Smart Grid: An Intelligent Way to Empower Energy Choices

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Smart Grid: An Intelligent Way to Empower Energy Choices

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***Abstract*—People of the world are now fully aware of the importance of measures against global warming. It raises high expectations for clean power generation and advanced technologies. In this regard, Smart Grid, which effectively controls supply and demand of electric power by information technology, is a leading tool for developing a "new town". Although many aspects of such new town have been observed recently and worth knowledge has been achieved, rarely can be found an article to make a comprehensive overview on smart grid and its related vision, therefore, in this paper a working definition is presented that will help to put in context the framework for better realization of smart grids.**

***Key Words*— distributed generation, renewable energy, Smart grid, Storage devices.**

I. INTRODUCTION

The conventional power grids and their assets that span large areas of the Earth are huge interconnected meshes. They are massively complex and are inextricably linked to other parts of societies and have close relation with social and economic activities [1]. One of the main disadvantages of such these networks are their reliance on large centralized power generation units connected to H.V transmission systems supplying power to M.V and L.V distribution systems locally[2]. Besides, existing transmission and distribution systems in many parts of the world use technologies and strategies that are many decades old. They make limited use of digital communication and control technologies.

To direct this aging infrastructure to a specific destination and to create a power system that meets the growing and changing needs of customers, developed societies try to create intelligent means which use advanced sensing, communication, and control technologies to distribute electricity more effectively, economically, and securely. Furthermore, there are some important factors for the consumers such as potential lower cost, higher service reliability; better power quality, increased energy efficiency and energy independence that are all reasons for interest in distributed energy resources (DERs) and focusing on what is called "Smart Grids", as the future of power systems [3]. Although the term "Smart Grid" is frequently used today, but there is no agreement on its definition, in other words the concept of intelligence in Smart Grid design and how it will be measured is unclear and, in this paper, a working definition is presented that will help to put in context the framework for discussing and designing the Smart Grid. The U.S. Department of Energy (DOE) mentioned in one of its recent issues that "a Smart Grid uses digital technology to improve reliability, security, and efficiency of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources." [4]. Later, In June of 2008, a meeting of industry leaders was held in the U.S. Department of Energy and seven different characteristics were declared for smart grid concept:

1) Better utilization of conventional assets, Optimization and efficient operation,
2) Accommodation of all generation and storage options in power grids,
3) Supply of Power quality as a great need of today's industry,
4) Prediction of events and fast response to system disturbances in a self-healing manner,
5) Robust operation against attacks and natural disasters,
6) Active participation of consumers,
7) Introduction of new services, products and markets.

The Smart Grid technology is sometimes applied to the smart meters and energy distribution infrastructures which provide a better and more effective approach for reducing the wasteful use of energy for householders and business owners.

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However, this concept may be called the "Super Grid" because it essentially has two components. First, it includes a low-loss transmission system with a long-distance from areas with a short number of people but a large number of renewable resources to the places where it can be used. Second, it involves embedded subsystems using data processing and very powerful and effective information technologies allowing costumers to use less and receive more and to sell electricity back into the grid if they have means of distributed generations

Energy management systems and power system optimizers accompanied by integration of new generation resources which form a whole Smart Grid vision, have the capability of serving as a basic tool to reach energy independence and climate changes objectives. It's worthy of note that, smart grid vision is not unique and it changes in different time and place horizons. For example from the view point of the North America this vision of the future electric system builds on the existing electric infrastructure. The same types of equipment that the system uses for electric delivery today - e.g., power lines, substations, and transformers - will continue to play important roles. However, the emergence of new technologies, tools, and techniques including distributed intelligence and distributed energy resources, will increase the efficiency, quality, and security of existing systems and enable the development of a new architecture for the electric grid. The result will be improvements in the efficiency of both power delivery and market operations, and a high quality network that provides secure sources of electricity to America. It's a fully automated power delivery network that monitors and controls every customer and node, ensuring a two-way flow of electricity and information between the power plant and the appliance, and all points in between. Its distributed intelligence, coupled with broadband communications and automated control systems, enables real-time market transactions and seamless interfaces among people, buildings, industrial plants, generation facilities, and the electric network (Fig.1).

