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Smart Grid Applications in the US: Technical Potential and Regulatory Barriers

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Abstract

Smart Grid refers to the design and implementation of a modern electrical power transmission and distribution system that incorporates intelligent controls. The sophistication of the control strategy and the controllers is a subject for debate and discussion. In this paper, a general review of the many interpretations of Smart Grid is presented, and available and proposed Smart Grid technologies are discussed. Various systems are described, and a matrix of potential benefits or risks is analyzed. The hierarchy of the more prevalent Smart Grid protocols are assessed and weighted against the risks for the overall safety of the grid and the benefits for the users. Finally, some case studies of utility experiences with pilot projects are reviewed and discussed.

Keywords: Smart Grid; Grid Connected Storage; Photovoltaic Generation; Renewable Energy Systems; Micro-Grid; Smart Appliance; Automated Meter Reading; Real-Time Pricing.

Nomenclature

AMI : Advanced Metering Infrastructure.
AMR : Automated Meter Reading.
CML : Customer Minutes Lost.
CPP : Critical Peak Pricing.
DG :Distributed Generation.
DNP3 :Distributed Network Protocol
HAN :Home Area Network
MDM :Meter data management
NERC :North American Electric Reliability Corporation
NSTB :National SCADA Test Bed
PHEV :Plug-in Hybrid Electric Vehicle
PV :Photovoltaic
SAIDI :System Average Interruption Duration Index
SCADA : Supervisory Control and Data Acquisition
TCP :Transmission Control Protocol
TOU :Time of Use

1. Introduction

Utilities all across the United States are implementing "Smart Grid" (SG) networks in small, medium and even large metropolitan markets. The networks are cooperative efforts between a local utility and private sector power distribution and software suppliers. City of Miami plans to develop a Smart Grid in cooperation with Florida Power & Light (FPL), General Electric and Cisco. The $200 million project has been called a "Blueprint for the Future of Power" by Time Magazine. FPL has made commitments to replicate the program for all of its 4.5 million customers. University of South Florida and Progress Energy have teamed up to design and implement a Smart Grid application that includes solar power generation and bio-diesel cogeneration In Tampa, Florida. PECO, a utility that operates in Pennsylvania, is investing $600 million to convert its power distribution system into a Smart Grid. Drexel University and the University of Pennsylvania are partners in that effort.

On the national level, in April 2009 Vice President Joe Biden unveiled a plan to develop a nationwide Smart Grid with a $3.3 billion investment. One of the many proposed long term plans is to develop local Smart Grid hubs that eventually link up with regional and then a national Smart Grid network. Most of these efforts are funded with Federal Stimulus funds, but a review of the various initiatives indicates that not all the participants have the same understanding of a Smart Grid, nor is there a consensus on the level to which a utility can micro manage its customers' loads. There is a great potential to make the power generation and distribution system more efficient, and safer when dealing with traditional electrical distribution problems. However, there are also risks involved in developing a network that can as a whole - or in its parts - be subject to software errors, cyber-attacks, and network issues that are usually associated with the internet. In addition, there are legal and regulatory barriers that may impede or even disallow some of the proposed Smart Grid (SG) technologies.

One can argue that the earliest application of Smart Grids were the rudimentary controllers that allowed phase and

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voltage quality conditioning in the early days of grid development in the 1950's. The great Blackout of 1965 may have been the earliest warning sign that a more advanced monitoring and control strategy was required for the interconnected grid. A more recent grid failure that affected 50 million people in August 2003 was shorter but alerted the utilities that minor transmission failures could have disastrous consequences, and the vulnerability of the grid to physical or cyber-attacks was also exposed. The need for a resilient, reliable, self-healing power delivery system has become even more evident with the introduction of the first generation two-way communication between the suppliers and the consumers. The basic communication protocols for these systems parallels the infrastructure and the software that supports the internet and is therefore vulnerable to the same risks and failures.

