are a problem. Volt/VAR optimization reduces voltage, losses and improves efficiency throughout the year but it also reduces electricity use by customers and consequently reduces utility revenue. Conservation voltage reduction (CVR) reduces only peak power demands (i.e., for a limited number of hours per year) which typically save utilities more in wholesale power costs than lost revenue that results from reduced voltage for peak hours; however, Volt/VAR optimization operates in all hours and will likely reduce utility revenues more than it will save in wholesale power costs. Expecting utility management, who answer to stockholders, to invest in improving distribution efficiency resulting in reduced revenues without some offsetting compensation is unrealistic. Public service commissions and other regulatory bodies have addressed some of these issues; however, regulatory balancing of shareholder and customer interests continues to delay some smart grid investments.

7.4 IT and data management systems
The role of data management and utility management systems has not been addressed in a detailed way here. AMI/smart meters typically provide automated meter readings at 15-minute intervals from each meter. The data must be scrubbed and verified to identify possible errors in transmission or metering and then passed on the appropriate utility management system including outage management, distribution management, billing exceptions, asset management and so on. Additional information from distribution system meters and equipment must be integrated in this process and all of this information must be digested, processed and presented in a way that provides value to the utility. This expansion of IT capabilities is significant and can be address only by expanding internal IT departments or by contracting with outside IT support firms to provide many of these functions.

8. Societal Benefits: Energy Efficiency, Energy Conservation, Energy-Saving Devices, and Emissions Reductions

Smart grids support energy-related policy objectives including:

8.1. Increased energy efficiency
An increase in energy efficiency is the production of the same energy services (e.g., lumens or amount of visible light) with less energy input (fewer watts of electricity). An important element in smart grid demand response programs is pricing incentives that charge utility customer more for electricity in peak period hours or provide rebates for saving electricity in peak period hours. Pricing differentials can be as great as ten to one – that is, peak period prices that are ten times as great as off-peak prices. These price signals can be expected to promote the purchase of more efficient energy-using equipment reducing electricity use in both peak and off-peak hours.

Smart power grids also promote combined heat and power (CHP) where electricity is generated on site and waste heat is used for air conditioning, water heating, space heating and process uses. Traditional power plants loose about one-third of input energy to waste heat to the atmosphere and transmission/distribution (T&D) losses as opposed to CHP which captures and utilizes much of that waste heat and incurs no T&D losses. CHP systems can achieve as much as 80 percent efficiency compared to traditional power production efficiency of about 65 percent.

8.2. Energy conservation
An increase in energy conservation is the reduction in energy services (lower lumen output) resulting in less energy input. Turning lights and televisions off more frequently, increasing thermostat setting in the summer and decreasing setting in the winter and other similar actions conserve energy by foregoing services that energy-using equipment provides.

Information programs in monthly bills and on internet portals are an important part of smart grids initiatives, often providing energy use comparisons to similar customers. These programs focus customer attention on electricity use and are reported to provide energy savings throughout the entire year and for other fuels. Technologies that focus on peak hour use such as programmable communicating thermostats also appear to focus customer attention on reducing electricity use in off-peak periods.

Prepayment programs which are supported with smart meters and are popular options among some customer segments (e.g., retirees) also recognized promot energy conservation.

8.3. Energy-saving devices

Smart grid initiatives focus utility customer attention on reducing peak hour electricity use and in the process impact behavior that reduces electricity use throughout the year. While energy efficiency and energy conservation have been promoted for decades, equipment manufacturers and software developers have responded to the new incentives provided by electric utility smart grid strategies with another generation of energy saving devices. For example, utility-controlled smart programmable communicating thermostats (PCT) provide both utility controls with customer override options that make program participation more attractive. Appliance manufacturers have begun providing "smart" appliances that can recognize utility commands and work is underway on a "modular communications interface" that will act like a USB port to provide low cost smart controls for all important energy-using appliances [8].

8.4. Reduced power plant emissions

Improved electric equipment efficiency, improved conservation and development of new energy saving devices reduce CO_2 and other greenhouse gasses along with particulates and other emissions that negatively impact human health.

References

1. Massachusetts Institute of Technology (2011). *The Future of the Electric Grid.* http://web.mit.edu/mitei/research/studies/the-electric-grid-2011.shtml

2. Gridwise Alliance (2012). *Realizing the Value Of An Optimized Electric Grid* http://www.gridwise.org/uploads/downloads/GridWiseAlliance_RealizingValueofOptimizedGrid_2_2012.pdf

3. Illinois Statewide Smart Grid Collaborative (2010). *Collaborative Report* http://www.ilgridplan.org/Shared%20Documents/ISSGC%20Collaborative%20Report.pdf

4. Faruqui, A. and Palmer, J (2012). *The Discovery of Price Responsiveness –A Survey of Experiments Involving Dynamic Pricing of Electricity*, EDI Quarterly 4(1): 15-18.

5. King, Chris (2013) *Smart meters: How much do they cost?* , https://blogs.siemens.com/smartgridwatch/stories/957/

6. Electric Power Research Institute (2012) *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid*

7. National Institute of Standards and Technology (2012*)* *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0*. http://www.nist.gov/smartgrid/upload/NIST_Framework_Release_2-0_corr.pdf

8. St. John, J (2013) *A New Standard for the Smart-Grid-Ready Home Appliance*, http://www.greentechmedia.com/articles/read/a-new-standard-for-the-smart-grid-ready-home-appliance