Appendix K: The Smart Grid

INTRODUCTION

Smart grid technology has the potential to bring revolutionary changes to the structure and operation of the power system. The technology could make make it possible for customers to participate in solving power system problems to an unprecedented degree. It could cut costs and improve reliability by giving system operators a level of understanding of the minute-by-minute state of the system, and an ability to make quick and effective adjustments in operation, that they have never had before. The changes could affect the power system from generation to transmission to distribution to consumption, and the potential range of change is often compared to that of the Internet.

COMPONENTS OF THE SMART GRID

The technologies that make up the smart grid can be grouped into three general categories: metering, communication, and intelligence and control.

Metering

The metering category includes a wide variety of devices such as: improved versions of utility meters that measure customers' use every few minutes or seconds; sensors in electrical equipment in consumers' houses or businesses; devices that sense load at many points in the transmission and distribution system; and sensors that read the chemical composition of cooling oil in substation transformers, warning of impending equipment failure. The increase in information on the state of the power system could be orders of magnitude, opening many possibilities for increasing the efficiency and reliability of the power system.

Communication

The enhanced data from improved metering must be communicated in order to be useful. That communication can be from the meter to the utility, from one part of the utility to another, or from the utility to customers. Communication technology continues to improve, both in capability and cost. The paths for communication across the power system range from copper wire and fiber optics to a variety of powerline carrier and wireless technologies. The preferred options are likely to vary depending on the particular application, and the relative advantages of the alternatives are still in flux.

Advanced utility meters could play a central role in communication, not only of customers' total use by time interval, but also in passing data from individual appliances and equipment inside the customers' houses and businesses. Such data can also move by such non-utility paths as the Internet.

Intelligence and Control

Improved collection and communication of data on the state of the power system does not guarantee improved operation of the system. The data must also be translated into information that guides decisions, and those decisions must be executed. This processing and execution may be simple and close to the data source, such as a single device in a clothes dryer that senses power system frequency and shuts down the dryer's heater when the frequency drops below a set level. Or it may be more complex; it could incorporate a real time price signal from the power system, current refrigeration equipment requirements, and adaptive control of multiple pieces of equipment to reduce demand for electricity in a grocery store. Or the processing may condense large amounts of hourly load data to summary differences in energy use that can be used to guide efficiency program strategy.

BENEFITS FROM THE SMART GRID

Predicting the long-term effect of these technologies is like predicting the effect of the Internet in 1990, before the introduction of web browsers such as Netscape Navigator.[1] However, significant benefits will likely come in three general areas: demand response, operational efficiency, and capital savings.

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[1] The Pacific Northwest National Laboratory conducted a 2003 study of the potential benefits of GridWise technologies, which generally correspond to the smart grid definition used in this appendix. That study arrived at a range of estimates from $46 billion to $117 billion net present value over 20 years (http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14396.pdf). The Rand Corporation conducted an independent study of the same topic in 2004, and arrived at an even wider range of benefits, $32 billion to $132 billion net present value over 20 years http://www.rand.org/pubs/technical_reports/2005/RAND_TR160.pdf). A study done now would probably not be able to narrow the range of benefits greatly.

Demand Response

Demand response is the temporary, voluntary change in electricity use when the power system is stressed. Demand response was first covered in the Fifth Power Plan and is treated in more detail in Chapter 5 and Appendix H of this plan. The general effect of smart grid technologies on demand response is to reduce its cost, increase its flexibility, and improve the verification of demand response. These technologies extend possibilities for demand response in a variety of ways:

1. The smart grid could send signals directly to customers' equipment, not only cycling air conditioners (as is done now) but also controlling such equipment as clothes dryers, water heaters, dishwashers and pool pumps. The extent of modification in each customer's pattern of electricity use could depend on the amount of stress the system faces and that customer's willingness to participate for compensation. The customer could also preprogram the response so that the equipment would respond automatically, unless he or she overrides the programmed response.

2. Devices that use an under-frequency signal to interrupt some appliance functions like clothes dryer heating, automatic defrosting of refrigerators, and water heating are very cheap when installed when the appliances are manufactured. This is a new kind of demand response, an almost instantaneous "last ditch" measure when other measures turn out to be inadequate and the alternative is rolling blackouts.

3. Sensor and communication equipment have helped create an industry of demand aggregators. These aggregators can pool and dispatch consumers' equipment to provide load reductions with response times, reliability, and numbers of megawatts that rival conventional generators.