Aside from system reliability and security, automated meter-reading (AMR), and transmission/distribution monitoring and control, the new Smart Grid needs to enable the needs of numerous stakeholders. The utilities are interested in more aggressive load shedding tools, such as smart appliances, Plug-in Hybrid Electric Vehicle (PHEV) storage, and consumption management. They are also looking at the Smart Grid for timely and efficient management of large-scale wind and solar assets that is coming online at accelerated rates. Consumers are hoping that SGs will help curtail ever increasing utility costs with time of use (TOU) electric rates, and net-metering options that allow two-way power transmission and accounting. The Federal and State governments want to assure a secure system that can handle any conceivable threat, whether natural, man-made, accidental or intentional. The matrix of interactions and interests between all the members, and the distinct elements that will eventually become a Smart Grid is complex and will require extensive analysis and discussion. Numerous studies are under way by Federal agencies such as the Department of Energy (DOE) and National Laboratories such as the Idaho National Laboratory (INL) and the Pacific Northwest National Laboratory (PNL), utilities and the Electrical Power Research Institute (EPRI). Numerous university research programs and consultants are also working to understand, set basic rules, and establish overall design criteria for SG. This paper deals with reviewing some of the more prominent configurations, and offering an analysis of the proposed architectures.

2. Elements of the Smart Grid

The predominant SG architecture is based on the current infrastructure of utility implemented control systems that monitor and manage generation and distribution of power. The current "semi-smart" system is in fact smarter and better equipped that even the grid of 2003, when the Ohio initiated blackout event occurred. It has gone through numerous iterations to deal with natural disasters by implementing self-healing features that re-route power, and sensors that can detect the location of a fault with increasing accuracy. Sub-station controllers incorporate two-way communication, and advanced cyber-security and protection elements. The "Smart Grid System Report" by US DOE [1], reviews and summarizes the requirements and a general definition for the Smart Grid. The SG, according to this report, shall be built upon the existing infrastructure, be capable of handling distributed generation, and provide reliable, secure and efficient delivery of power. Since the Smart Grid of the future has new stakeholders, new technologies and features need to be implemented. Among these:

Utility Interests that include:

- Incorporation of solar photovoltaic, solar thermal and wind resources owned or controlled by the utility into the supply stream.
- Load shedding, real-time and time of use (TOU) pricing, and peak shifting with storage such as PHEV
- Integration of consumer-owned and non-utility distributed generation at utilities' discretion
- System integrity and noise reduction due to potentially non-conforming sources
- Cyber-Security and asset protection

Consumer Interests that include:

- Cost savings from peak load reduction
- Export of solar or wind generated power at consumers' discretion to maximize financial benefits
- Less reliance on utilities if so desired
- Asset protection, including PHEV battery life
- Environmental Factors and consumer preferences

Governmental and Regulatory Interests

- National and Local security
- Environmental treaties and agreements
- Consumer Protection
- Utility and National Asset Protection

Figure 1 shows a typical Smart Grid configuration. The various interpretations of a smart grid do not always include every element shown in this schematic. The current configuration of the grid for most of the utilities in the United States, is a straight line from the grid through the local utility's control center, terminating at customer's meters. The INL Report [2] has compiled 74 initiatives in the US that include some elements of the new SG. As of the end of March 2009, there are 28 utility-initiated AMI projects, 18 AMI trial/pilot initiatives, 20 AMR projects, and 8 SG projects and pilots in the installation phase. The utilities with some SG initiative will grow exponentially in the next 3 to 5 years, especially with more than $3.6 Billion in stimulus funding that was awarded in October 2009.

On the supply side, as the utilities discover the benefits of distributed generation, and the return on investment picture for wind and solar improves, the wind/solar component will be a more frequent addition to the SG configuration. The intermittent nature of wind generation in continental US, and the cyclical nature of solar energy requires the addition of large scale storage or interaction with residential/commercial generators.