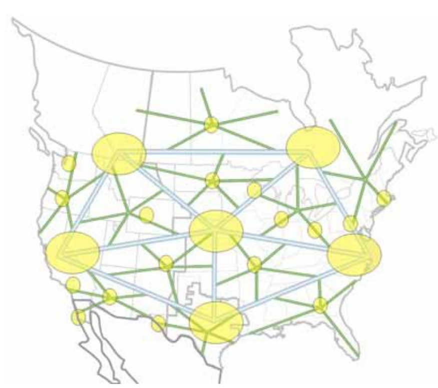

Figure 1- Conceptual design of the North America smart grid vision

Regardless of what managerial framework emerges and how it works or which regulatory system plays the role; the size and the complexity of the bulk power grids joined with the electrification of the local and main sectors(e.g. transportation sector) will necessitate adaptability and flexibility which both of them are inherent to future Smart power Grids.

What is not clearly defined in related articles, but is important as well, is that a highly developed smart grid outline carries more meaning than smart meters. It includes technologies not only at the transmission level but also at sub transmission and distribution level covering both hardware and software, such as supervisory control and monitoring systems, as well as primary tools like power transformers and protective relays [5]. A better list of smart grid criteria which is mentioned below covers much of the same grounds as DOE's, but focuses on broad characteristics rather than specific functions. Under this model, the smart grid is:

- Flexible, adaptive and versatile, with minimal dependence on operators, particularly in response to rapid conditional changes,
- Highly Secured from faults, attacks and naturally occurring disruptions.
- Prognostic, in the case of applying operational data for maintenance practices of devices and equipment and even determining potential failures or outages before they occur.
- Integrated, in terms of real-time two-way communications and control functions.
- Interactive between customers and markets.
- Optimized to enhance availability, efficiency, reliability and economic performance.

While details about the definition of a smart grid vary greatly, a general definition can be made as follow:

A smart grid is an intelligent, auto-balancing, self-healing power grid that accepts any source of fuel as its input and transforms it into a consumer's end use with minimal human intervention. It is a course of action that will result better utilization of renewable energy resources and reduce environmental vestiges as much as possible. It has a sense of detection to understand where is loaded beyond capacity and reroute power to lessen overload and impede potential outages. It is a base that provides real-time communication between consumers and the utility in order to optimize energy harvesting based on environmental benefits or cost preferences [6]. However, it should be noted that deployment of smart grid technologies will occur over a long period of time, adding successive layers of functionality and capability onto existing equipment and systems. Although technology is the focal point, but it is only a way to achieve the goal and the smart grid should be defined by more extensive characteristics. So how the smart grid differs from conventional grids we know today is illustrated in Table 1.

TABLE 1- CURRENT GRID VS. FUTURE SMART GRID

Features	Current Grid	Smart Grid
Grid Communication	*Non or one-way; typically not real time*	*Two-way; real time*
Interaction between Customers	*Limited*	*Comprehensive and Extensive*
Type of Metering	*Electromechanical*	*Digital(enabling real time pricing and net metering)*
Operation & Maintenance	*Manual equipment checks, maintenance*	*Remote monitoring, protective; time-based maintenance*
Power Generation	*Centralized*	*Centralized, Distributed*
Energy control	*Limited*	*Comprehensive, automated*
Reliability & Dependability	*Vulnerable to downfalls, failures and cascading outages; essentially reactive*	*Automatic, pro-active protection; outages prevention before starting*
Restoring procedure following disturbance	*Manual*	*Self-healing*
System topology	*Radial, generally one-way power flow*	*Network, multiple power flow pathways*

The last expression in the table, "system topology", refers to what is perhaps the most essential movement that a fully realized smart grid will require. Conventional networks are designed to support large power units that serve faraway consumers via one-way transmission and distribution grids as shown in Fig. 2, but the future grids will necessarily be two-way real time systems where power is generated not only by a large number of small and distributed energy resources but also large power plants. Power flow across the network is based on a mesh grid structure rather than a hierarchical one as shown in Fig. 3.

