What is the Smart Grid?

Definitions, Perspectives, and Ultimate Goals

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***Abstract*— It is no surprise that there is no unique definition of the Smart Grid (SG). Such a complex machine with so many technology options at hand to improve its functionality is bound to facilitate a variety of broad definitions. As a result, there are a variety of architectures, technologies and configurations already proposed or under formation for what can be described as smart grids. In this paper, we are going to give a perfect answer for the question "What is the Smart Grid?" envisioned by different organizations and authors. Meanwhile, we discuss on general aspects of smart grids and collect some crucial features which are mostly mentioned in academic papers and technical reports in order to elaborate its definitions in different perspectives. Finally, we will reveal the key findings arise from this survey.**

Keywords—Smart Grid; Digital Economy; Perfect Power System; Self-healing; SQRAE; Demand Side Management

I. INTRODUCTION

Defining the smart grid in a concise way is not an easy task as the concept is relatively new and as various alternative components build up a smart grid. Some authors even argue that it is "too hard" to define the concept [1]. Looking at different definitions reveals that the smart grid has been defined in different ways by different organizations and authors.

The electric power system delivery has often been cited as the greatest and most complex machine ever built. It consists of wires, cables, towers, transformers and circuit breakers—all bolted together in some fashion [2]

The smart grid is an innovation that has the potential to revolutionize the transmission, distribution and conservation of energy. Actually, the current electric power delivery system is almost entirely a mechanical system, with only limited use of sensors, minimal electronic communication and almost no electronic control [3]. On the contrary, smart grid employs digital technology to improve transparency and to increase reliability as well as efficiency. ICTs and especially sensors and sensor networks play a major role in turning traditional grids into smart grids.

The state of smart grid deployment covers a broad array of electric system capabilities and services enabled through pervasive communications and information technology, with the objective to improve reliability, operating efficiency, resiliency to threats, and our impact to the environment. By collecting information from a workshop, interviews, and research of existing smart grid literature and studies, this paper attempts to present a balanced view of progress toward a smart grid across many fronts.

For a power system, this permits several functions which allow optimization—in combination—of the use of bulk generation and storage, transmission, distribution, distributed resources and consumer end uses toward goals which ensure reliability and optimize or minimize the use of energy, mitigate environmental impact, manage assets, and contain cost [2].

In the short term, a smarter grid will function more efficiently, enabling it to deliver the level of service we've come to expect more affordably in an era of rising costs, while also offering considerable societal benefits – such as less impact on our environment [4].

Longer term, expect the Smart Grid to spur the kind of transformation that the Internet has already brought to the way we live, work, play and learn [4].

II. VARIOUS VISIONS REGARDING SMART GRID

Since there is no specific definition for Smart Grid, in this paper, some information have been gathered from different reports that show various perspectives of academia and research centers regarding Smart Grid.

A. EPRI's vision

A Smart Grid is one that incorporates information and communications technology into every aspect of electricity generation, delivery and consumption in order to minimize environmental impact, enhance markets, improve reliability and service, and reduce costs and improve efficiency [2].

In EPRI's viewpoint, a smart grid is the use of sensors, communications, computational ability and control in some form to enhance the overall functionality of the electric power delivery system. A dumb system becomes smart by sensing, communicating, applying intelligence, exercising control and through feedback, continually adjusting [3].

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end uses toward goals which ensure reliability and optimize or minimize the use of energy, mitigate environmental impact, manage assets, and contain cost.

B. U.S. Department of Energy (DOE)'s vision

The U.S. Department of Energy has defined the smart grid in terms of seven characteristics that are outcomes. In June of 2008, DOE held a meeting of industry leaders who identified seven defining traits of what a smart grid will do [2] and [4-6]:

1. Optimize asset utilization and operating efficiency.
2. Accommodate all generation and storage options.
3. Provide power quality for the range of needs in a digital economy.
4. Anticipate and respond to system disturbances in a self-healing manner.
5. Operate resiliently against physical and cyber attacks and natural disasters.
6. Enable active participation by consumers.
7. Enable new products, services, and markets.

Therefore, the definition of Smart Grin in DOE's viewpoint is:

"The smart grid is the electricity delivery system, from point of generation to point of consumption, integrated with communications and information technology for enhanced grid operations, customer services, and environmental benefits."

"A smart grid is self-healing, enables active participation of consumers, operate resiliently against attack and natural disasters, accommodate all generation and storage options, enable introduction of new products, services and markets, optimize asset utilization and operate efficiently, provide power quality for the digital economy."

What is not explicitly stated here, but is equally important, is that a fully developed smart grid concept goes far beyond smart meters. It includes technologies at both the transmission and distribution level and extends to both IT hardware and software, such as monitoring and control systems, as well as primary equipment like transformers and relays.

C. ABB's vision

ABB's list of smart grid criteria covers much of the same ground as DOE's, but focuses on broad characteristics rather than specific functions. Under this model, the smart grid is [7]:

1. Adaptive, with less reliance on operators, particularly in responding rapidly to changing conditions.
2. Predictive, in terms of applying operational data to equipment maintenance practices and even identifying potential outages before they occur.
3. Integrated, in terms of real-time communications and control functions.
4. Interactive between customers and markets.
5. Optimized to maximize reliability, availability, efficiency and economic performance.
6. Secure from attack and naturally occurring disruptions.

