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Worldwide Technological Revolutions and Its Challenges under Smart Grid Paradigm: A Comprehensive Study

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Abstract— —Smart Grid (SG) is one of the biggest challenges at plantery level that grab the attention of whole world. It is an umbrella term used for a set of technologies that are being developed as a substitution to old conventional power grid in context of future requirements. However, there exist differences in understanding and implementing the concept of smart grid in different countries. Power grid enterprises and organizations comprehend the concept of smart grid variously under different development environment and political requirement. Until now, there is no clear agreement worldwide on the smart grid related technologies. With a growing demand for sustainable electricity, the need for such a grid is vital that works more efficient, reliable with affordable maintenance, able to accommodate more renewable energy sources. Based on a vast amount of relevant documents on smart grid, the aim of this paper is to highlight the importance and needs of SG by providing an overview of the essentials of a progressive smart grid paradigm with different concepts in context with old grid. The key focus is on to shed some light for better understanding the concept and characteristics of SG according to different countries's vision. Additionally, future foreseeable challenges/issues in designing of SG are also categorized and addressed in this article.

Index Terms— Distributed Generation, Demand Response, Electric Power System, Energy Efficiency, Energy Storage,Smart Grid, Renewable Energy

1 INTRODUCTION

THE debate over what constitutes a smart grid is still emerging. However, recent efforts in building a SG system have focused on addressing the problems of global warming effects, rising energy demands and risks of peak loads. SG is a vision for the electric delivery systems of the future by employing a two-way cyber-secure communication, latest power electronic technologies with computational intelligence capabilities to balance production and consumption at all levels. Benefits associated with SG deployment include enhanced system reliability, work force safety, greater societal benefits, electric service innovations for customers etc. Therefore, SG technologies are key elements to modernize the durability, flexibility, and adaptability of the electricity infrastructure.

Existing electricity power grid across the world is facing numerous challenges, including diversification of generation, renewable energy accommodation, demand response, and reduction of carbon footprint. Such crucial issues cannot be addressed within the limitations of the existing electricity grids.[1],[2].

Given the vast landscape of the SG research, some of literature reviews have already been done covering different aspects of SG. For example H. E. Brown, S. Suryanarayanan, and G. T. Heydt [15] identified those technologies that could be applied in the future research in the smart distribution system. X. Fang [16] explored three major systems of SG, namely the smart infrastructure system, the smart management system, and the smart protection system. In this article, we survey the available literature on SG until 2012 from the industry and academia. Based on the results of the survey, a comprehensive but brief review on smart grid covering all its aspects and technologies along with its future challenges and research issues are also categorized and explored that has not been done before.

The remainder of this article is organized as follows: In Section II, traditional grid with its limitation is discussed.SG is demonstrated by covering all its related aspects such as definition, motivation factors, purpose, capabilities and functional integrated technologies in Section III. Section IV discusses the present roadmaps/projects, standardization and worldwide current status of SG. Section V, we will discuss the several major challenges and issues related with integrated technologies of SG. Finally, Section VI concludes this article.

2 TRADITIONAL GRID

Central power stations produce electricity and deliver it to end users via transmission and distribution networks in traditional grid layout as shown in Fig. 1. Existing hierarchical grid is facing many structural weakness and environmental shortcomings. Also has many deficiencies like about one-third of energy converted to electricity, without recovering the waste heat. Almost 8% is lost along transmission lines and about 20% of its generation capacity is able to meet peak demand only[17]. A comparison is presented in Table 1.It is clear that existing electricity grid is ill-suited to the needs of the 21st Century and failed to solve the critical issues within its limitations.

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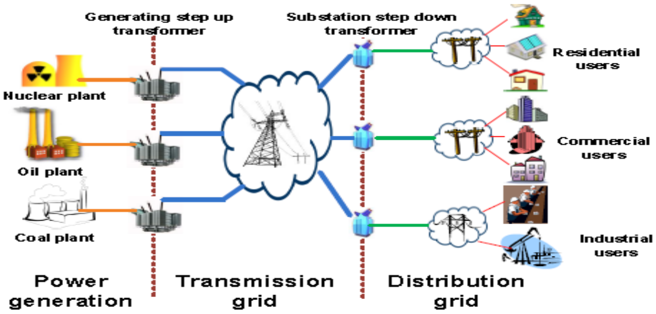

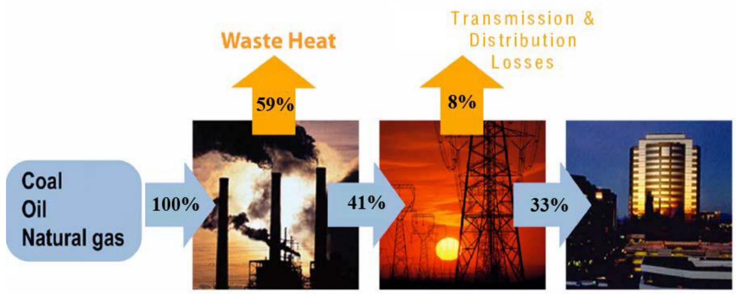

Fig 1: Traditional Grid and its Layout

Consequently, a new grid infrastructure is urgently needed to address these challenges. Therefore, a new concept of next generation electric power system, the Smart Grid, has emerged. A tremendous research and development on SG applications and technologies have been started in many countries e.g U.S., Canada, China, South Korea, Japan, Australia and European Countries (EC).

2.1 Drawbacks of Traditional Grid

Some of the weaknesses of traditional grid are given below:

1. Most of the traditional power networks are half a century old.
2. Power flow is from supply to demand which is in only one direction.
3. Dependance of system operation on historical data and experience.
4. Overloading of system is detected by the operators
5. Lack of flexibility to incorporate new distribution generation.
6. High power loss.
7. High maintenance costs.
8. Likely events of costly power interruption and power outage.
9. Lack of situational awareness.
10. Poor visibility.
11. Lack of automated analysis.
12. High Equipment failure.

