Creating Tomorrow’s Intelligent Electric Power Delivery System

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INTRODUCTION
The August 2003 blackout in Northeast U.S. and Southeast Canada was a potent wake-up call that electricity is indeed essential to our well being and economy. And it highlights one of the most fundamental of electric functions: getting electricity from the point of generation to the point of use. Power delivery has been part of the utility industry for so long that it is hard to imagine that this process has not already been optimized. However, the power delivery function is changing and growing more complex with the exciting requirements of the digital economy, the onset of competitive power markets, the implementation of modern and self generation, and the saturation of existing transmission and distribution capacity. Without accelerated investment and careful policy analysis, the vulnerabilities already present in today’s power system will continue to degrade. Simply stated, today’s electricity infrastructure is inadequate to meet rising consumer needs and expectations.

A Vision of the Electric Power Delivery System of the Future
Implementation of the power delivery system of the future will achieve the following goals:

- Physical and information assets that are protected from manmade and natural threats, and a power delivery infrastructure that can be quickly restored in the event of attack or a disruption: a “self-healing grid”.
- Extremely reliable delivery of the high quality “digital grade” power needed by a growing number of critical electricity end uses
- Availability of a wide range of “always on, price smart” electricity related consumer and business services, including low cost, high value energy services, that stimulate the economy and offer consumers greater control over energy usage and expenses
- Minimized environmental and societal impact by improving use of the existing infrastructure; promoting development, implementation, and use of energy efficient equipment and systems; and stimulating the development, implementation, and use of clean distributed energy resources and efficient combined heat and power technologies
- Improved productivity growth rates, increased economic growth rates, and decreased electricity intensity (ratio of electricity use to gross domestic product, GDP)

Barriers to Achieving this Vision
To achieve this vision, accelerated public/private research, design, and development (RD&D), investment, and careful policy analysis are needed to overcome the following barriers and vulnerabilities:

- The existing power delivery infrastructure is vulnerable to human error, natural disasters, and intentional physical and cyber attack.
- Investment in expansion and maintenance of this infrastructure is lagging, while electricity demand grows and will continue to grow.
- This infrastructure is not being expanded or enhanced to meet the demands of wholesale competition in the electric power industry, and does not facilitate connectivity between consumers and markets.
- Under continued stress, the present infrastructure cannot support levels of power, security, quality, reliability, and availability (SQRA) needed for economic prosperity.
- The infrastructure does not adequately accommodate emerging beneficial technologies including distributed energy resources and energy storage, nor does it facilitate enormous business opportunities in retail electricity/information services.
- The present electric power delivery infrastructure was not designed to meet, and is unable to meet, the needs of a digital society – a society that relies on microprocessor-based devices in homes, offices, commercial buildings, industrial facilities, and vehicles.

Many of the elements required for this transition are illustrated in Figure 1 below.
EPRI has developed a plan to make the Electric Power Delivery System of the Future a reality, by careful development and deployment of a number of innovations, principal among them being:

- An integrated energy and communications architecture (IntelliGrid Architecture)
- An Architecture for Distributed Energy Resources in Advanced Distribution Automation (DER/ADA), and
- A Consumer Portal

The IntelliGrid Architecture

The future of the power industry will require the continued development and integration of two infrastructures -- not just one (see Figure 2). The existing power delivery infrastructure that delivers energy to millions of homes and businesses has been formed by over a century of advancements in electrical engineering. The discipline of electrical engineering has advanced as the power delivery system has become increasingly more complex. To manage this complexity, however, the power delivery system will rely increasingly on data network communications combined with intelligent equipment that will enable a variety of improved energy delivery and consumer service applications. The required data networks and intelligent equipment, collectively known as “distributed computing,” must be recognized as a significant infrastructure in their own right. Power system engineers, operators, planners and many other “stakeholders” will increasingly rely upon the distributed computing infrastructure to operate the power delivery system. However, the electric power industry should recognize that the distributed computing infrastructure must be engineered and designed with as much technical discipline as the power system. The development of a system architecture for the self-healing grid and for connecting energy consumers with markets project is focused on designing the distributed computing infrastructure(s) necessary to support the future of the power industry. However, unlike the electrical engineering discipline that built the existing power delivery system, the distributed computing world does not have the benefit of a mature underlying engineering discipline.

