A Study Report on Smart Grids

(From an Engineering Technology Perspective)

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Abstract

This paper explores the Smart Grid, from its definition to its benefits, and also provides a description of the current power grid in the United States. It points out that the existing 100-year-old grid is reaching its design limits, which has resulted in increasing power outages and rising infrastructure costs. The aging grid is also inefficient and ill adapted to newer sources of energy (i.e. renewables). Utility companies have limited visibility and control over it since there is little intelligence built-in and even less redundancy.

The Smart Grid is intended to resolve many of the issues with the current power grid, but will require significant investment and take over ten years to fully deploy. Relying significantly on information technology, it will have the ability to detect problems and automatically react to them, providing increased reliability and efficiency. It will also give the end user more control over their power consumption by providing alternatives.

The paper also points out the security risks involved with deploying a Smart Grid. Because if its heavy reliance on information technology and networked communication, it will be exposed to much of the same types of risks faced by computers today. Malware that specifically infects control systems (including those used in power grids) has already been found.

It is concluded that the Smart Grid will provide many benefits, ensuring that the United States continues to have reliable and affordable power for many decades to come.

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1 Introduction

The United States power grid is an amazing piece of machinery, spreading out across every state in the nation and delivering electricity to millions of homes and businesses. At over a century old, “it is the largest interconnected machine on earth, so massively complex and inextricably linked to human involvement and endeavor that it has alternately (and appropriately) been called an ecosystem. It consists of more than 9,200 electric generating units with more than 1,000,000 megawatts of generating capacity connected to more than 300,000 miles of transmission lines.” (“The Smart Grid: an Introduction,” n.d.)

Although the system works remarkably well, the ever growing demand for energy is pushing it to its limits. In the era of bigger homes with multiple TVs, computers, electronics, electric vehicles, air conditioners, and other power hungry devices, the current grid is becoming inefficient, expensive, and unreliable due to the increasing failures. Since 1982, growth in peak demand for electricity has exceeded transmission growth by almost 25% every year (“The Smart Grid: an Introduction,” n.d.). The current grid is also not designed to integrate well with today's renewable energy sources which will experience substantial growth in the coming decades. Even at 99.97% reliability, it still allows for power outages and interruptions that cost Americans at least $150 billion each year—about $500 for every man, woman, and child (“The Smart Grid: an Introduction,” n.d.). Work is currently underway to make the current power grid “smarter”, but these improvements will not be enough to meet the nation's growing energy demand.

The Smart Grid is perceived as an evolution of the existing power grid, representing the longer-term promise of a grid remarkable in its intelligence and impressive in its scope, although still considered to be a decade or more from realization ("The Smart Grid: an Introduction," n.d.). It relies on information technologies to improve how electricity travels from power plants to consumers, allows those consumers to interact with the grid, and integrates new and improved technologies into the operation of the grid (Federal Smart Grid Task Force, 2010). Able to automatically respond to changing power demands and outages, the Smart Grid promises to add capacity, flexibility, and reliability to the US power grid as well as reducing its environmental impact. In many ways, it can be compared to the Internet where two-way communication exists across a redundant network allowing for real-time changes when needed.

2 History of the United States Electric Power Grid

The first central power station was constructed in New York City in 1882 by Thomas Edison and was limited to one square mile of electrification. It contained four key elements of a modern electric utility system: reliable central generation, efficient distribution, a successful end use (the light bulb), and a competitive price (Federal Smart Grid Task Force, 2010). A few short years later, electricity use grew dramatically as new uses were conceived and small central power stations were built in numerous cities to fulfill demand.

The first hydroelectric power plant was constructed at Niagara Falls in 1896 by George Westinghouse and ushered in the practice of placing generating stations far from consumption centers (Bellis, n.d.). This new plant was capable of providing electricity to Buffalo, New York, over 20 miles away. This was also when alternating current was chosen in favor of direct current and when the first transformer was invented, creating the ability to transfer power over great distances. These developments allowed electric utilities to spread rapidly.

At the beginning of the 20th century, new utility companies were creating "power pools" with other nearby utility companies to deliver electricity more effectively and efficiently (Federal Smart

Grid Task Force, 2010). In time, these companies developed small networks of jointly owned power plants and transmission networks which eventually evolved into three major regional power grids: the Eastern Interconnect, the Western Interconnect, and the Texas Interconnect.

By the 1970s, challenges began to surface in the electric power industry. Several events occurred (e.g. Three Mile Island, new pollution standards, oil embargo, inflation) that slowed growth and raised concerns about reliability. By the early 1980s, no growth was occurring in the electric power industry and electricity prices were rising rapidly.

3 Current State of the Power Grid

The existing century-old power grid has not kept up with today's energy demands and does not adapt well to new technologies including renewable energy. Chronic underinvestment in getting energy where it needs to go through transmission and distribution has further limited grid efficiency and reliability ("The Smart Grid: an Introduction," n.d.). Although investment in electricity generation is increasing along with the demand, the investments in transmission upgrades to facilitate this increasing power flow have been on the decline since 1975 (Federal Smart Grid Task Force, 2010). In addition, the current grid was not designed to be energy efficient, environmentally friendly, or to give the customer choices. As an example, a 5% increase in the grid's efficiency would equate to permanently removing the fuel consumption and greenhouse emissions of 53 million cars ("The Smart Grid: an Introduction," n.d.).

Reliability is also becoming an increasing concern. There have been five massive blackouts over the past 40 years, three of which have occurred in the past nine years. More blackouts and brownouts are occurring due to the slow response times of mechanical switches, a lack of automated analytics, and poor/inadequate visibility on the part of grid operators ("The Smart Grid: an Introduction," n.d.). Power outages are often not detected by utilities until a customer phones in to report it. In a world where home computers, TVs, phones, and an increasing number of other devices can easily be connected together to communicate over a global real-time network, this limitation is unacceptable. These power interruptions are becoming increasingly more frequent, larger, and more expensive with time.