Table 1: A comparison between SG and traditional grid

Smart Grid	Traditional Grid
Two way communication	One way communication
Digital	Electromechanical
Distributed Generation	Centralized genereation
Network	Hierarchical
A huge amount of sensor	Few sensors on selected places
Self Montoring attribute	Blind
Self Healing	Manual restoration
Adaptive and Islanding	Failures and Blackouts
Remote checks/test	Manual check/test
Pervasive Control	Limited Control
Many customer Choices	Few Customer Choices

3 Its All About Smart Grid

SG defines the evolution of electrical grids and a change of paradigm in the electric market organization and management. SG is sophisticated, digitally enhanced power systems that deliver electricity to consumers using two-way modern communications and control technologies. It enables the more efficient management of consumers' end uses of electricity by providing different type of Demand Side Management / Demand response choices to motivate them to participate in the operations of the grid. The emerging vision of the SG encompasses a broad range of applications, including technologies, hardware, and software that help out the utilities to identify and correct supply demand-imbalances instantaneously and detect faults in a "self-healing" process that improves service quality, enhances reliability, and reduces costs..[19],[20].

3.1 Definitions

There is no precise definition exit for SG. Many definitions circulate as different countries try to realize their own needs for SG, some definitions are given as follow:

According to IEEE "*the SG 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. All current definitions of Smart Grid share the same core idea: the convergence of the actual electrical power infrastructure (Energy) with the telecommunications*".

According to the US Department of energy,"*the SG 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*".

According to the Australian Government (Department of the Environment, Water, Heritage and the Arts) "*SG combine advanced telecommunications and information technology applications with 'smart' appliances to enhance energy efficiency on the electricity power grid, in homes and in businesses*".

According to the European Technology Platform," *SG 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 "*[21]

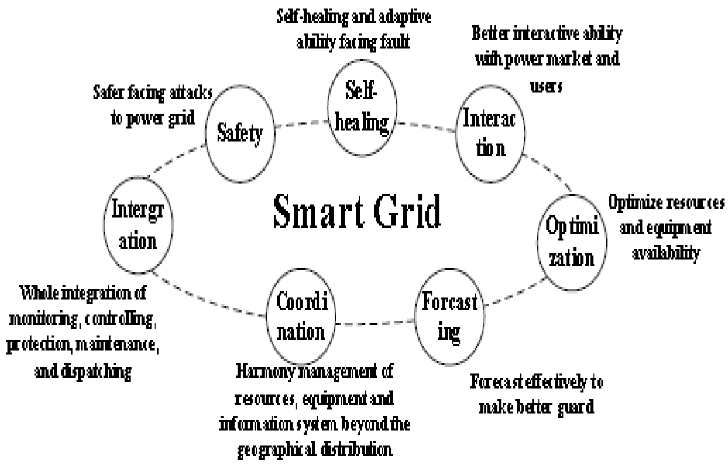

Fig.2: SG definition by EPRI[85]

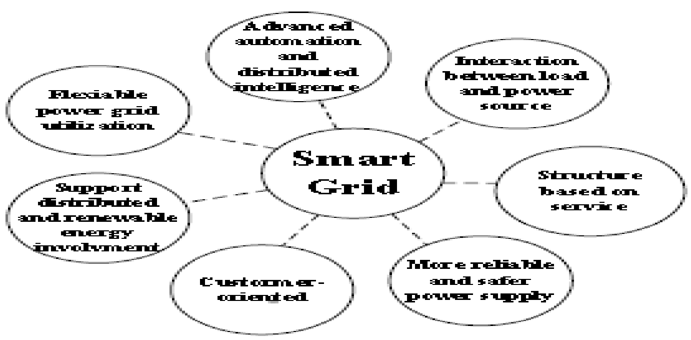

Fig. 3: SG definition by European Union[21]

3.2 Advantages of SG

Some of the advantages of SG are summerized in the following: [23],[24],[25],[26],[27].

1. SG can enhance energy efficiency on the electricity power grid, in homes and in businesses by using advanced information technology and smart appliances
2. SG will be able to automate, monitor and control the two-way flow of electricity across networks by using advanced meters, sensors, and digital controllers.
3. In SG, transmission and distribution companies can gather complex, real-time information about grid performance and will be able to improve control over the network
4. In SG, reliability of electric supply is enhanced by automatically preventing outages and improving the detection of power lines overloads and faults.
5. SG can reduce the losses of transmission & distribution lines and manage voltage within the grid.
6. In SG, utilities can manage their networks in better way and can reduce maintenance costs.
7. Giving the ability to customers better manage their energy costs and help reduce the demand for electricity in peak times by the use of smart meters and smart applications. Consumers know about their updated electricity usage and they can change their energy consumption during peak periods in order to save money on their electricity bills.
8. Reduces the need for building more power plants of large capacity.
9. Facilitate the integration of renewable energy sources into the electricity grid and enable the benefits of distributed power generation.
10. Provide Vehicles-to-Grid and Grid-to-Vehicles technolgy.
11. Good environmental impacts.

3.3 Motivation towards SG

In recent years, several factors have come into play that increases the necessity of changes into the existing electrical grid and moving towards a new SG. The fundamental triggers for SG can be divided into four distinct categories.[18]

Economical Aspect: In recent years, economical crisis has tempered the price of oil and will become more expensive in the future. The phenomenon of manipulation of energy supplies and competition over energy sources has impelled nations to reassess the price of dependence on imported energy [18].At a certain point, investments in the grid to save energy and optimize the power flow become profitable. Now-a-days, the industry is more depended on high quality electrical power. Decrease in power quality can lead to failing production processes and thus enormous costs for the industry. Therefore, investments in the grid are needed to maintain a reliable high quality power supply.

Technical Aspects: Centralized power generation as well as aging infrastructure would endanger the power system operation from a long-term perspective. The frequency of instigating peak load and power outage is likely to increase due to the usage of new appliances and technology like Electrical Vehicles. It will become harder to restore and prevent from happening as the demand for energy exacerbates rapidly. Without improving responsiveness from the system as well as consumers, rising demand may not be easily controlled at later times. Developments in the field of power electronics have led to a completely new range of devices for control of electric grid. Coupling these devices with new developments in the information and communication technology sector offers various new control possibilities for the grid. Remote monitoring and control of substations and distribution stations can improve the efficiency of the grid.