4. Until now, demand response has mostly been seen as a means of providing peaking capacity and contingency reserves. However, if smart grid technology continues to develop, it could provide ancillary services such as regulation and load following. This possibility is described in more detail later in this appendix and in Appendix H on demand response.

Operational Efficiencies

The smart grid could also enable operational efficiencies in the power system. Advanced metering should reduce the cost of meter reading, of course, but meters with two-way communication should also reduce the cost and delay of locating outages. With appropriate control capability, connecting new customers and disconnecting old ones should be cheaper and quicker.

The smart grid could also make possible significant reductions in energy use. Traditionally, distribution feeders are operated well above 114 volts. This practice wastes energy, but maintains a voltage margin that protects appliances from damage that can occur if voltage drops below 114. Some smart grid technologies allow more precise control of voltage on distribution circuits, allowing voltage to be maintained closer to 114 without risking excursions below 114, reducing line losses and appliance energy use. This practice is documented at in Chapter 4 and Appendix E as "conservation voltage reduction."

Energy Efficiency

In addition to the efficiencies in the operation of the power delivery system, the smart grid offers possible contributions to energy efficiency at the customer level. The smart grid can give customers more information about their electricity use, which could change how much energy they use or when they use it. It could also influence what appliances they buy.

Improving the quality of information available to efficiency program designers and managers is another potential benefit. Evaluating the effectiveness of efficiency programs has always been crucial, but difficult. The smart grid could make measured results at the customer level available in near real time. This offers great promise for understanding what works and for making improvements in programs quickly.

Capital Savings

The smart grid seems certain to allow existing resources to be used more intensively, reducing future investment requirements. For example, a substation transformer might serve one area with high loads during the day and then switch to serve a nearby area with high loads in the evening ("dynamic management of substation service"), avoiding the cost of a second transformer. Remote sensing and monitoring of line temperatures could also prevent excessive line sag, arcing to ground and the costs of outages and replacing transmission equipment.

NECESSARY DEVELOPMENTS

For smart grid technologies to realize their full potential, the following developments are needed:

Interoperability

Presently, many potential buyers of smart grid equipment have concerns about purchasing equipment that quickly becomes obsolete, concerns that discourage them from making the investment. To some extent, rapid technological advances make this unavoidable. But the risk can be reduced if, for example, meters purchased last year from manufacturer A and meters purchased this year from manufacturer B can both pass data over the same communication system. In that case, while last year's meters might not be this year's choice, they are still useful.

This is one example of the benefits of "interoperability," the ability to use equipment of different designs and manufacturers together. Interoperability is recognized as a difficult and important issue. The Gridwise Architecture Council was formed several years ago to take up this problem and continues to work on it.

Simplified Participation by Consumers

While the smart grid will make a great deal more information available to utility operators and consumers, consumers have limited attention to give to understanding energy issues and making decisions on energy use. Consumers' participation in demand response programs, for example, will need to be as simple as possible for them. Most consumers will not take time every day to monitor prices that change frequently, but they may be willing to spend time once to choose from a menu of automated responses to future prices. Utilities or aggregators for utilities that make participation easy for consumers will be able to tap those consumers' potential contributions to the economical development and operation of the power system.

Utility Operators' Experience with the Smart Grid and Consumers

Some smart grid technologies such as conservation and voltage reduction can be adopted by the utilities themselves so their evaluation by utilities should be relatively straightforward. However, many smart grid technologies like air conditioning cycling or critical peak pricing require consumer participation, which introduces an extra element of uncertainty to their evaluation. Until utilities and regulators have some experience with such technologies, they are unlikely to be widely adopted. Pilot programs and the experience gained from early adopters will help to encourage utilities to plan on these technologies as resource alternatives for the future.

THE SMART GRID OF THE FUTURE

Imagining what a smart grid would look like conveys a sense of the scale of change that is possible.

Meeting Peak Load

Spiking demand due to a summer heat wave could be mitigated by short interruptions in air conditioning, rotating among customers in a coordinated pattern so individual customers experience little or no change in their comfort. Other end uses such as refrigerator defrosting, clothes dryers, and swimming pool pumps could be included in a coordinated control strategy.

Notification and Location of Outages

The smart grid could notify utilities of system outages immediately, rather than receiving phone calls from customers (perhaps hours after the outage occurs). Smart meters could let the utility know very precisely where the problem is without requiring a repair crew to search it out.