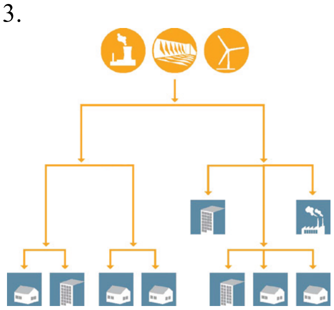

Figure 2- Conventional power system

Figure 3- Future power system

II. SMART GRID TECHNOLOGIES IN USE TODAY

Several categories are proposed toward Smart-Grid concept which includes: developing information technology (IT) and Integrated communications across the grid, SCADA/DMS (distribution management systems), designing advanced control methods, advanced sensing, metering and measurement devices and technologies, Real-time situational awareness and analysis of the distribution system, Substation automation (SA) and designing main and local supervisory control units along with suitable human interfaces. Of course, this is not an exhaustive list but generally speaking, five key technology areas for smart grids can be mentioned [7]:

- *Interconnected Communications*

Integrated communications allow each part of the network to be both "talk" and "listen." i.e. this exchange of information connects different components to an open architecture for real-time optimization and control.

- *Advanced Sensing and Measurement*

These advanced technologies provide more rapid and true responses, such as remote control and monitoring, time-of-use pricing and demand-side management.

- *Advanced Components*

Latest innovations and research in IT, superconductivity, power electronics, fault tolerance, renewable energies, storage options and diagnostics introduce advanced components of smart grids.

- *Advanced Control Methods*

Advanced control methods supervise essential elements, allowing rapid diagnosis and exact solutions appropriate to any event.

- *Improved Interfaces and Decision Support*

This technology enables decision-making which transforms grid operators and managers into knowledgeable workers.

III. BUILDING A SMARTER SMART GRID

A smarter energy ecosystem will enable improved consumer choices via different commodities and standards but in order to achieve such an intelligent structure some rules and agreements must be met appropriately. Reliability in power grids at any level of voltage is essential to assure adequate penetration of renewable energies (wind, solar, etc.) and to enable new services and products for consumers. As a matter of fact there is a need to develop new Smart Grid business models for continued investment beyond the current stimulus. Grid reliability requirements must be well defined through real-time metrical methods and wide area situational awareness to address the future challenges properly. However there may be a need to distinguish the available reliability of different grids based on consumer needs [7]. It should be also noted that there must be an uninterrupted effort to use existing standards and to develop new ones, but this should not impede our progress in deploying the new ecosystem. In other words, we must build on what we already have – focus on existing solutions including grid reliability solutions (energy and distribution management systems, situation awareness systems), advanced forecasting solutions, interoperability and standards, energy efficiency and smart devices. Moreover, demand-forecasting methodologies must be improved to optimize new consumer needs (demand response, electric vehicles, etc.). Cyber-security issues must be addressed to ensure that consumers and their data are protected, but we must not impede data transparency, which is a key for consumer decision process and participation. Additionally, asset management systems must be deployed to better utilize existing grid assets for real-time operations and condition-based monitoring for optimal asset performance. Aging engineer workforce must be addressed through investment in universities' engineering programs, further research, progressive methodologies and facilities. Another option includes modern knowledge-based solutions to capture existing situational data and plan for future generations. It should be also kept in mind that energy storage technology is essential to Smart Grid development and will enable further penetration of renewable and distributed generation. What's more is the vital role of consumers for the success of Smart Grid [8]. It must be ensured that tariffs and electricity prices do not increase aberrantly and do not impede the deployment of a Smarter Grid at any direction. Consumers must be educated (through scenario planning activities) on potential price increases in electricity due to load growth, fuel and generation scarcity situations. Consumers must be provided with incentives and data (electric price prediction, renewable energy generation patterns, etc.) to participate in energy conservation and improved electricity usage, as well [9].