Environmental Aspect: Around 80% of resources used to produce energy throughout the world today is fossil fuels, i.e., non-renewable. This has several negative consequences, the biggest being the exhaust of CO2 into the atmosphere. The greenhouse gas effect has likely caused climate change and environmental impact. Staying in the centralized form could restrict or impede the growth of the system to meet the energy demand and limited of innovation and modernization. Alternative sustainable energy sources are available but are usually distributed and in small-scale generators such as wind or solar power. These energy sources exhibit completely different behavior and require a differently organized grid.[18]

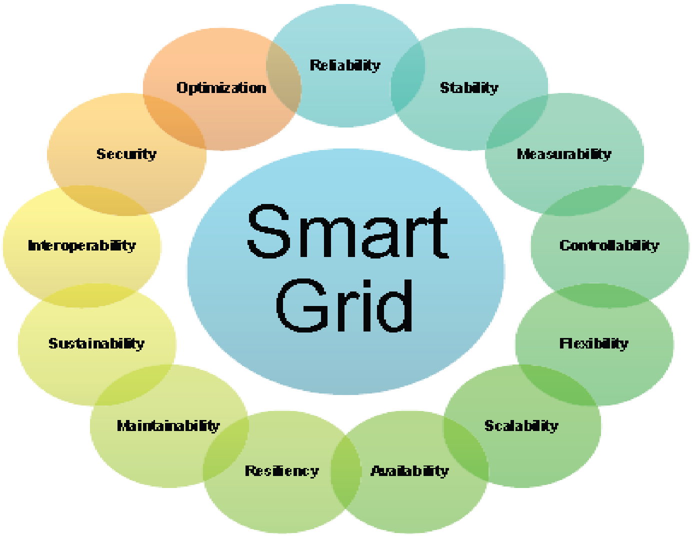

Fig.4: SG's characteristics[22]

Political Aspect: All member countries had to liberalize their energy markets in accordance with the EU guidelines. Therefore, existing utility companies had to split their grid operating activities into a new independent company. These grid-operating companies are owned by the government to ensures an open and independent grid. In this new situation the customers are more interested in their energy consumptions statistics and free to choose their energy provider which should increase competition and thus will lower the costs[18].

3.4 Characteristics of a Smart Grid

The SG reflects different characteristics according to the different comprehension by different countries and power enterprises. The characteristics of smart grid can be summarized here: [27]

According to the IEC, SG has summed up the characteristics of as follows.

1. Flexible: It can satisfy user's diversity of the electricity demand.
2. Accessible:It can ensure that all users access the grid easily, especially for renewable energy and
3. Efficient and clean local electricity.
4. Reliable: It can raise the stability and reliability of power grid.
5. Economical:Through reform and regulate the competition, it can realize the most efficient energy
6. Management and improve the grid economic benefits.

According to EPRI [85], SG has summed up the characteristics of as follows:

1. Self-healing grid: Complex power grid monitoring system would forecast and reply to system problem immediately to avoid or reduce unstable voltage problems or power failure.
2. Safer Grid: The new technology configuration could discern and handle the manually or naturally encroachments.
3. Optimize:The upgraded power grid would improve the transmission capacity, reduce losses and maximize the use of the lowest cost power source
4. Flexible:The standardized power and communication interface would allow the user link to fuel battery, renewable power source or the other dispersed power sources and easily use them in a plugin way.
5. Demand Response:The power grid would connect with the energy management system in intelligence building, so as to help users manage their energy use and reduce energy consumption cost.[28][29]

By analysis and comparison of different available definitions of smart grid, we presented detailed key features of smart grid as follow:

3.4.1 Self Healed Grid

Two-way communications with local and remote devices will help to analyze the undesirable system conditions. Acting as an "immune system," the grid's ability to intelligently monitor, diagnose and repair itself will help increase the overall reliability, security, affordability, power quality and efficiency of the network

3.4.2 Integrated Grid

This attribute enables utilities to deliver a highly secure and efficient electricity supply by allowing for interregional power transactions, added capacity, and network redundancy.with reduced environmental impact

3.4.3 Cyber Security Enhanced Grid

Enhanced security is an essential characteristic of the SG against malicious attack and disruption. This improves the speed of recovery from disruptions and security breaches Also reduces physical and cyber vulnerabilities. Enhanced security will reduce the impact of abnormal events on grid stability and integrity, ensuring the safety of society and the economy.

3.4.4 Interactive Grid with Consumers

New cost saving, energy efficiency products and attractive Demand Side Management programs will motivate the end user to actively participate in the grid and manage their energy consumption based the electric system's capacity to meet their demands.

3.4.5 Integration of Distribution Generation

One of the unique characteristic of SG is its accommodation of a diverse range of generation and storage options. This will enable energy markets to flourish, exposing and mitigating resource allocation inefficiencies.

3.4.6 Improved Quality of Power

Existing grid infrastructure cannot meet the demands of today's digital economy for reliable, high quality electric power due to its old design and construction. As part of the SG, new power quality standards will enable utilities to balance load sensitivity with power quality, and consumers will have the option of purchasing electricity at different prices with varying grades of power quality.

3.4.7 Resource Management with Asset Optimization

Optimized operations and increased asset life are a major objective for the Smart Grid [30].

3.4.8 Increased Visibility

The SG's ubiquitous sensors infrastructure and modern

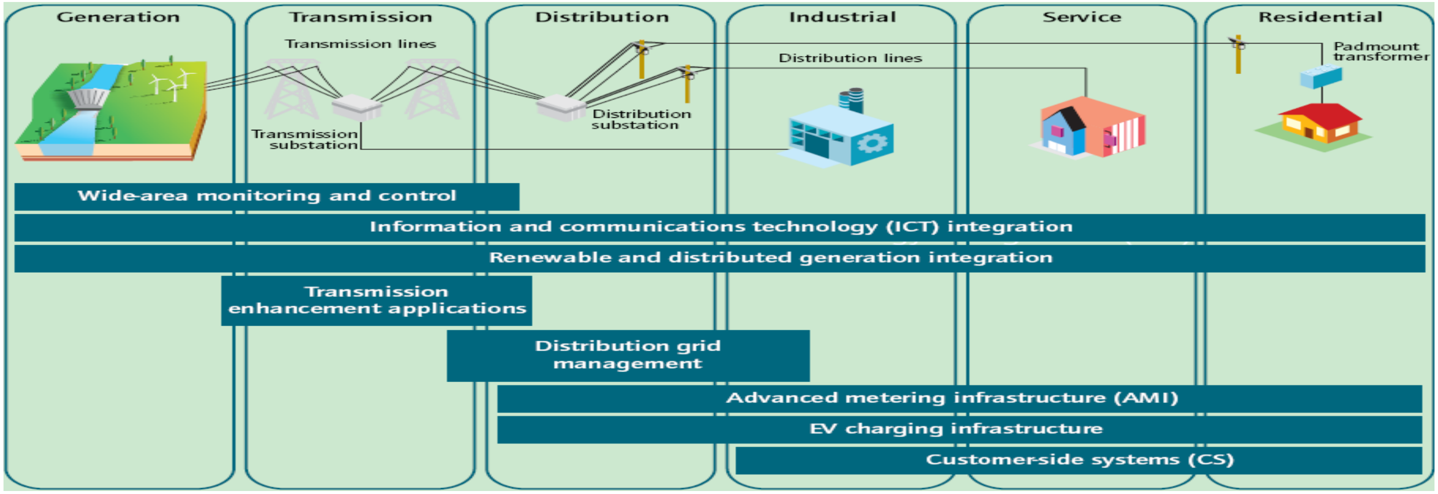

Fig.5: SG Layout & its Technologies

communications network will enable network operators to have better and greater observability into the grid's operational status, particularly with respect to the historically "blind" spots of the distribution networks. Aided by advanced visualization tools, operators will be able to accurately and quickly identify critical information, allowing them to provide essential human oversight to automated processes[30].

