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# Transforming the U.S. Electricity System

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Abstract— **The smart electric power grid of the future will integrate the traditional elements of supply and demand, transmission and distribution with new technologies such as superconductors, energy storage, customer load management, and distributed generation, using information to make them function as a "society" of devices in a complex, integrated system. The vision for transforming the nation's electric system—from central generation down to customer appliances and equipment—into a collaborative network filled with information and a myriad of market-based opportunities—is being put forward by leading thinkers in the U.S Department of Energy, national laboratories, and industry as a major scientific and engineering challenge for the nation and as an important economic value proposition for ratepayers and the electric industry. An overview of this vision and some illustrative examples are the subjects of this paper.**

**The nation's prosperity and the American way of life depend upon efficient and affordable energy. Without a major shift in the way the energy system is planned, built and operated, the U.S. will invest hundreds of billions of dollars in conventional electric infrastructure over the next 20 years to meet expected growth. Minimizing the cost of new electric infrastructure is a key to strengthening the U.S. economy.**

**The foundation for te GridWise™ vision for the future electric system is the assertion that information technology can revolutionize the electric system as it has other aspects of U.S. business because, fundamentally, "bits are cheaper than iron." Bringing the electric system into the information age would allow the nation to realize the benefits already achieved by leading-edge industries that use real-time information, distributed e-business systems, and market efficiencies to minimize the need for inventory and infrastructure, and to maximize productivity, efficiency, and reliability.**

**With the help of information technologies, the creation of a distributed, yet integrated system will empower consumers to participate in energy markets—the key to stabilizing prices. Market participants from utilities to new third parties to consumers will create value by developing and deploying solutions that cross enterprise and regulatory boundaries. At the same time, this transformation of the energy system responds to the urgent need to enhance national security. A distributed, network-based electric system will reduce single-point vulnerabilities and allow the grid to become "self-healing," by incorporating autonomic system reconfiguration in response to human-caused or natural disruptions.**

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## I. INTRODUCTION

Comparing the information flow in today's electric system to that of other major industries is a bit like comparing two soup cans connected with a string to the wireless, hand-held computers we use to quickly check our e-mail and call back to the office.

Since its creation, the nation's energy system has been based on linear, one-way flows of information. Electricity is sent from the generation source over transmission and distribution lines to the end user. End users send money to the energy provider to pay for the energy they used.

Over the last decade, leading-edge industries have been using real-time information, e-business systems and market efficiencies to minimize the need for inventory and infrastructure while maximizing productivity and efficiency. However, the energy system has yet to make those advancements, or reap their benefits. The electric power grid is full of massive and expensive infrastructure that is generally underutilized. To meet growing demand, utilities continue to put up more iron and steel, and pass the cost on to their customers, who have little say in the matter. To meet the load growth projected by the U.S. Energy Information Agency, $450 billion of new electric infrastructure must be added by 2020 if we continue this "business-as-usual" approach.

We think it's time for this to change. Efficient, affordable and reliable electricity is a cornerstone of our national prosperity and the American way of life. By moving the energy system into the information age, information technologies and newly created market efficiencies can optimize the system, minimize the need for new infrastructure, lower costs and make the system more secure.

And, on the heels of last August's major East Coast power outage, the nation should be more ready than ever to dramatically transform its energy system. Infusing the system with information technology will integrate traditional and distributed assets—from generation, transmission, and distribution, to end-use—into a collaborative "society" of devices.

## II. THE VIRTUAL ENERGY INFRASTRUCTURE

Information technology can be the genesis of a "virtual" energy infrastructure where smarter use of the physical infrastructure we have in place today could offset the need for new capital investments. Establishing this virtual infrastructure would rely upon an information-rich network that combines new energy markets, communications and controls to maximize the use of existing assets and gain efficiencies.

For example, on average, only 75 percent of the nation's generation assets and 50 percent of the distribution system assets are needed. Peak capacity for. By finding a way to better manage the system for the 400 or so hours a year when demand is at its maximum, only 5 percent of the time, we could easily reduce the distribution and generation assets needed to meet today's demand by 25 percent and 10 percent, respectively. Freeing up that those resources will lower prices in today's competitive electric markets and enable them to meet future growth without having to build new power plants, substations and transmission lines.