4 The Smart Grid

Trying to define the Smart Grid is a bit like trying to define the Internet. They're both a conglomeration of many complex technologies that work together in order to provide a real-time critical service. But unlike the Internet, which was originally designed in the 1960s and 1970s (and called the ARPANET), the Smart Grid is an evolution of our aging electricity grid. Its goals are to create a real-time delivery network that enables two-way flow of electricity and information, capable of monitoring everything from power plants to customer preferences to individual appliances. This two-way flow of information will enable near-instantaneous balance of supply and demand at the device level (“The Smart Grid: an Introduction,” n.d.).

In announcing the American Recovery and Reinvestment Smart Grid projects in October 2009, President Obama explained the importance of this transformation:

> It will make our grid more secure and more reliable, saving us some of the $150 billion we lose each year during power outages. It will allow us to more effectively transport renewable energy generated in remote places to large population centers, so that a wind farm in rural South Dakota can power homes in Chicago. And by facilitating the creation of a clean energy economy, building this 21st-century energy infrastructure will help us lay a foundation for lasting growth and prosperity. (Federal Smart Grid Task Force, 2010)

Several technologies will be used in building the Smart Grid. Advanced Metering Infrastructure (AMI) is an approach to integrate consumers based upon the development of open standards. It provides them the ability to use electricity more efficiently and provides the utilities an ability to detect problems in their system and to operate them more efficiently (“The Smart Grid: an Introduction,” n.d.).

Visualization technology will give utilities an ability to monitor the grid in real time and make adjustments immediately. For example, project VERDE (Visualizing Energy Resources Dynamically on Earth) is being developed for the Department of Energy to provide wide-area grid awareness, integrating real-time sensor data, weather information and grid modeling with geographical information. It has the potential to be able to explore the state of the grid at the national level and switch within seconds to explore specific details at the street level (“The Smart Grid: an Introduction,” n.d.).

Phasor Measurement Units (PMUs) are used to “sample voltage and current many times a second at a given location, providing an 'MRI' of the power system compared to the 'X-Ray' quality available from earlier Supervisory Control and Data Acquisition (SCADA) technology” (“The Smart Grid: an Introduction,” n.d.). PMUs can be used to ease congestion and mitigate blackouts.

5 Security Concerns

In the post 9/11 world, security has taken on new importance. Critical infrastructure must be protected from terrorist attacks in addition to natural disasters, and the power grid is arguably the most important infrastructure of all. Its centralized nature leaves it vulnerable to attack by organizations hoping to cause economic disruption. “Interdependencies of various grid components could bring about a domino effect—a cascading series of failures that could bring the nation's banking, communications, traffic, and security systems, among others, to a complete standstill” (“The Smart Grid: an

Introduction," n.d.). Although the Smart Grid will create a more decentralized network, new risks emerge due to its reliance on information technology (IT).

SCADA systems have been used in the power grid for over 30, becoming more advanced and complex as computer technology has advanced (Ericsson, Nordlander, & Sommestad, 2010). The development of SCADA pre-dates the Internet, and occurred during a time when IT security primarily meant physical access protection. Since then, SCADA systems have evolved to incorporate the Internet and non-proprietary (open standards) architectures. Because of this, they are now susceptible to threats and vulnerabilities that are increasingly found in that environment, as demonstrated by the recent Stuxnet virus, discovered in June 2010, that was designed to spy on and reprogram industrial SCADA systems ("Stuxnet", n.d.).

Conventional security solutions are not always applicable to SCADA systems since performance and availability requirements differ for administrative IT systems and SCADA systems. Control systems are time-critical and real-time whereas information technology systems only require consistent response times and are not real-time (Ericsson et al., 2010). An interruption to a real-time system produces real-time effects, and in the case of a power grid this could result in large or localized power outages with no advance warning.

These security concerns are not limited to just the grid itself. Even common household appliances may one day be at risk as they become interconnected and more intelligent, containing built-in central processing units (CPUs) and external network connections. This is not difficult to imagine when one thinks of the millions of cell phones that exist around the world today. These devices have also been susceptible to attack, as demonstrated by the "Cabir" proof-of-concept cell phone virus that was created by an international team of security researchers (Ellison, 2004).

6 Conclusion

Although the US power grid has served its purpose remarkably well over the past century, it is quickly becoming antiquated and at risk of increased failure. The age of the infrastructure is well past its stated design goals and investment has not kept up with increasing energy demand. It is also not a redundant system capable of re-routing power when necessary, nor is it efficient or able to interface well with renewable energy resources such as wind, solar, and geothermal.

Information technology advancements must be integrated into the power grid to keep it reliable, adaptable, and efficient. This is where the Smart Grid concept comes into play. It is inextricably linked with enhancing the sensing, actuation, and control structures within the power system (Hiskens, 2010). These enhancements will enable two-way communications, extensive customer interaction, digital metering, remote monitoring, increased decentralization, comprehensive power flow control, pro-active real-time protection, and self-healing restoration (Dickinson, n.d.).

Although information technology provides these greater capabilities, it also introduces new risks that come along with it. Viruses and other forms of malware are a constant threat that must be effectively countered in order to keep the system functioning normally. Creating a two-way communications network makes it easier for would-be attackers to launch cyber attacks against the grid. These risks cannot be understated in a world where even governments are creating their own cyber warfare divisions.

In the end, the deployment of the Smart Grid will provide many benefits along with ensuring that the US power grid remains a reliable, affordable, and adaptable infrastructure for many decades to come.

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