3.4.9 Environmentally Friendly Network Operation

It is an obligatory duty of network operators to minimize the negative impact of their actions on the environment; i.e. reducing their carbon footprint. What smart grid technologies can provide to reduce the carbon footprint of the power industry is a fast and automated service.[29]

3.5 Key Technologies of SG

Physically, the Smart Grid is comprised of following fundamental components: [31]

3.5.1 Communications Infrastructure

Communication infrastructure can be based on fiber-optics, infrared, microwave, power line carrier (PLC),and/or wireless radio networks(such as GSM and CDMA) for transfering massive amounts of data in SG.Integrated communications will allow the operator real-time control of grid to optimize system reliability, asset utilization, and security challenges.

3.5.2 Demand Side Management/Demand Response

Demand side management (DSM) can simply be described as any actions taken on consumer's side to optimize energy consumption. It is the process of managing the usage of electricity, generally to optimize the available generation resources. The main goal of electricity DSM strategies is to maximize end-use efficiency to avoid or postpone the construction of new generating plants. Demand side management focuses on reducing the energy demand through automation in the customer premises. It facilitates the efficient use of energy by means of energy conservation through both behavioral and operational changes. The great advantage of using DSM is that it does not require expensive additional resources (like generation or storage) to be erected. The only additional cost, associated with demand side management is that if the communication infrastructure needed to control and coordinate the operation of overall system (basically the activities of load curtailment and restoration). However, this involves smaller investment as compared to the huge ones for deploying new generation, increasing storage capacity, and/or improving transmission lines. Moreover, being a distributed solution, the demand side management can be more reliable because there is no single point of failure.All this makes the option of demand side management advantageous, and therefore attractive to cope with the problem of smart grid stability. Demand response may be defined by changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time. It may be implemented in the system through incentive payments designed to encourage lower electricity use at times of high wholesale market prices or when system reliability is in danger.Demand response includes direct load control schemes like partial or curtailable load reductions, and complete load interruptions on loads such asresidential air conditioners. Demand response provides a number of opportunities for improving the planning and operation of the power system. Installed of demand response modules (DRM) on consumer appliances will provide Demand response by communicating through PLC or wireless. The DRM will switch off/on a group of appliances in respond to changes of some objectives in the supply side depening onloading level of a branch or changes in system frequency.

3.5.3 Smart Metering

A smart grid replaces typical analog mechanical meters with advance digital meters that record usage in real time; provide a communication path extending from generation plants to electrical outlets (smart socket) and other smart grid-enabled devices. The smart meter as a basic means of communication between consumer and utilities, will enable the consumers to monitor their electricity consumption and take measures to reduce their usage and also transferred real-time consumption level data to the utilities. Another major benefit of smart meters is detection of electricity theft that account of some of the revenue of utilities. Since the communication is happening at real-time, any tampering with the metering equipment, or bypassing the meter can be transmitted to the utility [35].

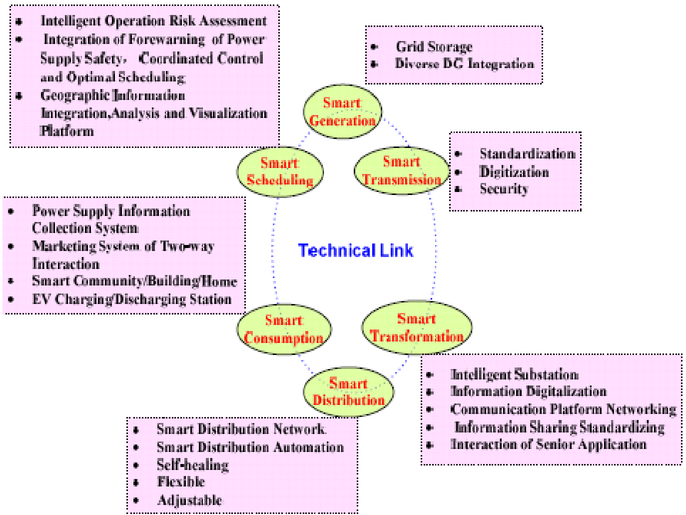

Fig.6: SG Technological functions[3]

3.5.4 Renewable energy, Energy Storage and Electric Vehicles

The social environmental requires lower carbon and wasting energy emission, promoting industry of renewable energy and electrical vehicles (EV). Due to most of the renewable energy maintain feature of decentralizing, Distributed Generation and Storage appears to be the best platform. What's more, DG provides chances for Combined Heat and Power (CHP), saving up to 30% energy lost. Depending on the different penetration level of electric vehicles into grid, the total load on the system will increase as a result of battery charging loads. However, a smart grid may accommodate the electric vehicles and benefits from the energy storage capacity they offer to the network. Some distribution companies have already taken steps towards enabling the utilization of the energy storage technology. Most of the current examples of energy storage projects are on a trial basis.

3.5.5 Active Thermal Rating Monitoring (ATRM)

Use of Active monitor for transmission voltages levels is common in almost all transmission operation centers. However, at distribution level, no specific information regarding the dynamic rating of individual branches is available. In ATRM system, installed sensors monitor and measure the real-time data of different loading level at all branches of distribution network and transmit this information to the utility. The application of dynamic ratings may enhance the economical operation by providing timely mitigation action so that to avoid dangerous system insecurity conditions by tracking the thermal state of equipment. There are several complications in the practical implementation of ATRM, which must be taken into account. Like communication links, SCADA/EMS flexibility and capability, instrument reliability etc. Due to these issues, dynamic ratings are still not widely integrated into power system operations.