ABB's view on Smart Grid is more than IT and smart meters and believes that smart grid is a political issue that many players need to be informed consistently [8]:

- Smart Grid is the future evolution of the entire power network.
- Smart Grid includes both transmission and distribution, focuses on the integration of renewable generation, reliability and efficiency of the grid.
- Smart Grid includes the demand response and the potential of new technologies such as large scale integration of electric vehicles.

Smart Grid includes both automation/IT and controllable power devices in the whole value chain from production to consumption.

D. European Union (E.U.)'s vision

According to Vision and Strategy of Europe's Electricity Networks of the Future, EU's electricity networks must be [9]:

- *Flexible:* fulfilling customers' needs whilst responding to the changes and challenges ahead.
- *Accessible:* granting connection access to all network users, particularly for renewable power sources and high efficiency local generation with zero or low carbon emissions.
- *Reliable:* assuring and improving security and quality of supply, consistent with the demands of the digital age with resilience to hazards and uncertainties.
- *Economic:* providing best value through innovation, efficient energy management and 'level playing field' competition and regulation.

Therefore, the definition of Smart Grin in E.U.'s viewpoint is:

"A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies."

Meanwhile, E.U. sees the smart grid as an active network:

1. To overcome the limits on the development of distributed generation and storage.
2. To ensure interoperability and security of supply.
3. To provide accessibility for all the users to a liberalized market.
4. To reduce the impact of environmental consequences of electricity production and delivery.
5. To enable demand-side participation.
6. To engage consumers interest.

E. Electricite de France (EDF)'s vision

EDF defines it as integrating distributed energy resources with dispersed intelligence and advanced automation [1]. The following EDF's principles informed the SG more [10-12]:

1. Empowers consumers to make choices about their energy use, both to save money and to support clean energy.
2. Supports the sale of demand-side resources into wholesale energy markets.

F. Hydro Quebec 's vision

Hydro Quebec has emphasized that a smarter grid is a necessity, not a choice. Its vision is [1], [13]:

1. To reach an Active Distribution Network.
2. Increase grid reliability and availability.
3. Improve energy efficiency of facilities.
4. Increase capacity to integrate new sources of renewable energy resources (RER) and distributed generation (DG).
5. Optimize investments (financial and other) in long-term operability, maintenance and security of supply.
6. Provide customers with the means to optimize consumption and reduce electricity bills.

G. General Electric's vision

General Electric (GE) sees the smart grid "as a family of network control systems and asset-management tools, empowered by sensors, communication pathways and information tools." [1], [14].

H. IESO's vision

Ontario Independent Electricity System Operator (IESO) is a leader in smart grids – with smart meters installed in almost every home and small business. Smart grids comprise many things, but they all use information and communication technologies to expand the capabilities of the electricity system to provide even greater benefits for consumers such as reliability, efficiency, sustainability, and customer control (by using smart meters) [15].

I. Ofgem's vision

Ofgem and its Electricity Networks Strategy Group believe that a smart network employs communications, innovative products and services together with intelligent monitoring and control technologies to [16]:

1. Facilitate connection and operation of generators of all sizes and technologies,
2. Enable the demand side to play a part in optimizing the operation of the system,
3. Extend system balancing into distribution and the home,
4. Provide consumers with greater information and choice of supply,
5. Significantly reduce the environmental impact of the total electricity supply system,
6. Deliver required levels of reliability, flexibility, quality and security of supply.

J. OECD's vision

Organization for Economic Cooperation and Development beholds Smart Grid in two perspectives [17]:

(1) From a *solution perspective*, the smart grid is characterized by:

- More efficient energy routing and thus an optimized energy usage, a reduction of the need for excess capacity and increased power quality and security.
- Better monitoring and control of energy and grid components.
- Improved data capture and thus an improved outage management.
- Two-way flow of electricity and real-time information allowing for the incorporation of green energy sources, demand-side management and real-time market transactions.
- Highly automated, responsive and self-healing energy network with seamless interfaces between all parts of the grid.

(2) From a *technical components' perspective*, the smart grid is a highly complex combination and integration of multiple digital and non-digital technologies and systems. The main components of a smart grid are:

a) New and advanced grid components;

b) Smart devices and smart metering;

c) Integrated communication technologies;

d) Programmes for decision support and human interfaces;

e) Advanced control systems.

These individual grids do not need to be centralized, but can have more control stations and be more highly integrated. The integration of many grids including country-spanning ones provides economic advantages, but there are challenges regarding security if they become too centralized and interconnected.

Table I gives an overview of more selected definitions. It shows two different approaches to define the smart grid: it is either defined from a solution perspective "What are the main advantages of the grid?" or from a components' perspective "Which components constitute the grid?".

