A BRIEFING NOTE FROM THE
DEPARTMENT OF ENGINEERING AND PUBLIC POLICY
CARNEGIE MELLON UNIVERSITY

July 2009

# The many meanings of "Smart Grid"

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America seems to have decided that a "smart grid" is what we need to solve the problems of our electric power system. But, what exactly *is* a "smart grid"?

The answer is that it is many different things. Some of the things that get talked about are relatively inexpensive and can go a long way toward solving key problems. Others will likely be very expensive, and at this stage may better be left to the realm of research.

*At the level of the customer:*

- <u>Meters that can be read automatically</u>, without sending a meter reader out once a month. This can be done in several different ways: with a signal that is sent back to the transformer or substation over the power line (power line carrier) and then on to the utility in some other way; by a radio link in the local neighborhood; or by a van that drives around the neighborhood and asks each meter to give an automatic readout, via radio links. Systems like this are already widely deployed by many power companies, and generally pay for themselves through reduced meter reading costs.
- <u>Time-of-day and time-of-use meters</u> (there is a difference). Most customers in the USA today pay a flat average rate for electricity. Some industrial and commercial customers pay rates that reflect the real cost of generating power, that can be cheap at night and expensive at times of peak demand when every generating unit is pressed into service, including old and inefficient ones. Time-of-day meters basically contain a clock and charge different rates at different fixed times of the day (e.g. "on-peak" and "off-peak"). These meters bill at a higher price at a time-of-day when the demand for power is typically high, regardless of actual demand on that particular day. A few utilities have had time-of-day systems in place for both residential and commercial customers for over 50 years.

  In contrast, "time-of-use" or "real-time" meters receive signals from the power company and switch to higher or lower rates as the actual cost of providing power to a customer goes up and down.

  Both technologies are intended to reduce peak loads so that less generation and transmission capacity is needed. Time-of-use meters can do this more effectively and can respond in real time to unusual stresses on the system. Research done in Carnegie Mellon's Electricity Industry Center has shown that in most systems, only about 20% of the larger and more flexible customers need to be switched from conventional meters to real-time meters, in order for everyone to get as much as 80% of the benefits that would be achieved if all customers were on real-time meters. This suggests that today the

At Carnegie Mellon, research on the electricity system is being conducted by the campus-wide Electricity Industry Center (www.cmu.edu/electricity) and by the Electric Energy Systems Group in Electrical and Computer Engineering (www.eesg.ece.cmu.edu/). Research on information system security is conducted in CyLab (www.cylab.cmu.edu).

optimal strategy is not to give every customer an expensive real-time meter, but rather to introduce them selectively to the larger more flexible customers.

- Meters that communicate to customers. Just as the utility can gain valuable information on current usage, so can the customer. Today, most customers only receive information through their monthly bill, which arrives days after decisions such as whether to turn the thermostat up or down. A display that tells interested consumers their current rate of electricity use, and its cost, would give customers information to make informed decisions.
- Control of customers' loads. Nobody wants to sit and watch the meter all day to see what the price of electricity is. Adding simple control circuits allows loads like air conditioners or water pumps to be cycled on and off automatically, without damage to the equipment and little or no customer discomfort. Often turning off or "shedding" as little as 5% of the load can halve the need for expensive peaking generation. Since more than 5% of total load is being wasted in lighting unoccupied rooms or cooling unoccupied residences, or being expended on activities such as washing dishes and clothes that can easily be shifted to periods when electricity usage is low, the cost to consumers is minimal.

  Implementing such a system requires two engineering design choices:
  1. Appliances and other loads must be able to receive the signal to defer use (either by wire or by wireless connections) and must contain automatic switches that can turn them on and off.
  2. Someone has to choose when to turn loads on and off (see the section below: *Who should be in charge?*).

Simple versions of systems in which the utility can connect and disconnect loads are commonly used with some industrial customers who have "interruptible rates." For 40 years a small number of utilities have also had systems to control water heaters, air conditioners, and pool pumps. Today, in a few very limited trials, customers have control of their own appliances in response to price changes.

In addition to controlling individual loads on the customer side of the meter, these automated systems can also be designed to disconnect a customer in an emergency (see the section on distribution automation below) or when customers do not pay their bill.

*At the level of the distribution system:*
Electric power reaches end customers through the high voltage transmission system (large steel towers carrying high voltage lines) and then at lower voltage through the distribution system (the poles along the streets or in underground conduits). When people talk about "smart grid" they often include several things that can be done to improve the control and operation of distribution systems. These include:

- Distribution system automation. While transmission systems are laid out as "mesh grids" that interconnect through substations in several locations, most distribution systems are made up of simple "tree-like" structures called "distribution feeders." In a typical distribution feeder, all the power enters at one point (the root) and then flows out to the loads along the branches of the distribution feeder to the customers. If there is a problem (e.g. a vehicle hits a power pole, or lightening strikes a transformer), circuit breakers may automatically disconnect the entire feeder. If a feeder can be fed from more than one place (i.e. branches from two separate trees can be connected together), such an incident need not take down the entire feeder. Some utilities have added sensors and remote control switches that can isolate and cut off the problem. A number of power companies have already found it cost-effective to install distribution system automation. While commercially available, this is a rapidly changing technology, and today is deployed in only a few areas.

- Selective load control. Today, if a system emergency occurs (e.g. a large ice storm, human error, or a terrorist attack) that reduces electricity supply below demand, all customers will be blacked out unless sufficient load is shed to have supply match demand. At present, the only way to do this is by disconnecting entire distribution feeders. It would be far better to be able to control individual loads along a distribution feeder so that critical services such as police stations can remain connected, while loads that provide less critical services can be dropped. With a combination of smart meters and advanced distribution automation, this is possible, but almost no utilities have implemented this capability. Part of the reason that this has not happened is that the benefits of such a capability accrue more to society than to the operating utility.