3.5.6 Sensing and Control Infrastructure

The core duties of this infrastructure are evaluation of grid stability and congestion, monitoring health of equipment, energy theft prevention, and support of control strategies.

3.5.7 Phasor Measurement Units

PMUs, also called High-speed sensors, are distributed throughout the grid.their network can be used to monitor power quality and in some cases respond automatically to them.

3.5.8 Outage Management and Active Fault Level Monitoring

The security and quality of supply is vital for power grid. It is assessed depending on various objectives; number of interruptions, duration of an interruption. Smart sensors with Geographic Information System (GIS) capability can immediately transmit the location and nature of the incident to the local maintenance team. Hence take shorter time to be reported and corrected; this may improve the performance of a distribution network company. Active Fault Level Monitoring monitors the different locations in the network in real time, to assess the level of connected generation and overall fault level. The system may change the network topology by splitting the busbar and changing the equivalent impedance when fault levels approach maximum permitted limits.

3.5.9 FACTS Devices

SG solutions such as FACTS (Flexible AC Transmission Systems) devices can transform the power grid into a highly efficient and reliable system with improved power quality and quantity. Some of the benefits related with FACTS device are: Steady-state and dynamic reactive power compensation and voltage regulation; Steady-state and dynamic stability enhancement; Increasing power transfer capability of existing assets; Reduced fault current; Reduced transmission losses; Improving power quality. Recent researches on FACT devices are being carried out to develop new devices and materials for high-current, high-voltage switching power electronics, new device configurations/systems and the control of these switching devices The new equipments are to be developed by lowering the cost associated with FACTS equipments so that these devices can be used cost-effectively at distribution voltage levels.

3.5.10 Automation

Power system automation enables rapid diagnosis of and precise solutions to specific grid disruptions or outages. These technologies rely on and contribute to each of the other four key areas advanced control methods used for automation are: distributed intelligent agents (control systems), analytical tools (software algorithms and high-speed computers), and operational applications (SCADA, substation automation, demand response, etc). The Voltage Stability Monitoring & Control (VSMC) software uses a sensitivity-based successive linear programming method to determine reliably the optimal control solution.

3.5.11 Advanced Analytic Applications

Due to information systems, operators and managers have tools to operate effectively and efficiently a grid with an increasing number of variables. Technologies include visualization techniques that reduce large quantities of data into easily understood visual formats, software[31].

4 Standardization And Legislation Process: An Overview

4.1 Existing Programs and Roadmaps [5],[3]

There have been great deals of effort for the development of SG by governments, industry, and research organizations. In order of a comprehensive and quick assessment of recent progress especially in the industrial sector, a summarized table is given in Appendix[21].This covers smart meter, AMI, transmission grid, distribution grid, distributed resource, virtual power plant, home application, microgrid, electric vehicle, and integrated systems. Just at the beginning of the SG transition, there already exist several integrated system projects in the U.S., Europe, and East Asia, a significant amount of investments is devoted to projects in almost all countries, which address the integration of different SG technologies and applications. Most of the technologies are known, but their integration is the new challenge. [21][37][38] [39]

Several standardizations have also come up in different areas, countries, or organizations. A cooperative standardization roadmap crossing different areas, countries, and organizations are desirable in order to drive all the dimensions of the future standards of SG. In the meantime, existing standards may need to be developed and revised to adapt the changes within technical, political, and regulatory aspects. SG interoperability provides organizations the ability to communicate effectively and transfer meaningful data, even though they may be using a variety of different information systems over widely different infrastructures, sometimes across different geographic regions and cultures. IEEE P2030 [109] views the SG as a large, complex “system of systems” and provides guidance to navigate the numerous SG design pathways throughout the electric power system and end-use applications, focuses on a system level approach to the guidance for interoperability components of communications, power systems, and information technology platforms.

Following is the list of several major SG standardization roadmaps and studies:

1. United States: NIST IOP Roadmap [96];
2. European Union: Mandate CEN/CENELEC M/441 [112];
3. Germany: BMWi E-Energy Program [115],
4. China: SGCC Framework ;
5. Japan: METI Smart Grid roadmap [118];
6. Korea: Smart Grid Roadmap 2030 ;
7. IEEE: P2030 [116];
8. IEC SMB: SG 3 Roadmap [123];
9. CIGRE: D2.24 [117];

4.2 Need for Standardization

A standard defines the meaning, representation, and protocols for transportation of data are essential for any complex “system of systems” like SG to interoperate seamlessly and securely. Transition from the existing infrastructure of traditional grid into the smart grid requires an underlying foundation of standards and protocols and establishing these standards is a large and complex but urgent challenge. In industry sectors, many suppliers(automotive manufacturers, information and communication technology) have no experience to work together. Under the SG paradigm, they all needed to communicate and work together e.g energy management systems, customer-owned smart appliances, and electric vehicles will need to communicate within the SG. Lack of standards may also impede the realization of promising applications, such as smart appliances and. cause risk to the huge investments in SG to become prematurely obsolete or, worse, if implemented without adequate security measures. Development of standards for the SG also requires efforts at regional and international levels. As, many of the suppliers of equipment and systems used in the smart grid are global companies that seek to address markets around the world. Unnecessary variations in equipment and systems to meet differing national standards add cost, which eventually gets passed on to consumers. International standards promote supplier competition and expand the range of options available to utilities, resulting ultimately in lower costs for consumers.[40][41]

4.3 Smart Grid Standards

Technical standards for the smart grid are under process by many standards development organizations (SDOs), such as IEEE, IEC, ISO, ITU-T, IETF, etc. Coordination of the standards work by the SDOs is critically important since the standards need to work together to support an overall system,. During 2009, NIST engaged over 1500 stakeholders representing hundreds of organizations in a series of public workshops over a nine-month period to create a high-level architectural model for the smart grid.