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TABLE I. A SUMMARY OF SMART GRID DEFINITIONS IN DIFFERENT PERSPECTIVES

Organization/ Author	Grid/ Concept	Definition
IEEE [18]	Smart Grid	The "smart grid" has come to describe a next-generation electrical power system that is typified by the increased use of **Communications** and **Information Technology** in the generation, delivery and consumption of electrical energy.
IET [19]	Smart Grid	The Smart Grid is fully functional around 2030 that will cost efficiently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to ensure an **economically efficient**, **sustainable** power system with low losses and **high levels of quality** and **security** of supply and **safety**.
PG&E [20] (Pacific Gas and Electric Co.)	Smart Grid	The Smart Grid is a modernized electric system that combines advanced communications and controls to create a responsive and **resilient energy delivery network**.
EPRI [2-3], [21]	ElectriNet^{SM}	The ElectriNet^{SM} recognizes the evolution of the power system into a highly interconnected, complex, and **Interactive network** of power systems, telecommunications, the Internet, and electronic commerce applications.
AEMO [22] (Australian Energy Market Operator)	Smart Grid	Smart Grid creates opportunities for consumers to change their **energy consumption** at short notice in response to a variety of signals that include price.
IESO [23] (Ontario ISO)	Smart Grid	Using information and communication technologies (especially **smart meters**) to expand the capabilities of the electricity system to provide even greater benefits for consumers.
SIEMENS [24]	Smart Grid	It's about the big picture of improved energy delivery, informed consumption and reduced environmental impact (Siemens recognizes that Smart Grid **doesn't just mean smart meters**.)
Ofgem [16]	Smarter Grid	A Smart Grid as part of an electricity power system can intelligently integrate the actions of **all users** connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies.
DOE [4-6] (U.S. Department of Energy)	Grid 2030	Grid 2030 is 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 networks.
ABB [7-8]	Smart Grid	A smart grid is an evolved grid system that manages electricity demand in a **Sustainable**, **Reliable** and **Economic** manner, built on advanced infrastructure and tuned to facilitate the integration of all involved.
AUC [25] (Alberta Utilities Commission)	Smart Grid	Smart grid is a broad concept that describes the integration of hardware, software, computer monitoring and control technologies, and modern communications networks into an electricity grid.
Climate Group [26]	Smart Grid	A "smart grid" is a set of software and hardware tools that enable generators to route power **more efficiently**, reducing the need for excess capacity and allowing two-way, real time information exchange with their customers for real time **Demand Side Management (DSM)**. It improves efficiency, energy monitoring and data capture across the power generation and T&D network.
Adam & Wintersteller [27]	Smart Grid	A smart grid would employ digital technology to optimize energy usage, better incorporate intermittent "**Green**" sources of energy, and involve customers through smart metering.
Miller [17]	Smart Grid	The Smart Grid will: ▪ Enable active participation by consumers ▪ Accommodate all generation and storage options ▪ Enable new products, services and markets ▪ Provide power quality for the **Digital Economy** ▪ Optimize asset utilization and operate efficiently ▪ Anticipate and respond to system disturbances (**Self-heal**) ▪ Operate resiliently against attack and natural disaster
Franz, and et al. [28]	eEnergy	"Convergence of the electricity system with **ICT** technologies"
SmartGrid.gov [29]	Smart Grid	The Smart Grid is a developing network of new technologies, equipment, and controls working together to respond immediately to our 21st century demand for electricity. The Smart Grid represents an unprecedented opportunity to move the energy industry into a new era of **Reliability**, **Availability**, and **Efficiency** that will contribute to our **Economic** and **Environmental** health.

III. LESSONS TAKE HOME

To sum up, a fruitful deduction that is the result of our survey is presented here. In this paper, we can conclude that "Smart grid" that we call it *Thinking Network*, is the term commonly used to refer to an electrical grid whose operation has been transformed from a twentieth century analog technology base to the pervasive use of *Digital Technology* for communications, monitoring (e.g., sensing), computation, and control. In a smart grid, much of the intelligence and situational awareness necessary to understand the state of the grid and to maintain safe, secure, efficient, and reliable operation of the grid reside within the grid's digital information infrastructure itself.

Meanwhile, smart grid should be a more stable grid because automated responses to threats to grid stability can be easily implemented. The ability to anticipate or detect emerging problems at a very early stage, where minor automated adjustments can easily rectify the condition, is realized with a smart grid.

The key findings and in actual fact the ultimate goals arise from this survey are revealed in the following:

- Enhancement of power system infrastructure (sensors, communications, computational facilities, etc.);
- Different entities share the benefits of Smart Grid;
- Creation of new business opportunities.
- Enhancement of SQRAE (Security, Quality, Reliability, Availability, Efficiency) features of power system.
- Mitigation of emission;
- Establishment of optimized and perfect power system;
- Vast deployment of emergent technologies;
- Asset Management and Cost Control;
- More competitive electricity market with Open Access;
- Integrating of variety of stakeholders of Smart Grid.

This modernization enables the extensive use of computer-based automation to maintain grid stability and to enable modern grid features such as *Demand-Side Management*, *Distributed Generation*, *Real-Time Pricing*, and automated meter activation and reading.

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