IV. SMART GRID CYBER SECURITY STRATEGY AND RISK MANAGEMENT

While developing an efficient and reliable strategy to ensure interoperability of solutions across different parts of an intelligent infrastructure, there will be a need for overall cyber security strategy including both domain-specific and common requirements. From the other point of view, implementation of such security plans for the Smart Grid architecture requires the development of a comprehensive cyber security risk management framework which is based on existing risk management approaches developed by both private and public sectors. This risk management framework provides means for combination of different information on impacts, susceptibilities, vulnerabilities and threats to produce an estimation of risk for the Smart Grid, its domains and sub-domains, such as homes, industrial companies and businesses. The desired point toward building a smarter grid is to reach a comprehensive assessment of its systems and components, so in a smart grid includes a variety of systems and components from the Integrated communications, advanced sensing and measurement devices to Improved Interfaces and Decision Support mediums, the risk management framework is needed to be applied on an asset, system, and network basis, as applicable. The next step is to select and accommodate the security requirements. All in all, in a typical risk management process, assets, systems and networks are identified; risks, including vulnerabilities, impacts and threats are assessed; security requirements are specified; and security controls are selected, implemented, assessed for effectiveness, authorized, and then monitored over the lifecycle of the system. When the security requirements are specified, the risk assessment process for the Smart Grid will be completed. These requirements will be selected on the basis of a risk assessment and will not be allocated to specific systems, components, or functions of the Smart Grid. Anyway, when a system comes to an operational phase, the implementation, assessment and monitoring of security controls are applicable. In other words, anything considered as the output of the Smart Grid risk management process should be used in these steps. In addition, when new systems are implemented or existing systems are modified the full risk management process should be applied as well. Recently, several documents have been published in developing the risk management approach for the Smart Grid. Some are as follow:

- North American Electric Reliability Corporation (NERC), *Security Guidelines for the Electricity Sector: Vulnerability and Risk Assessment*, 2002;
- FIPS 199, *Standards for Security Categorization of Federal Information and information Systems*, February 2004;
- Federal Information Processing Standard (FIPS) 200, *Minimum Security Requirements for Federal Information and Information Systems,* March 2006;
- ANSI/ISA-99, *Manufacturing and Control Systems Security, Part 1: Concepts, Models and Terminology*, 2007 and *Part 2: Establishing a Manufacturing and Control Systems Security Program*, 2009;
- National Institute of Standards and Technology (NIST) Special Publication (SP), 800-39, *DRAFT Managing Risk from Information Systems: An Organizational Perspective*, April 2008;
- The *Advanced Metering Infrastructure (AMI) System Security Requirements*, 2008.
- *The National Infrastructure Protection Plan*, 2009;

Although there are many documents and standards that may be applicable to the operation of the Smart Grid, but at this time there are only two authenticated standards which are obligatory for a specific domain of the Smart Grid; the North American Electric Reliability Corporation (NERC) and Critical Infrastructure Protection (CIPs). The following standards are directly relevant to Smart Grid [10]:

- NERC CIP 002, 003-009
- IEEE 1686-2007, *IEEE Standard for Substation Intelligent Electronic Devices (IEDs) Cyber Security Capabilities*
- AMI System Security Requirements, 2008
- *Utility AMI Home Area Network System Requirements Specification,* 2008
- IEC 62351 1-8, *Power System Control and Associated Communications* – Data and Communication Security

The risk assessment, including identifying vulnerabilities, impacts and threats will be achieved through different ways, among them top-down and bottom-up approaches are more rampant. The top-down approach concentrates upon the entire Smart Grid functionality while the bottom-up approach emphasizes on perceptible problems that need to be addressed well, such as authenticating and authorizing users to system architectures, protocols, Intelligent Electronic Devices(IEDs), key management for meters and intrusion detection for power equipment. Moreover, reciprocity among Smart Grid domains will be taken into account while evaluating the consequences of a cyber or physical security incident because an incident in one or more infrastructures can result in failures in other domains or systems.

V. RENEWABLE ENERGIES AND STORAGE OPTIONS IN SMART GRID

As said beforehand, the ability to better integrate renewable energy is one of the driving factors in some smart grid installations. With low incorporation of renewable energies the total effect on grid operations is confined, but as the penetration of such resources increases their mutual effects increase too. Nevertheless, exploitation of renewable energy sources (RESs), even when there is a good potential resource, may be problematic due to their variable and intermittent nature. Earlier studies have indicated that energy storage can compensate for the stochastic nature and sudden deficiencies of RESs for short periods without suffering loss of load events, and without the need to start more generating plants [11]. Using storage options reduces Peak load problems, improves electrical stability and eliminates power quality disturbances. Furthermore, energy storage systems in combination with power electronics are expected to be key elements for the growth and integration of distributed generation (DG) and renewable energy sources (RES) into the eclectic system to build future smart grids [12],[15]. Thus, the main focus should be on small to medium sized storages which are installed closely to distributed energy resources.