In short, being a complex system, Smart Grid will ultimately require hundreds of standards and specifications The NIST Release 1 framework identifies 75 standards or families of standards that are applicable or likely to be applicable to support smart grid development. The standards address a range of functions, such as interconnection of distributed energy sources (IEEE 1547), meter standards (ANSI C12), basic communication protocols (e.g. IPv6), information models (IEC 61850), cyber security (e.g. the NERC CIP standards) and others. These standards are produced by 27 different standards development organizations at the national and international level, such as the International Electrotechnical Commission (IEC), International Organization for Standardization (ISO), The Institute of Electrical and Electronics Engineering(IEEE), SAE International, Internet Engineering Task Force (IETF), National Electric Manufacturers Association (NEMA), North American Energy Standards Board (NAESB), etc. The Institute of Electrical and Electronics Engineering (IEEE) has recently taken the enterprise to identify these standards and write guidelines on how the grid should operate using in power engineering, communications, and information technology . Several standards have almost been finalized in recent years such as:

- Smart metering infrastructure: ANSI C12.19 (for utility industry end device data tables) and ANSI C12.22 (protocol specification for interfacing to data communication networks), ZigBee/HomePlug SEP 2.0 (for home area networking)

- Substation Equipment: ModBus (communication protocol Between substation equipments), IEC 61850 (for communication networks and systems in substations)
- Distribution Automation: DNP3 (distributed network protocol used by a Supervisory Control and Data Acquisition [SCADA] system), IEC 61850
- Distribution management system: IEC 61968 (support the inter-application integration of a utility enterprise that needs to connect older existing or new disparate applications), MultiSpeak (for exchange of data among software applications commonly applied in utilities)

4.4 SG Development around the World

Many countries like U.S., Canada, China, Japan, South Korea, Australia, and European countries have begun or are planning for doing research and development on smart grid applications and technologies. In this regard, an overview about the country wise development of smart grid is presented in this section[13], [17],[37],[42],[43]

4.4.1 SG Development in USA

The main focus of the SG researches in US is primarily on the development of advance communication network of intelligent instrumentation and advanced transmission and distribution to quickly grasp the status of various disturbances and faults, and progressively realize the unified network management of solar energy, wind energy, geothermal energy. Its development priorities are in the distribution and consumption side, focusing on business model innovation and customer service enhancement. A study of Department of Energy (DoE's) in 2002 highlighted hundreds of millions of dollars in economic costs due transmission bottlenecks and related transmission practices in the US power system. In April 2003, DOE held a workshop that resulted in a proposal for a transformed national electricity grid to be constructed by 2030, The Grid 2030 summary vision was Grid 2030 energizes a competitive North American Market place for electricity. It connects everyone to abundant, affordable, clean efficient and reliable electric power anytime, anywhere. It provides the best and most secure electric services available in the world. Electric Power Research Institute (EPRI) has estimated the market for smart grid-related projects to be around $13 billion per year over the next 20 years in US. Several consortia working on smart grid issues in US.such as EPRI's IntelliGrid program and department of energy (DoE's) GridWise Alliance. A recent study by Pacific Northwest National Laboratory (PNNL) provided homeowners with smart grid technologies to monitor and adjust the energy consumption at their homes and household reduced its annual electric bill by 10%. This could save up to $200 billion in capital expenditures on new plant and grid investments [44]

4.4.2 SG Development in Europe

The main focus of SG's research in Europe is to increase the proportion of clean energy and to reduce the use of fossil fuel by the construction of a "smart, dispersion, autonomic and highly integrated" power grid with high power quality assurance. This intelligent network will introduce the offshore wind power in the North Sea and the Atlantic, the solar power in southern Europe and North Africa, and other new and renewable energy into the European power grid to meet the demand for electricity of the future European power grid. One of the project titled "Renewable Energy Super-Grid " launched by the European North Sea countries will join the coastal wind farms in Scotland, Belgium and Denmark, the large-scale photovoltaic power plants in Germany, and fjords hydroelectric power station in Norway together to achieve the network interconnection of North African and the European, eventually balance the supply of electricity across the continent to improve the security, stability and reliability of renewable energy generation effectively[13]

4.4.3 SG Development in China

Electricity consumption in China has been growing at an unprecedented rate due to the rapid growth of industrial sectors .Smart Grid technology in China started late with the goal of large-capacity, long-distance, low loss, high performance. China has also announced the Strengthened SG plan in May 2009. At present in China, the SG is focusing more on the transmission networks rather than the distribution networks and the use of clean energy generation is relatively limited. The country initiated a number of technical research and development projects. During the 11th "five year plan" , major projects and key projects were established in three major areas of Advanced energy technologies, including coal gasification based polygeneration demonstration project, MW-level grid connected photovoltaic power systems, solar thermal power technology and system demonstration project. According to State Grid Corporation of China, smart grid plan in China can be divided into three stages, i.e., planning and testing (2009-10), construction and development (2011-15) and upgrading (2016-20).[45]

4.4.4 SG Development in India

As India keeps one of the weakest electric grids in the world, the opportunities for building smart grids are high. India's grid is in need of major improvements because of variety of system failures, e.g., poorly planned distribution networks, overloading of system components, lack of reactive power support and regulation services, low metering efficiency and bill collection, and power theft. , however, it may make sense in India's constrained power grid where high levels of delinquency have increased system load without revenue returns. India has formed smart grid forum & task force to study and finalize the smart grid road map[19].

4.4.5 SG Development in Japan

The main focus of SG's research in Japan is on the area of large scale new energy power generation utilization, Several researches are conducted for the combination of solar and other new energy power generation with transmission network, gradually forming a "New Generation of Transmission Network" in conformity with the National Conditions of Japan. Japan has launched the "Smart City" pilot project in Yokohama City, Toyota City, Kyoto City and Kitakyushu City. In addition, Japan has newly promoted the "Intelligent Energy Community" demonstration project, and plans to begin construction in 2011. With a "smart energy system", this project plans to reduce carbon emissions and increase use of renewable energy through the coordination of electricity, heat and transport energy use and management in Toyota City, Yokohama City, Kitakyushu City and Kansai Science City.[46] [47].

5 TECHNOLOGY WISE FUTURE CHALLENGES AND RESEARCH ISSUES

SG concept is complex and consists of many interdisciplinary technologies and strategies. It is difficult to view smart grid as separated technologies The vision of SG is to realize and leverage multiple disciplines that have been evolving during the past ten-twenty years[48].Based on the results of the survey, future Challenges and research issues related to the Smart Grid are explored and technology-wise categorized here.

5.1 Smart Meters and Sensors Infrastructure

Vulnerabilities challenges

Vulnerabilities may allow an attacker to penetrate a system, obtain user privacy, gain access to control to the system applications and alter load conditions to destabilize the grid in unpredictable ways[21][49][50]. Since the smart grid will be based on an information network, hacking into utility databases is a huge threat and the deployment of advanced infrastructure in smart grid like smart meters, sensors, and PMUs, opens up many new vulnerabilities challenges although it empowers us to realize more powerful mechanisms to defend against attacks and handle failures. [51][52][53].

