A Scalable Approach to Smart-Grid Technology
or
"A Smarter Smart Grid"

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Abstract

As the United States prepares to make significant investments in "Smart Grid" technology and policy, policy-makers should carefully consider the privacy, security, scalability, and economic costs of competing smart-grid designs. Some existing designs, particularly regarding the management of consumer electricity consumption, rely on a top-down architecture that could be excessively costly and require substantial privacy sacrifices. Such designs could inhibit consumer adoption and slow the innovation process. An alternative approach to the smart grid would be one modeled after the Internet, which has a decentralized, bottom-up design that enables consumer choice and facilitates social goals with minimal centralized management.

Motivation

There is broad agreement in the electricity industry that the US electricity infrastructure needs to modernize to facilitate increasing electricity demand, increasingly complex long-distance transactions, and the reduction of greenhouse emissions. As such the American Recovery and Reinvestment Act of 2009 allocates $4.5 billion to "modernize the electric grid." Much of the smart-grid technology that is intended to facilitate this transition aims to enable devices that consume electricity in a way that is more grid friendly. If consumer devices could choose to consume electricity when it is less environmentally and economically costly to do so and when it is unlikely that consumption will cause a blackout, we would certainly see tremendous social benefits. The existing grid is not well suited to handle large fluctuating power sources, such as large wind farms and solar energy systems. If electricity-consuming devices were a bit more grid friendly, we could obtain a larger portion of our electricity from these sources without the reliability problems that can come with large-scale deployment of intermittent sources.

While many talk about the need for a smart grid, a small but growing number of research and industry groups have developed and tested technology for managing residential and commercial electricity consumption. Some of this technology has been in existence for decades under a variety of load management programs (see

Morgan and Talukdar, 1979, Schweppe et al., 1980). However most of the early automated demand-side management (DSM) programs were offered only to very large commercial or industrial consumers, many of whom chose not to participate due to the high costs associated with the sudden loss of electricity service. Programs that gave customers the option to reduce their consumption without automated equipment have had greater longevity in the electricity industry.

More recent experimental DSM programs, enabled by progress in information technology, have shown that it is possible to extend smart grid technology to smaller consumers. The GridWise Olympic Peninsula Project, led by researchers at the DOE Pacific Northwest National Lab, demonstrated that information technology can enable more grid-friendly electricity consumption, reducing costs and enhancing reliability (Hammerstrom et al., 2007). By equipping homes with technology creating a data connection between loads and utility computer servers, customers were able manage their electricity consumption according to preferences for price and comfort. This was accomplished by having customers upload upload their economic and comfort preferences to the utility, which could subsequently send signals to switch loads on and off. The project was successful in that the customers who had the energy manager devices shifted much of their electricity consumption to off-peak, lower-price hours, thus proving the feasibility of using technology to facilitate more grid-friendly energy consumption patterns.

While the benefits of demand responsiveness are rarely disputed, important policy questions arise as we consider how to implement the technology and policies that will enable demand-side smart grid behavior. Three goals are of particular importance as smart-grid policies go forward: privacy, security and scalability. Without privacy, consumers will be very reluctant to participate. Without security, the smart grid will be vulnerable to outside disruption, putting critical infrastructure at risk. Without scalability, a growing smart grid will become increasingly difficult to operate, inhibiting growth. With a design that cannot grow rapidly the smart grid will not realize its advertised economic and environmental benefits.

In order to evaluate the privacy, security and scalability of a given smart grid policy and/or technology design one needs to pay particular attention to the flow of information and the flow of control signals. As Congress has specifically mandated that part of the smart grid funds in the Recovery Act be used to answer outstanding questions related to developing and implementing smart grid standards, now is the time to study proposed designs carefully.

Top-down smart grid design

In most smart grid/DSM designs information flows from the consumer to the utility and control signals flow from the utility to the consumer. This top-down architecture has worked fairly well for programs serving large industrial customers. A utility or other load serving entity monitors a customer's demand and when conditions warrant emergency action it sends control signals that disconnect loads and thus reduce stress in the system. This roughly describes the DSM program operated by PJM Interconnect, the grid operator in the Mid-Atlantic States. Customers can sign up with "Curtailment Service Providers" who provide customers with attractive electricity rates in return for the right to interrupt loads when signals from PJM indicate that reductions are needed.

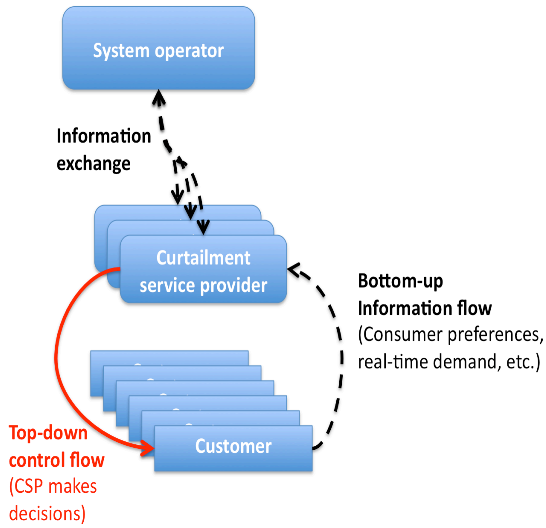

Figure 1. A pictorial description of top-down smart grid architecture

Top-down control flow and bottom-up information flows pose a number of challenging privacy, scalability and security problems. First, there are significant privacy concerns associated with the uploading of detailed user preferences and data from the consumer to the supplier. Many privacy-conscious consumers would choose not to participate if they felt that there was even a very small risk of information being misused by electric companies or other information brokers in the energy delivery system.