  Once smart meters and loads become widely used, an even more sophisticated emergency response could become possible, in which individual loads within customers' premises are turned on or off.
- Managing distributed generation and "islanding". Small distributed generators that both make electricity and produce usable heat energy (to provide water and space heating, run absorption chillers for air conditioning, etc.) have a number of advantages: they make more efficient use of the energy of the fuel that is used; they can relieve stresses on transmission and distribution systems; and, they can increase the reliability of power supply to local customers. In an emergency, it would sometimes be desirable to be able to disconnect a distribution feeder from the main power system and run it as an isolated "island," serving only a few of the most critical loads. For technical, legal, safety, and regulatory reasons, today's power systems cannot do this. However, with the right technology, control systems, and regulatory environment, there is no reason why they could not do this in a safe and efficient manner. Changes in state laws are needed to allow the development and wider use of distributed generation and small "micro-grids."

*At the level of the transmission system:*
Electricity generated at large central-station power plants and wind farms is moved to "load centers" (e.g. cities and major factories) over very high voltage transmission lines. Using high voltage keeps the current low and so reduces loss (i.e. energy that is wasted heating the wires). Transmission systems already have some instrumentation that allows control centers to monitor power flows and open and close circuit breakers at substations. However, there is much more that can be done.

- Measurement of phase and other advanced measurements. While transmission systems automatically measure power flows and report them back to control centers where human and computer operators make control decisions, there is additional information that could be collected to improve dramatically the control and stability of high voltage grids. The voltage and current in the U.S. power system oscillates at a frequency of 60 cycles per second (60 Hz). However, current and voltage do not oscillate in phase (go up and down together). Further, in order to move power over a long line, there has to be a difference in phase between the two ends of the line, but if that difference becomes too great, the line will no longer transmit power. There are very few measurements of phase being made across today's transmission systems. With many more measurements at key locations, and with high-speed communication and advanced control systems to make use of the data, the efficiency and stability of power system operation could be improved substantially. Some of these changes are being made, but much more slowly than many experts believe is socially desirable. More advanced capabilities are also possible, but funding for such research has been limited.

- <u>FACTS and other advanced control devices.</u> Power flows through transmission grids in accordance with the laws of physics, not the laws of economics. This means that often it will flow in parts of the network where it is not wanted, and not flow in places that would be more economically desirable. A family of devices based on solid-state power electronics can change the electrical properties of lines and make power flow where it is wanted. These <u>F</u>lexible <u>AC</u> <u>T</u>ransmission <u>S</u>ystem control devices are called FACTS devices (there are a variety of different devices that can all be lumped under this general name). While FACTS devices are expensive, a few utilities have started to use them when they are the most cost-effective way to solve a transmission problem (e.g. because using them is cheaper than building whole new lines, or because such lines simply cannot be built). The control of FACTS systems requires advanced communication and system-level control technology. Today, most FACTS devices run on single lines. If FACTS devices become more widely used, it will become necessary to develop advanced control systems to deal with the potential interaction between these systems. Again, funding for such research has been limited.
- <u>Distributed and autonomous control</u>. Today, power systems are controlled centrally by human operators, assisted by advanced computer systems. Only a few elements of the system (such as protective circuit breakers) operate automatically, and typically these do not cooperate with each other. It takes time to move information from across a far-flung system back to central controllers, process it, and make control decisions. That places limits on how effective power system control can be, especially under emergency situations. Researchers at Carnegie Mellon and elsewhere have built models that demonstrate that in some situations distributed advanced automatic control systems (using computers that take measurements and talk to each other) could do a better job. As with most of the other technologies and strategies for transmission-system control, funding for such research has been limited.

In short, many advanced technologies and strategies could be used to turn the high voltage transmission system into what some have termed a "smart self-healing grid." A few important things could be done today. However, before the more advance ideas can be implemented, additional research and small-scale demonstration will be needed.

*Who should be in charge?*

In considering the control of customer loads and distribution systems, a key policy issue is <u>who gets to choose when and where to turn things on and off</u>? In the smart grid systems being built in some parts of Europe, such as the Netherlands, the answer is the utility is in charge. In emergency situations, that is surely the best arrangement. But, for day-to-day operations, we believe that it is far better to leave control in the hands of customers, who are free to respond to price signals. Nobody wants to sit and watch the meter, but in our electronics age there are simple inexpensive devices that can carry out our instructions as electricity prices change (see the discussion above on time-of-use meters and on control of customers' loads).

*What vulnerabilities could "smart grid" create?*
All the systems we have described require communication between various components. Some of this communication will take place over wires or fiber optics. Some of it will involve wireless connections. All of these communication links introduce vulnerabilities, especially if they can be accessed over the Internet. We should not build a power system in which a hacker working for a burglar can tell when you are home by monitoring your control systems or a hacker on the other side of the world can cause system-wide instabilities and blackouts. Many of the designers of these systems offer assurances that they are being built in compliance with all the current security standards. However, such standards have by necessity been developed before a smart grid existed, or a clear consensus has emerged regarding the nature of a smart grid. Thus, serious scrutiny is needed to ensure that such standards are truly adequate. The social vulnerabilities that a "smart grid" may create are receiving far too little attention. Figuring out how to minimize or avoid these vulnerabilities is an issue in urgent need of study. A good place to start would be with a request from Congress for a careful study by an expert National Academy committee.