Integration of Plug-in Hybrids

Plug-in hybrid electric vehicles (PHEV) could be combined and controlled to function as a storage battery for the power system. Many parties have suggested this possibility in which the combined PHEV batteries act as a large storage battery for the power system when they are connected to the grid, at home, at work or elsewhere. This aggregate battery accepts electricity when the cost of electricity is low, for instance at night, and gives electricity back to the system when the cost is high during hot afternoons or cold snaps.[2] The smart grid could coordinate[3] this exchange.

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[2] One such description of how PHEV could contribute to the power system is at the Regulatory Assistance Project's web site www.raponline.org under the title "Plug-In Hybrid Vehicles, Wind Power, and the Smart Grid."

Water Heaters for Peak Load, Load Following, and Energy Storage

Smart grid technologies could help coordinate the use of water heaters to: 1) meet peak load; 2) provide regulation and/or load following services; and 3) store energy. In this case, there is enough data to estimate the range of benefits to the power system. For the sake of illustration, it is assumed that the whole resource is available. Although it is unlikely to have full participation, if smart grid controls are installed at the factory, it seems likely that eventually a large percentage of water heaters could be coordinated.

Currently, there are about 3.4 million electric water heaters in the region. If each heater has a heating element of 4,500 watts, the total connected load is about 15,300 megawatts. Of course, water heaters are not all on at the same time; load shape estimates suggest that the total water heating load on the system ranges from about 400 megawatts to about 5,300 megawatts, depending on the season, day, and hour.

Controlling Water Heaters to Meet Peak Load

In normal operation, the heating elements of a water heater come on almost immediately when hot water is taken from the tank, to heat the replacement (cold) water. But if the elements don't come on immediately, the water in the tank is stratified, hot at the top and cold at the bottom. Opening a hot water faucet continues to get hot water from the top of the tank until the original charge of hot water is gone. This means that heating the replacement water can be delayed, reducing load for some time without depriving water users of hot water. Based on the load shape estimates cited above, the maximum available reduction ranges from about 400 to about 5300 megawatts, depending on when it is needed.[4]

Smart grid technology could sense when water heaters are at risk of running out of hot water and begin heating replacement water, while also postponing heating in other water heaters that still have adequate reserves of hot water. Peak load could be reduced without depriving consumers of hot water when they want it. This reduction could be maintained for a few hours, after which all water heaters would be restored to normal operation, increasing total load while the average temperature in each heater is raised to its normal level. Figure K-1 illustrates the effect of reducing water-heating load on total load, and the recovery of water heaters when the load reduction is no longer needed.

In the figure, the 2010 forecast annual load was combined with 2002 weather to create hourly loads for 2010. Solid lines show the January 4, 2010 hourly forecast loads for both water heating ("WH") and "Total." The broken lines for "Modified Total" and "Modified WH" show the effect of reductions in water-heating load of 1,000, 1,300, and 900 megawatts for the hours between 7:00 a.m. and 10:00 a.m. These reductions would result from delaying reheating of hot water used in those hours. The broken lines then show increases of 700, 1,200, and 1,300 megawatts in the hours from 10:00 a.m. to 1:00 p.m. as water is reheated to return all water

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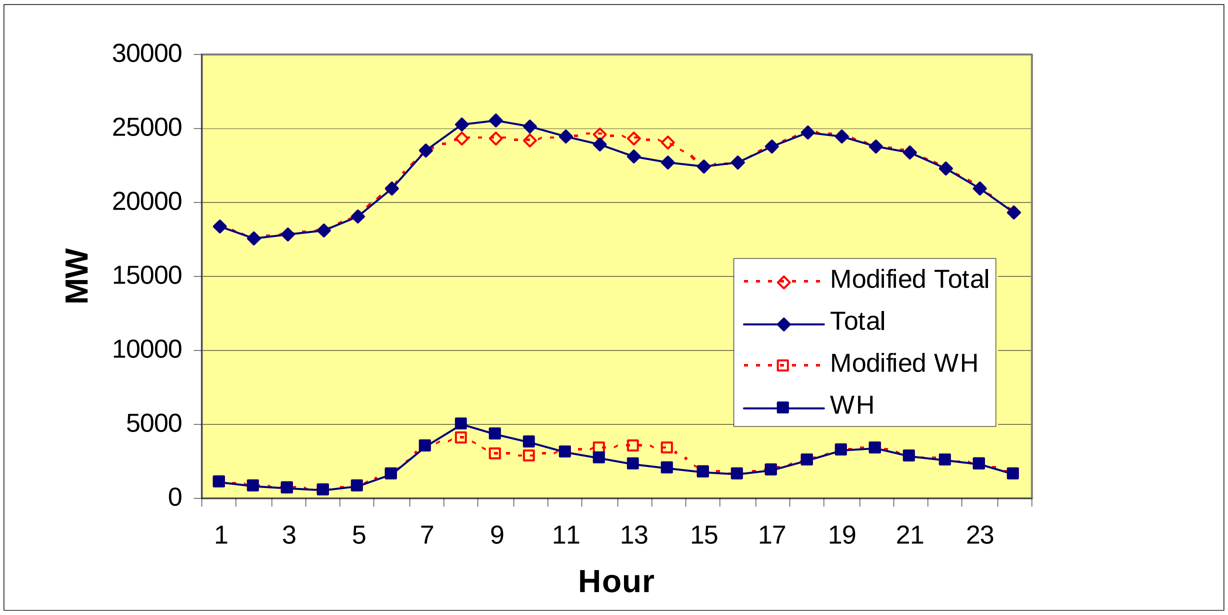
[3] A common assumption is that this coordination includes a requirement that the charge in the battery at the end of the day is sufficient to get home. Even if this requirement is not met, however, PHEV have the ability to charge their own batteries, so that they are not stranded.