## III. LOOK WHO'S TALKING

So how would these efficiencies be gained? What kind of communication and integration would it require? Here is just one view of the situation. From a customer perspective, a smart meter or similar device will be communicating with suppliers about the amount of energy a household or business is using and will need in the minutes, hours, days, and months ahead. In turn, suppliers will be communicating with the customer's meter about the availability of their resources, their prices and the any incentives they might offer to curtail use or run distributed generators during times of peak demand. In some cases, the meter will automatically determine which deals to make, in others it will alert the consumer when there is an attractive offer on the table for their consideration.

Furthermore, the information that energy service companies gather through routine energy audits, such as the possibility of improving energy efficiency by retrofitting a heating and air conditioning system with a more modern, efficient system, could now easily be tallied up. With better data and an understanding of how a change at one point in the system could bring benefits across the system in areas previously not considered, energy providers can readily see how combining several of opportunities could bring a significant benefit. Perhaps the energy service company would then decide it was worth the investment to offer an entire neighborhood an incentive to make for certain energy efficiency improvements because it could delay the need to add a new substation, for example

## IV. A FOCUS ON DEMAND RESPONSE

The abundance of information, including price signals and grid conditions, will allow demand response technologies to play a significant role in a virtual energy infrastructure.
Consider that regardless of time of day or even time of year, 20 percent of the load on the nation's energy system is from consumer appliances that cycle on and off such as heating, air conditioning, water heaters and refrigerators. At the same time, generators also maintain steady operating reserves on "hot standby" that are equivalent to about 13 percent of the total load on the system in case problems suddenly arise. Why not find a way to reduce the demand of these appliances in times when operators would typically by dipping into the expensive cushion?

The Grid Friendly™ controller developed at Pacific Northwest National Laboratory senses grid conditions by monitoring the frequency of the system and provides automatic demand response in times of disruption. Within each of three vast interconnected areas of the North American power grid (East, West, and Texas), a disturbance of the 60-Hz frequency is a universal indicator of serious imbalance between supply and demand, that, if unarrested, leads to a blackout. This simple computer chip can be installed in household appliances and turn them off for a few minutes or even a few seconds to allow the grid to stabilize. The controllers can be programmed to autonomously react in fractions of a second when a disturbance is detected, whereas power plants take minutes to come up to speed. They can even be programmed to delay restart instead of all coming on at once after a power outage to ease power restoration.

By integrating the controllers with appliances at the factory, costs can be reduced to a few dollars per appliance and customers will not even notice the short interruption (by turning the compressor off but leaving the light on in a refrigerator, for example). In the process, customers become an integral part of power grid operations, and could even be rewarded for their participation in helping prevent a widespread outage. So, without the need for any formal communications capability, appliances are transformed from being part of the problem to part of the solution, acting as assets that forming a much quicker and better safety net under the power grid, and freeing up power plants from standby duty to increase competition and lower prices and meet future load growth.

## V. COUNTING THE LINKS IN THE VALUE CHAIN

An integrated, information-rich network provides the catalyst needed to accelerate improvements in efficiency and the penetration of distributed resources and other new technologies such as distributed generation, storage and load management technologies.

Traditionally, customers would not consider making these kinds of investments unless they see a three-year payback, however, they haven't been able to see the whole picture when making this decision. With access to new kinds of information that allow all of the benefits and value that distributed resources bring to the different parts of the system to be recognized, the true payback becomes apparent. Cumulatively, the savings across the system are much more substantial and the motives for pursuing them are suddenly much more appealing. For example, the addition of distributed generation could provide multiple benefits to more than one level of the system, including avoiding central generation, relieving congestion on transmission lines, improving power quality at the distribution level and lowering electric costs to the consumer—all of which should be incentives for inserting new technologies or adding distributed resources to the system.