The scope of such an architecture spans advancements in existing energy systems as well as future scenarios of energy system operations. This future includes advancements in power system automation as well as an expanded role that includes more dynamic interaction with consumers. Concepts such as “self healing” power delivery systems that are self aware and better able to respond to fault conditions should be included among other scenarios of how grid operations can be improved through distributed computing technologies. The future of the power delivery system will include more dynamic operation with building and automation systems that can effectively respond to real-time pricing and other power system dynamics necessary to ensure a high level of power service reliability. This architecture should be independent of and compatible with different corporate structures of the industry. For example, the architecture should be equally applicable to a Regional Transmission Organization, a for-profit transmission company and a rural electrical coop. This infrastructure will enable a free market to supply the interoperable intelligent equipment necessary to manifest the visions of the future power system.
Architecture for Distributed Energy Resources in Advance Distribution Automation (DER/ADA)

Most of today’s distribution systems are based on designs that originated in the 1950s. While these systems were adequate to serve the analog loads that predominated during the last half-century, the demands placed on distribution systems have increased dramatically in the last decade. Now, with consumers expecting greater reliability and higher-quality power, the leading challenge for distribution system owners/operators is to balance consumer needs with the cost of upgrading their systems, while also addressing regulatory and economic pressures to reduce operating costs.

Distributed energy resources (DER) has the potential to bring about the most significant changes to the distribution system in the past 50 years (see Figure 3). Hailed as the technology with the greatest promise to improve distribution system reliability and security, DER also presents significant challenges. Chief among these are lack of control systems, lack of power quality standards, high costs, and grid integration complexities. Presently, each DER installation must be custom-engineered, which dramatically raises costs and reduces flexibility. A standard method needs to be developed for connection and synchronous operation of distributed generators with utility and consumer systems. Communication protocols and devices also must be developed and standardized to enable dispatch and control of DER. Additionally, new technologies will be required to effectively limit fault currents from numerous DER installations.

The need is urgent. Despite the high costs of distributed generation, By 2005, sales of fuel cells and microturbines are projected to be $900 million and $500 million, respectively.¹

Consumer Portal

A consumer portal enables a client on one network to access to data and controls residing on another, possibly unrelated network. In practice, a consumer portal provides a physical and logical link between wide area access networks (such as the telephone system, powerline carrier communications, or satellite data networks) and a consumer’s in-building networks and/or intelligent end-use equipment. It is a device, or set of devices, that enable intelligent equipment and networks within consumer facilities to communicate (two-way) with remote systems over wide area access.

In function, a portal is similar to an intelligent router or a gateway. These are devices that integrate different networks and enable communications between equipment residing on different networks. A router passes messages among different networks without translating their meaning. A gateway performs the work of a router and includes the ability to translate meaning and form of messages to make them understandable among equipment residing on different networks with different codes and protocols. A consumer portal could do either, although, ideally, portal communications should limit or eliminate the need for message translation through the use of standardized application layer messaging.

However, the term portal is used to mean diverse things, and is experiencing growing use as remote data access and control become more attractive in a variety of industries. In particular, portal is used to describe Internet-based web servers that provide a view into government and business activities. As shown in Figure 4, the consumer portal integrates and interfaces elements of the IntelliGrid Architecture and offers a view into consumer facilities.