4 Water heating load tends to be high when total load is high, so that the available water heating reductions to help meet peak total load are nearer to 5,300 megawatts than 400 megawatts.

heaters to their original average temperatures. The reductions could have been as much as the entire water-heating load, for example, 5,000 megawatts in hour 8 (7:00 a.m. to 8:00 a.m.).

The broken lines illustrate the expected pattern: a reduction in both water-heating and total load, followed by increased load as the water heaters require more energy to restore their original storage temperatures.

Figure K-1: Peak Reduction Illustration - Controlled Water Heaters



Controlling Water Heaters to Provide Regulation or Load Following

Energy users can help the power system by reducing load as shown in Figure K-1, but reductions alone are not enough to keep the system in balance; load must also be increased when the system needs it. These adjustments up or down are referred to as regulation or load following. Water heaters, unlike most other loads, are able not only to reduce load temporarily but can also temporarily increase load as well.

While water heaters are usually set to maintain water at 120 degrees Fahrenheit, they can operate at significantly higher temperatures, and were commonly set at 135 degrees before the energy crisis of the 1970s. Raising the storage temperature to, for example, 135 degrees does not increase the total number of gallons of hot water in the tank, but it does increase the total energy stored in those gallons. A mixing valve would ensure that enough cold water is added to the 135-degree water as it leaves the tank to make sure water at the tap never exceeds 120 degrees for safety concerns.

A water heater that is set at 135 degrees will provide more gallons of (mixed) 120-degree water than the same tank set at 120 degrees. Therefore, a water heater with appropriate controls and a mixing valve could accept extra energy from the power system, and store it in the form of higher-temperature water. Then when its hot water is used, the water heater could “return” the energy to the power system in the form of reduced load by heating replacement water only to the original 120-degree setting.

Smart grid technology could enable system operators to control water heaters in both directions in real time, as unscheduled variations in load or generation occur. Water-heating load could, in principle, increase up to the maximum connected load,[5] or decrease down close to zero, but the duration of the increases and decreases would be limited. The duration of load increases would be limited by the allowed rise in water temperature above its normal setting. The duration of load reductions will be limited by the reserves of heated water in the tanks.[6]

Fortunately, regulation and load following require both increases and decreases in load within the hourly operating schedule of the power system. These increases and decreases tend to balance each other over the operating hour. Therefore, these services do not usually require large net increases or decreases over several hours.

Controlling Water Heaters for Energy Storage

With smart grid controls and communication, water heaters could also act as virtual batteries, storing electricity generated at times when there is little or no demand for it, and releasing it when it has more value. An example of such a condition is 4:00 a.m. during the spring runoff, when demand for electricity is low, river flows cannot be reduced, not much non-hydro generation is operating, and winds are increasing. System operators have few good options – they can cut hydro generation by increasing spill, which loses revenue and can hurt fish, or they can require wind machine operators to feather their rotors, losing both market revenue and production tax credits.