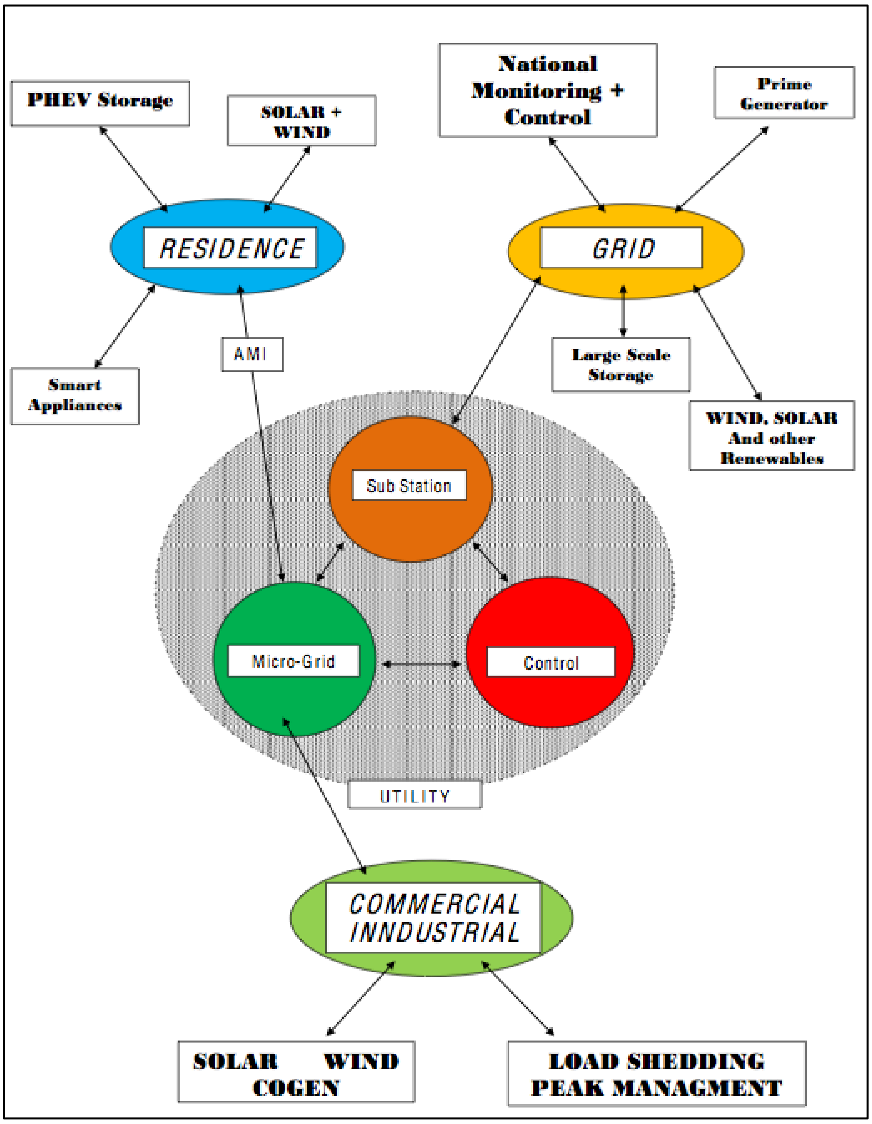

Figure1. a typical Smart Grid configuration.

Energy storage technologies will be critical for the successful implementation of a SG that rely on renewable energy sources. The technology for large scale energy storage is still in its early developmental stages.

Battery performance and cost are barriers to large scale energy storage. New battery technologies and ultra-capacitor development may change the storage options in the coming decade, but at this point in time, utilities will need to rely on residential storage systems. While this may be a short term solution, it is not clear that homeowners will jeopardize the integrity of the PHEV batteries to participate in a national storage landscape, not until battery cycling is decoupled from battery life.

The other major difference between the configuration shown above, and the more widely publicized schematics, such as the block diagram developed at INL [2], is the prominence of the Micro-Grid (MG) block. The MG is usually a passive pass-through part of the network, where local monitoring, fault-detection, and self-healing features are implemented. There are a number of operational and regulatory protocols that constrain the Micro-Grid as an integral part of the grid, with no capability for autonomous operation unless the entire grid is operational. One example is that even though a commercial solar/cogeneration component within the MG is generating power, the utility command and control (UCC) will not allow the flow of electricity from this generating source to let's say a residential customer within the MG. With the current grid and even some of the anticipated SG designs, there are no contingencies for this to occur. However, disabling local distribution in case of a large scale power outage, steals away some of the more valuable qualities of distributed generation: security, redundancy, and active grid re-formation after a massive fault. Wilson Clark, one of the earliest advocates of distributed power generation in the context of a modern grid, attributed distributed power generation in Japan [3] to the difficulty encountered by the allies in its defeat.

Another important feature of the SG advocated by utilities is the Smart Appliance component. A recent study co-sponsored by Portland General Electric, a local utility with PNL and Whirlpool Corporation [4], tested the application of smart appliances for SG responses. The actual effect of this technology needs further evaluation. The experience with many of the appliance control programs around the US has had a limited success rate. The incentives offered by utilities, such as FPL in Florida are not enough to encourage the consumers to transfer the control of major appliances such as air conditioning equipment to the utility. Programs that offer real-time pricing may do better, but the interactive systems need to be user-friendly and result in real and tangible benefits and savings. There is a general distrust of intrusive technologies, and while the concept of being green and energy efficient does have some traction, when it is in conflict with personal choices or habits, especially inside one's home, may lose its momentum. There is a risk that too much control could backfire, especially if the smart appliance is vulnerable to a smarter virus that may penetrate the controller through the two-way communication path with SG. One wholesale failure of a smart appliance group would seriously affect the entire program.

