Impact of Smart Grid on Distribution System Design

Richard E. Brown
Fellow

***Abstract*—There has been much recent discussion on what distribution systems can and should look like in the future. Terms related to this discussion include Smart Grid, Distribution System of the Future, and others. Functionally, a Smart Grid should be able to provide new abilities such as self-healing, high reliability, energy management, and real-time pricing. From a design perspective, a Smart Grid will likely incorporate new technologies such as advanced metering, automation, communication, distributed generation, and distributed storage. This paper discussed the potential impact that issues related to Smart Grid will have on distribution system design.**

***Keywords*—distribution design, distribution automation, smart grid, adaptive protection, distributed generation, advanced metering infrastructure.**

I. Introduction

Fads and trends have abounded in the electric utility industry. Several times a decade, a concept or catch phrase catches the attention and imagination of people and results in a wave of talk, buzz, papers, presentations, and self-proclaimed experts. Sometimes these concepts validate themselves and are gradually integrated into standard business practices. Sometimes these concepts fade away and make room for the next big thing.

One of the recent frenzies is feeding on the idea of a high-tech and futuristic distribution system. The distribution system of the past is radial and dumb. The distribution system of the future is meshed and intelligent [1-2]. There are many names being ascribed to a futuristic distribution system, but the dual concepts of meshed and intelligent make Smart Grid the preferred term of the author.

There are certainly some proven technologies that will have a role – more or less – in distribution systems moving forward. This includes advanced digital meters, distribution automation, low-cost communication systems, and distributed energy resources. In fact, there are already many demonstration projects showing the promise of these and other technologies. This includes the use of broadband communications for distribution applications [3], closed-loop systems using advanced protection [4], and many using distributed storage and generation [5-6]. However, these projects tend to use a single technology in isolation, and do not attempt to create an integrated Smart Grid using a variety of technologies. The closest thing to a Smart Grid to date is perhaps the Circuit of the Future at Southern California Edison [7]. Even this effort is more of a test bed for emerging technologies and is limited to a single circuit.

Many of the current research and development activities related to Smart Grids share a common vision as to desired functionality. Technology should not be used for its own sake, but to enhance the ability of the distribution system to address the changing needs of utilities and their customers. Some of these desired functionalities include:

- Self-healing
- High reliability and power quality
- Resistant to cyber attacks
- Accommodates a wide variety of distributed generation and storage options
- Optimizes asset utilization
- Minimizes operations and maintenance expenses

Achieving these functions through the aforementioned technologies poses an important question. Will the Smart Grid impact the way that distribution systems are designed? If so, how should utilities begin implementing these changes now so that, over time, existing distribution systems can be transformed into Smart Grids of the future?

The remainder of this paper discusses current research activities in the area of Smart Grid, and then discusses the potential design implications related to driving technologies and integration of these technologies.

II. Current Research Activities

There is presently a large amount of research activity related to Smart Grids. This section discusses the major projects in the distribution area (summarized from an NRECA report on industry research efforts).

EPRI IntelliGrid. Founded by EPRI in 2001, the IntelliGrid initiative has the goal of creating a new electric power delivery infrastructure that integrates advances in communications, computing, and electronics to meet the energy needs of the future. Its mission is to enable the development, integration, and application of technologies to

Richard Brown is with Quanta Technology. He can be reached at rbrown@quanta-technology.com.

facilitate the transformation of the electric infrastructure to cost-effectively provide secure, high-quality, reliable electricity products and services. At present, the IntelliGrid portfolio is composed of five main projects: IntelliGrid architecture; fast simulation and modeling (FSM); communications for distributed energy resources (DER); consumer portal; and advanced monitoring systems.

EPRI Advanced Distribution Automation (ADA). The overall objective of ADA is to create the distribution system of the future. The ADA Program envisions distribution systems as highly automated systems with a flexible electrical system architecture operated via open-architecture communication and control systems. As the systems improve, they will provide increased capabilities for capacity utilization, reliability, and customer service options. ADA has identified the following strategic drivers for the program: improved reliability and power quality; reduced operating costs; improved outage restoration time; increased customer service options; integration of distributed generation and storage; and integration of customer systems.

Modern Grid Initiative. Established by the U.S. Department of Energy (DOE) in 2005 through the Office of Electricity Delivery and Energy Reliability (OE) and the National Energy Technology Laboratory (NETL), this program focuses on the modern grid as a new model of electricity delivery that will bring a new era of energy prosperity. It sees the modern grid not as a patchwork of efforts to bring power to the consumer, but as a total system that utilizes the most innovative technologies in the most useful manner. The intent of The Modern Grid Initiative is to accelerate the nation's move to a modern electric grid by creating an industry–DOE partnership that invests significant funds in demonstration projects. These demonstrations will establish the value of developing an integrated suite of technologies and processes that move the grid toward modernization. They will address key barriers and establish scalability, broad applicability, and a clear path to full deployment for solutions that offer compelling benefits. Each project will involve national and regional stakeholders and multiple funding parties.