Similarly, studies conducted at Pacific Northwest National Laboratory have examined the value that tomorrow's transformed energy system, which we call GridWise™, has to offer. Our results show that the savings could exceed $80 billion over the next 20 years. These figures are based on deferring new construction by actively managing load, reducing outage costs through active grid management, increasing customer efficiencies through advanced controls and diagnostics and a number of other opportunities to cut costs across the system.

## VI. Opening New markets

The key to stabilizing energy prices lies in creating elasticity in the demand for energy. Today, consumers are passive participants. There are few short-term market cues for retail customers since their prices are averaged over time, so they continue using energy however and whenever they want, even when wholesale prices skyrocket. Merchant generators undertake construction only when high prices, intimidating to consumers and regulators alike, prove there is sufficient demand. Resulting booms in power plant construction dramatically lower subsequent prices and rates of return on generation investments, stifling investment until demand catches up and prices again skyrocket. The resulting boom and bust cycle of power plant construction provides the worst of both worlds – high prices that inhibit economic growth and uncertain returns that oblige investors to add a risk premium on the interest they charge for capital invested in new infrastructure – which is passed along to consumers in the form of higher rates.

By empowering customers to participate in the energy markets, they can help defer or eliminate future investments. An elastic demand for energy would increase the lead time for adding capacity and reduce business risk to utilities, allowing them to better focus their investments to meet customer needs. Adding smaller increments of new capacity with shorter lead times in the form of distributed generation and demand response programs provides the flexibility needed to adjust supply additions to match short-term and local variations in demand growth, minimizing both stranded over-investments and risk of under-investment.

The key to leveraging customer and third-party investments for collaborative operation of the power grid is revealing all values to all parties involved. Whether in a regulated utility environment utilizing systems of incentives and resource bidding, or a de-regulated market-based system, these advantages can be realized as long as access to the values are revealed and communicated to the participants and the technology is available to take advantage of them. Changes in the regulatory environment are essential to revealing value with active collaboration of utilities. Advanced information technology is the key to both the communication and control technologies that make it possible to take advantage of the market opportunities presented.

Information technology is also essential for this new era of energy commerce to be conducted in a more open, transparent manner. The debacle of unfair practices in California (Enron, et al) was not uncovered for more than nine months due to the lag between when transactions occurred and when data was available for analysis. That is simply unnecessary in today's information age. Efforts are underway to develop market simulation tools and techniques to craft open, fair and effective markets that provide stable incentives and prevent untoward profits. Furthermore, we are developing advanced analytic tools that could be used to detect and correct market abuses. Unlike the situation during California's energy crisis, readily available data would allow for better oversight and make it easy to spot unusual occurrences.

## VII. Forces of Change

### *A. Utility Restructuring*

The time is right for a revolutionary change to the energy system, and several forces are already at play in making it a realistic vision. The first is utility restructuring. If the nation continues moving toward a deregulated electric utility industry, there will be new opportunities to craft markets and incentives that express the real value of electricity based on system constraints and the seasonal and daily fluctuations in demand. The availability of these signals and the nature of these free markets would give customers the flexibility to collaborate across enterprise boundaries and customize their energy choices to minimize their rates while bringing benefit to the utilities that serve them.

### *B. Distributed Generation Potential*

The second force for change is the advance of increasingly cost competitive distributed generation technologies. In the last decade or so, distributed generation has been perceived as a threat to the utility system because it doesn't fit nicely into the linear paradigm operators and utilities were used to. It disrupts that one-way flow of power from suppliers to customer and the reverse flow of revenue in exchange. With the advent of better and less expensive distributed generation technologies, people are starting to think differently about the opportunities these could bring to consumers and the system. As part of a collaborative network, these technologies could become plug-and-play resources that if they were easily integrated and controlled to maximize their benefits. Even more fundamentally, they break down the linear paradigm, opening the door for other distributed resource technologies to enter the marketplace.

### *C. Trend to Universal Connectivity*

Third, telecommunications technologies and the number of communication channels have exploded in the last 10 to 20 years and, at the same time, their cost has dropped. To make the kind of transformation we envision today a decade or two earlier would have required a massive investment in new lines of communication and information technology that would likely have been cost-prohibitive. Now, the energy system can take advantage of the ubiquitous communications networks already in existence and under construction to share information across the system and collaborate in new ways, essentially piggybacking on systems put in place for other industries and entertainment that have been leading the way.