In such conditions, water heaters could absorb extra energy by raising the temperature of stored water and return it to the system by reheating to a lower temperature later. If, for example, the temperature is raised from 120 degrees F. to 135 degrees F, 3.4 million 50-gallon water heaters can accept 6,198 megawatt hours[7] of energy and store it at the cost of roughly 24 megawatt-hours per hour from higher standby losses. Figure K-2 is similar to Figure K-1, except that January 2, 2010 loads are used. The “Modified WH” and “Modified Total” broken lines illustrate an increase of 3,099 megawatts in water heating and total load in each of the hours from 3:00 a.m. to 5:00 a.m. and reductions over the hours from 7:00 a.m. to 11:00 a.m. as the water heaters return to their original temperatures.[8]

In contrast to the pattern in Figure K-1 of reductions in load followed by increases, the pattern in Figure K-2 is the opposite -- increases in load as the water heaters absorb the energy to be stored, followed by decreases in load as fewer gallons of cold water need to be heated to 120 degrees.

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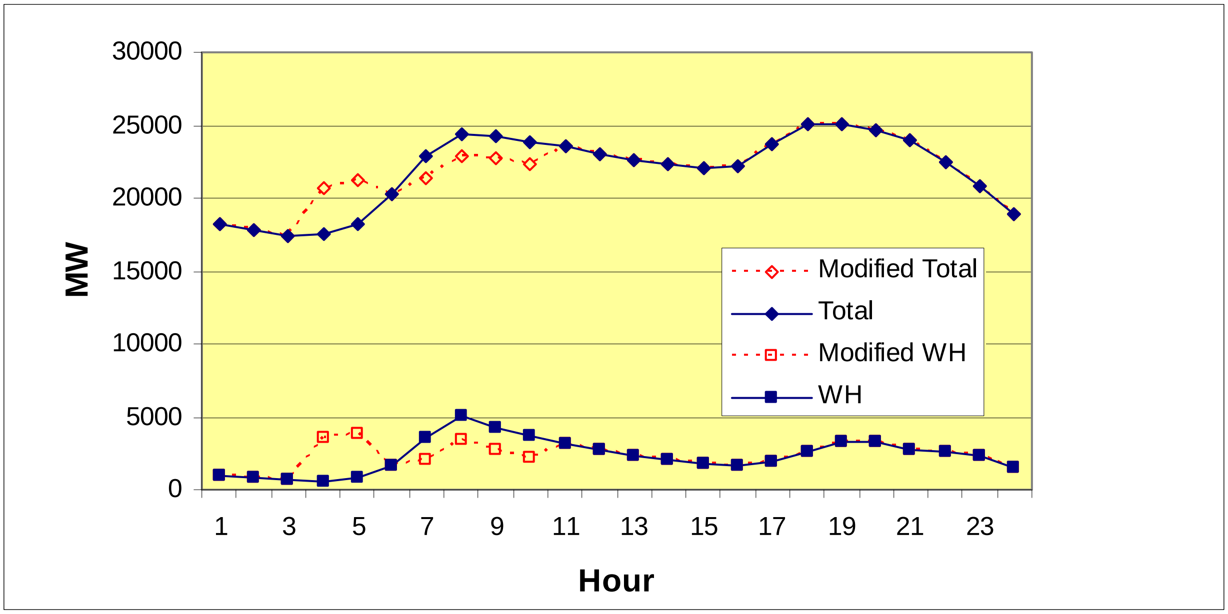
[5] This would imply an increase of 14,900 megawatts in hours when water-heater load is at its minimum (15,300 – 400) or 10,000 megawatts when load is at its maximum (15,300 – 5,300). As a practical matter, the system will never need this much load for regulation or load following, and calling on the full amount could well cause local distribution problems in any case. It’s enough to say that several thousand megawatts could be available.

[6] If consumers find themselves without hot water very often, they are likely to withdraw from the program.

[7] This rise could result from an increase in load of 6,198 megawatts for an hour, or an increase in load of 3,099 megawatts for two hours, etc. If we allow water temperatures to rise more, water heaters can provide more regulation or load following flexibility.

[8] The return of the energy to the system could be managed to occur later in the day (for example in the high-load hours from 5:00 p.m. to 9:00 p.m.) if that was more useful to the power system. The extra standby losses would amount to about 264 megawatt hours, or about 4.3 per cent of the stored energy.

Figure K-2: Energy Storage Illustration
Controlled Water Heaters



The practicality of water heating as a source of load following and/or energy storage depends on the cost of the sensors, communication, and controls that have been assumed in this illustration. It may be that the technology is already sufficiently developed to make load following with water heaters practical if it can be built into the heaters at the factory instead of retrofitted after the heaters are installed in customers's houses. In that case, the new federal administration's announced willingness to act aggressively on new applicance standards and to encourage smart grid technologies offers the opportunity to see this possibility become reality.