For the actual operation of smart grid forecasts of future requirements are essential to be able to prepare the flexible systems to behave in the appropriate manner. Unplanned renewable resources introduce new variable to decision making procedure and complicate balancing act. The fact that these types of generations cannot be dispatched in the traditional style can bring about problems for conventional system operation. A smart grid takes advantage of potential improvements that can be made to conventional operation through the use of communications and information. While renewable energy cannot necessarily be operated in a conventional manner, its behavior can be predicted and the forecast information is exactly the kind of information that a smart grid must use to improve system efficiency. In fact, as renewable energy penetration levels continue to increase, non-scheduled renewable energy may become the single largest source of variability on the power system. This makes the employment of accurate forecasting of renewable energies a key component of a smart grid.

VI. SMART ENERGY MANAGEMENT SYSTEMS

In a smart grid, decisions are dynamically made based on information about electricity supply and demand. Basically, in the world of renewable energies, it is the forecasted information feeds the smart grid. Hence, designing a supervisory control unit and a smart energy management system (SEMS), which allows instantaneous optimization of alternative and renewable power sources, is necessary [13], [14]. The function of these control systems is to generate set points for all the sources and storages in such a way that economically optimized power dispatch will be maintained to fulfill certain load demand, i.e. a smart energy management can be viewed as a plan of actions chooses a proper set of generators that can supply certain loads in an efficient and economical manner. During this smart planning, forecasting of demand and power generation as well as some fast online algorithms is used to define the energy availability and to optimize power dispatch signals to the loads and the grid using advanced components. This energy management system generally consists of prediction module, optimization module and online control module, as shown in Fig 4.

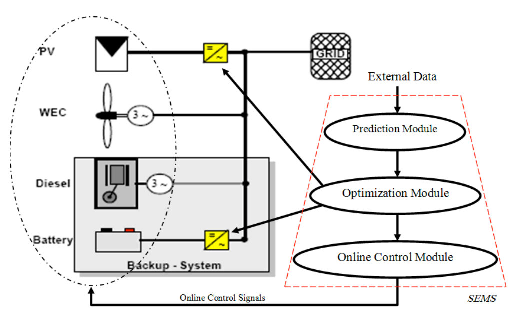

Figure 4- SEMS in smart grid

VII. RECOMMENDATIONS FOR DEVELOPING SMART GRID TECHNOLOGY

Fundamental agreements and Key elements will drive solutions within a few years and it should feasible to achieve meaningful benefits that drive extra intelligent actions on Smart Grid utilization over a longer period of time.

- *Establish open standards and architecture*:

A nationwide platform for Smart Grid technology programs should seek open standards and architecture i.e. clear security standards, transportability, data accessibility and interoperability should be designed in a way that ensure all partners and cooperators invest together for a common execution, risk and reward sharing for using Smart Grid technology (similar to the telecommunications industry [9]).

- *Transparency:*

Recognize that we are creating smarter consumers, so there must be transparency in pricing and operational signals to consumers and operators. Clear data should be generally ready for use in order to facilitate innovation and technology development.

- *Rate-making:*

Address rate-making changes that utilize decoupling, capitalizing efficiencies and demand response. Rate-making must also be transparent.

- *Define essential foundational elements of "Smart Grid":*

The definition must provide the foundation for making choices about what to do first. Seek an industry agreed upon definition of what Smart Grid encompasses.

- *Workforce improvement:*

Development of expert opinions in some fields of study such as electrical and power engineering, information technology, mechanical engineering and promotion of utility operations and maintenance could be helpful for smart operation of future power grids i.e. it is required to update our knowledge of engineering, our systematic and routine curriculum and programs along with investing in worker recruiting and retraining programs.

- *Offer external incentives:*

Stimulus patterns or supportive actions must be provided in societies and among engineering communities in order to develop workforce, create and fill the jobs that will implement new technologies.

VIII. Conclusion

An intelligent grid can lead to a revolution in power system operation, a revolution that will take place if new ideas and technologies along with very large penetrations of renewable energy are to be incorporated onto the grid. However, in order to efficiently operate and make good decisions, a smart grid must have information feeding supervisory control unit and Smart Energy Management System (SEMS). This information can be used to create better procedures and capabilities for the smart grid and allow more prudent investments. Moreover the optimal integration of decentralized energy storages will be an extremely important task in the near future for the utilities. On the other hand, to reach a pathway toward intelligent structures, first the barriers must be identified and then research, development and demonstrations must be conducted to overcome these barriers.

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