### *D. Rapid Advances in Information Technology*

Finally, advanced information technology has become more sophisticated and less expensive, making it possible to consider new concepts such as agent-based controls for operations and transactions, and automated diagnostics and prognostics. Computers can talk to one another, fuse and analyze data, make decisions based on pre-set preferences, and take action without the involvement of a human being. The energy system can shift away from brawn and more toward brain when it can exploit the expansion of computing power.

## VIII. Benefits

In addition to saving money and providing opportunities for distributed resources that are more environmentally friendly, the transformed energy system would be more resilient, more secure and self-healing in times of emergency. Today's system is physically dispersed with centralized control – undoubtedly the configuration most vulnerable to disruption, whether by nature or malicious intent.

Distributed, network-based control of our energy system with the self-optimizing and self-organizing properties of free and fair markets reduce single point vulnerabilities and enhances ability to dynamically reconfigure itself as needed. It allows vastly more flexible options for managing allocation of limited resources during a crisis.

## IX. Future Work

So, what will it take to get from where we are today to this new world? Several key activities are being launched to start the energy system transformation.

One involves the development of communications architecture and standards that will make it possible for generators, transmission and distribution utilities, energy service companies and consumers to share information and form an integrated network.

Second is the need for simulation and analysis. While promising, many of these concepts have not been fully explored or tested. Before any sweeping changes, new tools are needed to simulate energy markets and energy systems and validate the vision. These tools will combine operations and economics in a single model, something that hasn't been done before. Likewise, tools are needed to analyze and monitor the system as changes are implemented to determine the impacts and ensure fairness.

The energy system transformation will rely upon new smart energy technologies. Investments in developing these technologies, both from the government and industry, are needed to help jump-start the revolution. While industry will likely invest in the technologies they see as potential profit-makers, the government should help seed the early development of technologies that individual commercial companies might otherwise not take the risk to pursue. In both cases, as these technologies evolve, regulatory, institutional and market frameworks for their use will be formed.

As technologies are developed and explored, test beds and demonstration projects will provide experiments of ever increasing scale to prove their worth or reveal their faults. These demonstration projects will help build momentum for the changes that lie ahead and increase the support and reduce the perception of risk, building acceptance of the concept of a transformed energy grid.

Lastly, a change as dramatic as this will require the support and involvement of stakeholders and institutions. It will take time to gain the acceptance and active participation of utilities, vendors, regulators and customers, all of whom will have a role to play and be affected by the changes taking place.

Already industry is beginning to embrace the vision of a modernized grid and is starting to work together to realize its benefits. Last year, several corporations came together to form the GridWise Alliance, including Areva (formerly Alstom Esca), Battelle, IBM, PJM Interconnection, the Rockport Group, Sempra Energy Solutions and UAI. Additionally, stakeholders including commercial companies, utilities, regulators national laboratories and industry have met to begin outlining a federal program to lead the way.

The federal role in this transformation, especially that of DOE's Office of Electric Transmission and Distribution where this program resides, is to build consensus among these constituents, broaden the vision, and seed the research and demonstration required to make the transformation happen in a cohesive, well-planned manner. Federal involvement also ensures that consumers, the economy and the environment are protected along the way and benefit in the final outcome.

## X. Biography

**Robert Pratt** Mr. Pratt leads PNNL's Energy Systems Transformation Initiative that has spawned the GridWise vision of an information-rich future for the power grid. He leads a team within the initiative whose focus is simulation and analysis of the combined engineering and economic aspects of the current and future grid. He has specialized in the application of metered loads and end-use data to the analysis of energy systems planning and performance, and has developed a detailed understanding of utility planning processes from an assignment with the Northwest Power Planning Council. He has applied this expertise to a broad range of problems, from the potential for distributed resources (generation, storage, and customer load-management) to defer costly upgrades of the electrical distribution system, to developing technology for ensuring the performance of commercial building systems through advanced automated diagnostics.