GridWise. The GridWise program represents the vision that the U.S. Department of Energy (DOE) has for the power delivery system of the future. The mission of the DOE Distribution Integration program is to modernize distribution grid infrastructure and operations, from distribution substations (69 kV and down) to consumers (members), with two-way flow of electricity and information. The GridWise R&D program is composed of the GridWise Program at DOE, GridWise demonstration projects (with both public and private funding), and the GridWise Architecture Council.

Advanced Grid Applications Consortium (GridApps). Formed by Concurrent Technologies Corporation in 2005, and sponsored by DOE, the GridApps consortium applies utility technologies and practices to modernize electric transmission and distribution operations. GridApps works on the application of technologies that are either not implemented by others or to finish their commercialization into broadly deployed products. Technologies applied by GridApps can be classified in three domains: T&D monitoring and management technologies; new devices; and system integration/system engineering for enhanced performance.

GridWorks. GridWorks is a new program activity in the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability (OE). Its aim is to improve the reliability of the electric system through the modernization of key grid components: cables and conductors, substations and protective systems, and power electronics. The plan includes near-term activities to incrementally improve existing power systems and accelerate their introduction into the marketplace. It also includes long-term activities to develop new technologies, tools, and techniques to support the modernization of the electric grid for the requirements of the 21st century. The plan calls for coordinating GridWorks' activities with those of complementary efforts underway in the Office, including: high temperature superconducting systems, transmission reliability technologies, electric distribution technologies, energy storage devices, and GridWise systems.

Distribution Vision 2010 (DV2010). The goal of DV2010 is to make feeders virtually "outage proof" through a combination of high speed communications, switching devices, intelligent controllers, and reconfigured feeders. This will enable customers to avoid interruptions for most feeder faults. DV2010 concepts would not be applied to all feeders. Rather, the concepts would be used to create "Premium Operating Districts" (PODs) serving customers that require and would be willing to pay extra for such high quality service.

California Energy Commission – Public Interest Energy Research (PIER) Program. The CEC-PIER program was established in 1997 as part of electricity restructuring. The PIER program is designed to enable sustainable energy choices for utilities, state and local governments, and large and small consumers in California. The PIER program provides advanced energy innovations in hardware, software systems, exploratory concepts, supporting knowledge, and balanced portfolio of near-, mid-, and long-term energy options for a sustainable energy future in California. The program is divided in six program areas plus an innovation small grant program. The most relevant program for Smart Grid is the Energy Systems Integration (ESI) program. Ongoing work in the ESI program is currently focused on distributed energy resource integration, valuation of distribution automation, and pilots of distributed energy resources and demand response.

III. Impact of Technologies on Design

With all of the Smart Grid research activity, it is desirable to investigate whether Smart Grid technologies will have any design implications for distribution systems. Will the basic topology and layout of a Smart Grid be similar to what is seen today? Alternatively, will the basic topology and layout of a Smart Grid look different? To answer these questions, the design implications associated with the major technological drivers will be examined. After this, the next section will examine the design implications of all of these technologies considered together.

A. Advanced Metering Infrastructure (AMI)

A Smart Grid will utilize advanced digital meters at all customer service locations. These meters will have two-way communication, be able to remotely connect and disconnect services, record waveforms, monitor voltage and current, and support time-of-use and real-time rate structures.

The meters will be in the same location as present meters, and therefore will not have any direct design implications. However, these meters will make a large amount of data available to operations and planning, which can potentially be used to achieve better reliability and better asset management [8].

Perhaps the biggest change that advanced meters will enable is in the area of real-time rates. True real time rates will tend to equalize distribution system loading patterns. In additions, these meters will enable automatic demand response by interfacing with smart appliances.

From a design perspective, peak demand is a key driver. If peak demand per customer is reduced, feeders can be longer, voltages can be lower, and wire sizes can be smaller. Most likely, advanced metering infrastructure will result in longer feeders.

B. Distribution Automation

Distribution automation (DA) refers to monitoring, control, and communication functions located out on the feeder. From a design perspective, the most important aspects of distribution automation are in the areas of protection and switching (often integrated into the same device).

There are DA devices today that can cost-effectively serve as an “intelligent node” in the distribution system. These devices can interrupt fault current, monitor currents and voltages, communicate with one-another, and automatically reconfigure the system to restore customers and achieve other objectives.