Secondly, top-down control flows pose substantial scalability problems that could limit the reach of load management programs, thus limiting the benefits of smart grid technology. This scaling problem is dealt with in the PJM case through a hierarchical design in which intermediate service providers act as mediators of control and information flows between consumers and the system operator. While the hierarchical method does reduce the scalability problems associated with top-down control flows, it adds substantial cost and complexity to the system that may not be necessary.

Finally, security is an acute concern with this model. Any individual who can mimic the curtailment control signals may be able to create de-stabilizing demand patterns, and potentially initiate a blackout. While security is a challenge with any smart grid technology, the technological uniformity that could result from a hierarchical design exacerbates these challenges.

Bottom-up smart grid design

An alternative to the top-down model is to design smart grid policy and technology to facilitate bottom-up control flow and top-down information flow.

Wikipedia is an example of this bottom-up approach. Wikipedia servers disseminate an enormous quantity of information, including the text of twelve million articles and tools for users to edit those articles. Control of article content lies almost exclusively with readers. Information flows top-down and control is local to the consumers of the information. With bottom-up input from millions of readers, Wikipedia grew to be the world's largest encyclopedia in four years and according to a recent study in *Nature* (Giles, 2005), its articles are nearly as accurate as those found in *Encyclopedia Britannica*. Its operating costs are a miniscule fraction of those of print encyclopedias. It would be impossible to achieve this level of growth and economic efficiency with a centralized, top-down control flow. This same bottom-up scalability is found in the Internet as a whole, where the number of Internet addresses has grown from 315 in 1982 to 2.7 billion in 2008 (Heidemann, 2008). This explosive growth has facilitated enormous economic and social benefits, increasing productivity and decreasing the cost of financial transactions (Carlsson, 2004).

With this in mind, a "Smarter Smart Grid" would employ the bottom-up concepts of the Internet to enable electricity consumers to make socially valuable decisions, such as reducing electricity consumption during high-price, high-emissions, or high-blackout risk periods. In the bottom-up approach proposed here, policy makers develop regulations requiring utilities to publish ongoing usage and rate information on a web site or some other broadcast portal (much of this data is already posted on public web sites) and to develop rate structures that reward consumers for responding to posted signals in socially beneficial ways. With this information available and incentives established, customers could reduce their electricity costs by acting in grid-friendly ways. Technology will certainly be necessary to enable consumer response, but by keeping the information flow paths simple and uniform, a wide variety of competing technology options can meet the needs of different consumers.

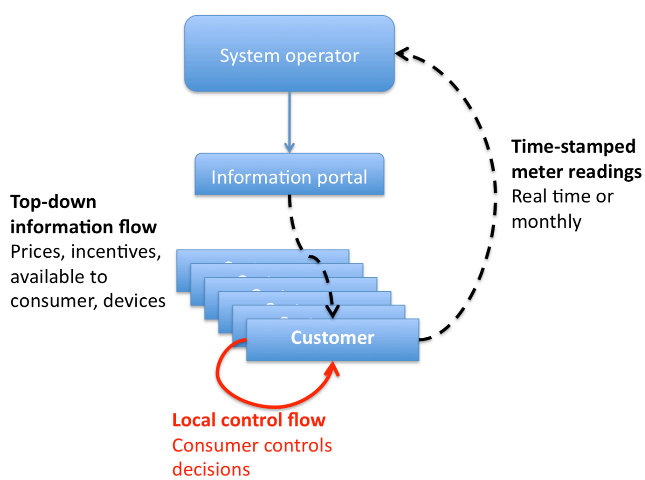

Figure 1. A pictorial description of bottom-up smart grid architecture – a model the authors argue must be considered to ensure highest value U.S. smart grid investment

In this approach, the only bottom-up information flow would be time-stamped meter readings for each customer. While time-stamped metering is not ubiquitous, popularity is growing quickly. A meter that time-stamps its measurements is the simplest version of the ”Advanced Metering Infrastructure” that is a central component of current smart grid designs.

More sophisticated (and expensive) smart meters can engage in two-way communication with both the utility and with customer loads. These more sophisticated meters could eventually lead to a bottom-up smart-grid structure, however a utility-owned device that engages in two-way communications with consumer-owned loads raises important privacy concerns that, as mentioned earlier, could impede adoption.

Instead, by leaving the task of load-control to consumer-owned devices and with the top-down information flows separated from the meter, many different competitors could produce energy-manager devices and software appealing to a wide variety of consumers, thus opening up markets for iPod-like devices for home and small business energy management. Load serving entities would be free to offer a technology of their choosing, but could not impede consumer choices. The meter would perform only its traditional task of verifying the extent to which customers respond to price signals.

The privacy and scalability advantages of the bottom-up approach are clear. Avoiding bottom-up information flows should greatly reduce privacy concerns. Avoiding top-down control flows reduces complexity by avoiding the need to centrally control individual loads via intermediate entities (Curtailment Service Providers). Without centralized control, new participants do not add additional cost to the system—leaving the growth of the smart grid unbounded (scalable).

With regard to security, the bottom-up approach has diversity on its side. Technological uniformity can make it easier for an attacker to find holes in security measures. With a wide variety of energy management technology deployed, attackers will need to hack into the central information portal to have a significant effect on the grid. While this is certainly not impossible, tools available for defending against such an attack are widely available.

Action items and conclusions

Congress has wisely allocated funds for continued development and execution of communications standards for smart grid technology, much of which is being conducted by public-private partnerships such as the GridWise Architectural Council, EPRI’s Intelligrid team, and the Modern Grid Strategy. As NIST and DOE supervise these standardization efforts they should pay careful attention to the privacy, scalability and security implications of competing architectures. Designs that sacrifice privacy or security, or do not scale well, will fail to deliver on the myriad benefits promised by smart grid proponents. However, with an open, bottom-up architecture the possibilities for innovation and social benefits are limitless.

For Further Reading

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