Prone to Cyber Attack

Widespread deployment of smart meters opens up a door to the cyber attacks, such as from disgruntled employees, industrial spies, and terrorists, which could result in broad effects and even large-scale disasters. The deployment of tens of millions of smart meters controlled by a few central controllers provide a opportunity to cyber attacker who can compromise these controllers and send the combination of commands that will cause meters to interrupt the supply causing disastrous results. [49],[54]

Privacy Implications

The main concern about privacy issues in Smart Grids is that metering data can leak sensitive and private energy use information stored at the meter that acts as an information rich side channel, and can be repurposed by interested parties to reveal personal information such as individual's habits, behaviors, activities, preferences, and even beliefs.

False-Data Injection Threat

Wide deployment of monitoring and measurement devices (e.g. sensors and PMUs) could also lead to system vulnerabilities. The effective operation of SG depends on the widely deployment of accurate measurement devices for transmitting measurements data to a control center, such as Supervisory Control and Data Acquisition (SCADA) Systems State estimators in the control center estimate the power grid state through analysis of measurement data and power system models. Therefore, it is very important to guarantee the integrity of the data. A typical attack to compromise data integrity is the stealth attack (also called false-data injection attack.

5.2 Information Technologies and Communication Infrastructure

This system in smart grid is used to support information generation, modeling, integration, analysis, and optimization purpose[55]. Some challenges related with information management, including data modeling, information analysis, integration, and optimization is presented as follows:[56]-[57]

Malware

The interconnection of the SG with the public internet will cause a potential spread of malwares into grid software. These are easily found in large numbers across the public internet. Hence can cause disruption in power services or false data being exchanged in the link.

Complexity and Expansion

The advanced infrastructure used in SG will increase system complexity and expansion. Increased interconnection and integration can easily lead to an increase in vulnerability to cyber attacks and system failures into the grid. Failure to address these problems will hinder the modernization of the existing power system. SG may consist of tens of millions of nodes that make it difficult to anticipate how attacks may be manifested by an unpredictable and intelligent adversary, and what failures could happen due to many dependent or independent unpredictable factors. Thus, a complete solution needs to consider both autonomy and interconnectivity.

Performance

Smart Grid communication is a very complex due to heterogeneous systems, large-scale deployments, interdisciplinary areas (such as control, communication, power, etc.), and dynamic and non-deterministic systems. This may affect the performance of system.

Interoperability

Communication of a large number of distributed energy distribution networks, power sources, and energy consumers under many different administrative domains is a big challenge for future research. Different vendors, users, and utility companies may adopt different communication technologies so that multiple heterogeneous communication technologies and standards could coexist in different parts of the SG therefore interoperability becomes a large challenge to make a SG work.[31],[58]

Interdisciplinary

The research areas are interdisciplinary in nature in Smart Grids include many different organizations and societies and consist of system of systems

Scalability

Since a SG involves millions of users, scalability is also an issue for SG systems.

Effective information storage

A large amount of information data will be sampled from smart meters, sensors, and PMUs in SG and sent to the control system. One important problem is what information should be stored in the control system so that meaningful system or user history can be constructed from this data for analyzing system operations, and user history is important for analyzing user behaviors and bills. Considering that the amount of information received by the control system is huge, solving this

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problem is challenging.

Dynamic communication network

The communication network in smart grid may be dynamic due to unpredictable nature of topology changes . For example, both the operation of connecting / disconnecting the electric vehicle (EV) to/from the grid and the motion of vehicle may result in the change of communication network topology. The dynamics of an SG communication network is a big issue and have not been fully explored.

5.3 Distribution Generation

The share of decentralized and intermittent renewable generation feeding into distribution networks is steadily increasing day by day. However, this offers new challenges to normal grid operation and for network management, which needs to guarantee the balance of generation and demand at every point in time because of its intermittent nature of supply like wind and photovoltaic generation and the reduced predictability of feedin energies. Furthermore, the distributed supply feedin can reverse power flows, cause voltage rise or increase fault levels[27],[59],[60]. By the application of DG in distribution networks, demand becomes more flexible but may also cause reliability problems. The variability in the supply of most renewable is often defined as 'intermittency' that increases unreliability. These factors give rise to the operating challenges for a smart grid as follow:

Grid Strengthening

Ensuring that grid is strength, enough to provide a sufficient transmission capacity for newly interconnect energy resources, especially renewable resources.

Synchronization

One of the prerequisite prior to adding renewable energy source to the grid is synchronization that requires a well define and accurate mechanisms of control devices.

Harmonic Distortion

Harmonic distortion must be restricted to within an acceptable limit before connecting the renewable energy sources to the grid. Harmonics are mainly caused by the interaction of distorting customer loads, power electronics devices and nonlinear devices used with control circuits. Main drawbacks caused by harmonic distortion include heating of induction motor, transformer and capacitors.

Voltage Fluctuation

Voltage fluctuations occur due to intermittent nature of the renewable energy sources energy, pose a major drawback while they are integrated into the grid network.

Frequency Fluctuation

Another drawback of renewable energy sources is the frequency fluctuation. Such fluctuations need to be stabilized before connecting these energy sources to the grid.

Reactive Power Compensation

Line, transformer, inductive loads generally consumes the reactive power in a power system. This affects the power quality of the system. To compensate this reactive consumption additional reactive power must be provided locally or from generating station tp overcome losses and improving the power quality of the supply.

Energy Storage

For the effective usage of DG, there must be needed some storage arrangement of the energy produced from renewable energy sources. This needs to be considered while designing an efficient load management scheme for smart grid.

Decentralized Architectures

One of the big challenges for enabling smaller scale electricity supply systems to operate harmoniously with the total system is to transform the present grid into decentralized architectures.

5.4 Integration of Grid-to-Vehicle and Vehicle-to-Grid Technology

A slowly but steady rising share of electric vehicles (EV) within the public and private transportation sector leads to two concepts, namely Grid-to- Vehicle (G2V) and Vehicle-to-Grid (V2G). EVs may be considered as active loads, increasing the demand on the network during charging, and as generators when operating in regeneration mode. Therefore, the impact of EVs when operating in both modes, charging and regeneration, need to be analyzed. The impact is expected to be significant challenge due to the high-energy capacity and mass deployment of EVs in the future.