3. Benefits and Risks

There is no doubt that the grids in the US and around the world need to be re-configured to adapt to new generation and distribution realities. Some countries such as Germany and China have already started this process. The case for the US is more challenging. With numerous private utilities, local cooperatives, and regional entities such as the Tennessee Valley Authority, the design and operation of a central UCC is a formidable task. There are operational challenges for improving service while implementing rigorous interoperability standards between the SG components. Ipakchi [5] reports that US System Average Interruption Duration Index (SAIDI) or Customer Minutes Lost (CML) is 120-160 minutes, while Western Europe with a higher degree of automation maintains 60-80 minutes, and some utilities in Asia have a CML target of 5 minutes, with "substantial monitoring and control, high reliance on automation and extensive self-healing grid design." The ultimate goal of an advanced SG is to achieve these higher goals for service quality, operate two-way communication with the end-user, integrate the grid with large scale renewable generation, and accommodate distributed generation of the end-user. There are certainly risks. Bi-directional communication is vulnerable. There can be natural disasters, man-made accidents, and intentional attempts at harming the system infrastructure, or the communication links. Loss of data between UCC and a group of smart appliances may develop into a major disaster. Minor software glitches in monitoring or control of even the lowest controller in the SG hierarchy could lead to bi-directional damage harming both the supplier and the consumer.

It is conceivable that the need to integrate solar, wind and other renewable has the greatest single impact on the design of the new SG. Peak shaving, remote appliance control, and TOU electric rates were introduced and implemented almost 40 years ago. Even the thermal solar systems that were introduced in the 1970's were initially received as potential peak shavers, but because their utilization cannot be controlled, they were eventually lost to low cost gas and TOU electric rates in the US. What distinguishes Concentrating Solar Thermal Power (CSTP) and solar photovoltaics (PV), is that they are ideal as peak generators. Solar irradiance does for many utilities coincide with peak demand. Wind, through less predictable than solar energy on a daily basis, has a better long-term predictability functions and has become more competitive and a favorite of utilities as a reliable component in their supply chain. With political, regulatory and environmental pressures on utilities to generate cleaner energy that reduces emissions and imports, renewable energy has finally been embraced by mainstream electric producers. No one however predicted the public's desire to generate their own rooftop electricity. Even as recently as 1990's, the promulgation of rooftop solar installations could not have been predicted. European utilities paved the way by introducing Feed-in-Tariff (FIT) and showing that utilities could benefit from rooftop solar.

The integration of centralized and distributed renewable energy, and awareness of energy efficiency were once considered as visionary and futuristic. Utilities now consider these as integral to their overall generation and power delivery strategies. Smart Grid can benefit the utilities, power generators, and the consumers. There are certainly risks involved. Some of the threats can be predicted, and many are yet to be discovered. The hesitation of some utilities to move slowly in adopting SG is understandable. The benefits for utilities may at some point conflict with the benefits to consumers. Regulatory guidelines and standards are still being developed, and not all the stakeholders are at the design table.

4. Conclusions

A standard definition or description of the Smart Grid is still in the development stage. While there is a general understanding of what an SG implies, a standard has not yet been developed, and no metrics have been developed to classify Smart Grids. There will certainly be a great deal of input from utilities both public and private, academicians, consumers, and technology representatives on how best to design and implement an SG. There will probably be variations, exemptions, and numerous addenda. What is clear is that a sustainable SG should be built on an equitable distribution of potential benefits, minimize the risks, and provide reliable and secure power. It should also provide opportunities for those consumers who want to contribute, encourage distributed power generation, and their preferences with regards to emissions and global warming issues, and their choice of energy sources.

For the Smart Grid to be successful, it is essential that it demonstrates to the consumers that it can lead to energy saving and user friendly interaction, resolve potential issues, and be self-learning and continuously improve itself. While no element or protocol in the SG configuration should in anyway jeopardize the security or the reliability of the system, the needs and interests of end-users shall not be compromised, and the concept of a localized micro-grid that can operate autonomously in case of grid-wise failure shall be evaluated and considered.

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