The ability to quickly and flexibly reconfigure an interconnected network of feeders is a key component of Smart Grid. This ability, enabled by DA, also (1) requires distribution components to have enough capacity to accept the transfer, and (2) requires the protection system to be able to properly isolate a fault in the reconfigured topology. Both of these issues have an impact on system design.

Presently, most distribution systems are designed based on a main trunk three phase feeder with single-phase laterals. The main trunk carries most power away from the substation through the center of the feeder service territory. Single phase laterals are used to connect the main trunk to customer locations. Actual distribution systems have branching, normally-open loops, and other complexities, but the overarching philosophy remains the same.

A Smart Grid does not just try to connect substations to customers for the lowest cost. Instead, a Smart Grid is an enabling system that can be quickly and flexibly be reconfigured. Therefore, future distribution systems will be designed more as an integrated Grid of distribution lines, with the Grid being connected to multiple substations. Design, therefore, shifts from a focus on feeders to a focus on a system of interconnected feeders.

Traditional distribution systems use time-current coordination for protection devices. These devices assume that faster devices are topologically further from the substation. In a Smart Grid, topology is flexible and this assumption is problematic. From a design perspective, system topology and system protection will have to be planned together to ensure proper protection coordination for a variety of configurations.

C. Distributed Energy Resources

Distributed energy resources (DER) are small sources of generation and/or storage that are connected to the distribution system. For low levels of penetration (about 15% of peak demand or less), DER do not have a large effect on system design as long as they have proper protection at the point of interconnection.

A Smart Grid has the potential to have large and flexible sources of DER. In this case, the distribution system begins to resemble a small transmission system and needs to consider similar design issues such as non-radial power flow and increased fault current duty. Other design issues related to the ability of a distribution system to operate as an electrical island, the ability of a distribution system do relieve optimal power flow constraints, and the ability of DER to work in conjunction as a virtual power plant [9].

IV. An Integrated Smart Grid

Consider a distribution system with pervasive AMI, extensive DA, and high levels of DER. As mentioned in the previous section, each of these technologies has certain implications for system design. However, a true Smart Grid will not treat these technologies as separate issues. Rather, a Smart Grid will integrate the functions of AMI, DA, and DER so that the total benefits are greater than the sum of the parts.

Much of the integration of functions relates to communication systems, IT systems, and business processes. These are not the focus of this paper. Rather, what will the system design of a distribution system look like when it can take full advantage of AMI, DA, and DER working together? A Smart Grid will increasingly look like a mesh of interconnected distribution backbones. This Grid will likely be operated radially with respect to the transmission system, but non-radially with respect to DER. Protection on this backbone will therefore have to be "smart," meaning protection setting can adapt to topology changes to ensure proper coordination. Radial taps will still be connected to the backbone, but lateral protection will gradually move away from fuses cutouts. DA on laterals will become more common and laterals will increasingly be laid out in loops and more complex network structure.

Currently, distribution systems are designed to deliver power to customers within certain voltage tolerances without overloading equipment. In a Smart Grid, these criteria are taken for granted. The driving design issues for Smart Grid will be cost, reliability, generation flexibility, and customer choice.

V. Conclusions

In twenty years, many distribution systems will not resemble the distribution systems of today. These systems will have advanced metering, robust communications capability, extensive automation, distributed generation, and distributed storage. Through the integrated use of these technologies, Smart Grids will be able to self heal, provide high reliability and power quality, be resistant to cyber attacks, operate with multi-directional power flow, increase equipment utilization, operate with lower cost, and offer customers a variety of service choices.

If a Smart Grid were designed from scratch, design issues would be complicated but manageable. Of course, there is already an existing distribution infrastructure that was not designed with Smart Grid in mind. This creates the following situation: first, Smart Grid is significantly different that distribution systems today from a design perspective; second, modifying the existing system into a Smart Grid will take decades.

With this situation, the only viable way to realize an extensive Smart Grid is to develop a vision for the ultimate design of a Smart Grid and then make short term decisions that incrementally transform existing distribution systems into this future vision. Within a utility culture of annual budget cycles, functional silos, and hard-to-change standards, this is a tall order. What is needed now is an effort to develop an integrated vision for Smart Grid, and strong leadership to ingrain this vision on the people who are ultimately responsible to make it happen. Going forward, do we want the design of our distribution system to be dumb and radial, or a Smart Grid?

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VII. Biographies

Richard E. Brown is the Vice President of Operations for Quanta Technology. He has published more than 80 technical papers related to power system reliability and asset management; is a regular instructor on these topics; and is author of the book *Electric Power Distribution Reliability*. He is an IEEE Fellow, vice-chair of its Planning and Implementation Committee, and is a registered professional engineer. Richard earned his BSEE, MSEE, and PhD from the University of Washington in Seattle, and his MBA from the University of North Carolina at Chapel Hill.