The consumer portal carries the network view definition further by providing communications with energy management systems (EMS) and even end-use subsystems and equipment and not necessarily based the web. Additionally, because the portal will have locally available computing resources, it also can support local data management, monitoring, storage, and other generic functions, such as:

- Inter-networking communications: providing consumer data to all actors of the grid (as appropriate), and providing data from the grid to the customer
- Network communications management device
- Data management
- Remote consumer site vicinity monitoring

Because a portal provides such a diversity of services, ultimately every factory, business, and residence is envisioned as having one. As a result, the portal is commonly envisioned as part of the electricity meter, in part because of the meter’s ubiquity and its link to consumers energy data. The meter is one logical choice of location to place a portal, but it is not the only choice. A portal could reside in a home or business PC, cable set-top box, gas or water meter, its own dedicated device, a telephone, or other device. Or not even in one location; it could exist as a logical construct assembled of numerous software and hardware entities distributed throughout a home or factory.

Additional services are expected to arise as well, such as
automatic equipment monitoring and management (upgrade, diagnose, or control via the portal), tamper/theft detection, multi-utility services (water, gas, electricity, cable, etc), intrusion or damage alerts, etc. In short, the portal delivers the communications integration that harness the power of existing intelligent controls and computer technology for global benefit, rather than in today’s piecemeal fashion (Figure 4).

**IntelliGrid Architecture**

![IntelliGrid Architecture Diagram]

**Communications Technologies**

Figure 4
The Consumer Portal as Interface between Customers and Broader Communications Networks

**Conclusion**

Significant investments in the bulk supply system and customer-side equipment will be needed to determine optimal solutions to digital end users’ SQRA requirements, but it is not clear at this stage what balance of investment in the supply side versus the customer side is required to most cost effectively meet the needs of the growing digital power market. The ideal approach will be location dependent – based upon the characteristics of the existing power system and nature of the load at each specific site. Locations with more reliable utility supply systems (such as urban areas where networks could be used) will need to rely less on customer-side equipment to reach high levels of performance. Locations with poorer reliability (such as rural areas where radial distribution is used) will need to place more dependence, and, hence, investment in customer-side solutions such as distributed generation and UPS type equipment. In some cases, it may even be desirable to have an off-grid solution that is totally dependent on distributed generation and customer-side solutions. Some key factors that determine the optimal solution on the utility system side are the number of customers that demand high reliability, the amount they are willing to pay for it, the size of these loads and the spatial distribution of such loads within the service territory. These and other factors will determine the optimal balance of investment in bulk supply versus customer side solutions.

EPRI has formed IntelliGrid to provide the strategic framework for this serious commitment to upgrading the electric system. Strategic in nature, IntelliGrid is a collaborative research initiative, supporting recommendations made in EPRI’s Electricity Technology Roadmap – EPRI’s long-term strategic vision, forecasting society’s electrical needs on a 25-year basis. Fittingly, the Technology Roadmap’s three primary “destinations” -- advanced electrotechnologies for increased economic productivity, a power supply system hardened against disaster, and an engaged customer in control of their energy use -- support a new mega-infrastructure caused by the convergence of energy, telecommunications, transportation, the Internet, and electronic commerce.

The worldwide participation of energy companies, universities, government and regulatory agencies, technology companies, associations, public advocacy organizations, and other interested parties is necessary to refine this vision and evolve the needed technology. Only through collaboration can the resources and commitment be marshaled to reach these goals.

**About the Authors**

**Marek Samotyj** is Program Director of IntelliGrid, an initiative established by EPRI in 2001. Through a unique collaboration of public, private, and government stakeholders, IntelliGrid seeks to transform the electric infrastructure to cost-effectively provide secure, high-quality, reliable electricity products and services with minimal environmental impacts.

Mr. Samotyj received his M.S. degree in Electrical Engineering from Silesian Technical University in Poland. He received an M.S. degree in Engineering-Economic Systems from Stanford University. He has completed a post graduate program in Journalism at Jagiellonian University in Cracow, Poland. From 1981 to 1982, he was a Fulbright Senior Scholar, and a Fellow of the Professional Journalism Program at Stanford University.

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