In G2V ,the wide use and deployment of EVs add an unknown load to the grid as a result of being plugged for charging[63].Vehicle charging will lead to a significant new load on the existing distribution grids, with the fact that many of these circuits not having any spare capacity results in the voltage degradation lowering the power quality.[64] Basically, the power quality is affected by the non-linear current consumption for uncoordinated charging of the large number of EV[65], [66].Penetration levels of EVs, charging regime and charging periods have major impacts on system losses and can result in expensive power losses, unacceptable voltage violations, extensive line loadings and THD voltage levels above the recommended limits of the IEEE-519std.Following are the EVs related challenges need to be overcome:

1. Increase in the thermal loading of network infrastructure and loss of life of components.
2. EVs loading adversely affect system voltage regulation. (Voltage excursions, regulator operations, cap operations, etc.)
3. Potential for disproportionate penetration on particular phase and results on system unbalance
4. Distribution system losses.

In V2G, EVs could be designed to operate as part of a 'SG' and provide a new way to store and supply electric power for ancillary services such as supply/demand matching and voltage/frequency control. V2G-enabled EVs can communicate with the grid to deliver electricity into the grid, when they are parked and connected to the grid. In V2G, the challenge is the availability of EVs, since an EV can only deliver power to the grid when it is parked and connected to grid. As a result, this increases the uncertainty of the power supplied by EVs.[36],[67],[68].

5.5 Smart Demand Side Management/Demand Response

Now-a-days, demand-side management (DSM) is an active research topic. Intelligent control strategies for (dis)charging EVs is being one of its parts along with energy efficiency and demand profile. As in G2V, high penetration levels of uncoordinated electric vehicle (EV) charging will significantly reduce power system performance, efficiency, and even cause overloading. Some typical issues related with DSM/DR are following: [26],[44],[69], [70].

Maturity and Acceptance of Technology

One main challenge of consumer-side smart grid implementation is technology adoption. It is obvious that technology availability does not imply consumer adoption. Home automation will not become reality if consumers do not buy smart appliances. If consumers are not interested in participating in the new system of energy, smart grid benefits cannot be fully realized. Consumer acceptance is the priority while developing consumer-side applications or products, including home automation appliances and demand response programs.

Interoperability at Consumer End

Another main challenge is interoperability at the consumer end. The consumer-side applications and products are mass-market oriented issues. Much like home electrical outlets, these products must be 100% compatible. All the standards need to be open, flexible, secure, and supported by majority stakeholders and manufacturers without worldwide.

Customer's Dilemma

Insufficient knowledge of consumers about the issues of power generation can put an obstacle in the way of having some programs to make consumers participate in the energy management of the Smart Grid[17].

Benefit Recipient of SG Efforts

The implementation and benefits of a SG are unknown and are still being evaluated at this time. Incentive is the key for consumers' acceptance and participation .From the consumer-side, the costs and incentives of smart applications and products for consumers should be balanced, so that a smooth adoption can be realized. Smart appliances must not cause significant disruption or lifestyle changes throughout a person's normal daily life.

Distributed Decision Making Systems

Complexity of the Decision Making is a big challenge for SG More complex decision problems have to solve within shorter time to avoid any failures under DSM as SG may have tens of millions of nodes. A possible solution is trying to use more distributed decision-making systems while considering how to balance the response time and the effectiveness of the local decision. [39],[71],[72].

6 CONCLUSION

Smart grid as a "next generation power grid trend" is on the evolutionary path. Although, it may have multiple meanings and not well defined yet. A well defined roadmap for the construction of smart grid is getting more and more intention these days. The purpose of this article is to introduce a SG, to explain why it is extremely desired, and how it can be accomplished. The paper reviews all fundamentals of smart grid for better understanding of issues and challenges associated with these new future technological revolutions due to their unique physical and economic characteristics. In this respect, this paper is an attempt to shed some light for better understanding of the concept and characteristics of SG w.r.t different countries vision. It also summarizes different issues and challenges of various emerging technologies to help the reader to critically think beyond the scope of this paper.

7 APPENDIX

A Summary of Major Worldwide Projects [16]

No.	Project Name	Organization	'Country	Period	Brief Description
1	**Acea Distribuzion**	Acea Distribuzione	IT	From 2004	The implementation of the integrated advanced metering management system began in 2004 with the objective of improving energy efficiency in Italy's capital. The system includes high accuracy bi-directional meters and smart grid applications such as network operation control, and the ability to monitor low and medium voltage line status automatically.
2	**American Transmission Company's Phasor**	American Transmission Company	US	2010-2012	It aims at building a fiber optics communications network for high-speed communications to maximize the full capability of phasor measurement networks across American Transmission Company's transmission system.
3	**Austin Energy Smart Grid**	Austin Energy	US	From 2003	Smart Grid 1.0 deployment started in 2003. It is the first fully operational SG deployment in the U.S. Smart Grid 2.0 deployment started in 2008. It offers improved customer services, including 1) by phone or online real-time meter reads, 2) web-based management of smart consumer appliances, and 3) remote service turnon and shut-off.
4	**CERTS Microgrid Test Bed**	American Electric Power	US	From 2006	It aims at enhancing the ease of integrating small energy sources into a microgrid.
5	**DLC+VIT4IP**	Kema Nederland BV	DE, AT, UK, NL, IT, BE, IL	2010-2013	It aims at developing, verifying, and testing a highspeed narrow-band powerline communications infrastructure using the Internet Protocol (IP) which is capable of supporting existing and extending new and multiple communication applications
6	**EU-DEEP**	GDF Suez	FR, GR, UK, DE, BE, ES, SE, PL, LV,	2004-2009	It brings together eight European energy utilities and aims at removing most of the technical and nontechnical barriers that prevent a massive deployment of distributed energy resources in Europe.
7	**Fenix**	Iberdrola Distribuci´on	ES, UK, SI, AT, DE, NL, FR, RO	2005-2009	It aims at boosting distributed energy resources by maximizing their contribution to the electric power system, through ggregation into large scale virtual power plants and decentralized management.
8	**Grid4EU**	ERDF	DE, SE, ES, IT, CZ, FR	2011-2015	It is led by a group of European distribution system operators and aims at testing in real size some innovative system concepts and technologies in order to highlight and help to remove some of the barriers to the SG deployment (technical, economic, societal, environmental or regulatory).
9	**INOVGRID**	EDP Distribucao SA	PT	2007-2011	It aims at replacing the current low voltage meters with electronic devices called Energy Boxes, using Automated Meter Management standards.
10	**IntelliGrid**	Electric Power Research Institute	US	From 2001	It aims at creating a new electric power delivery infrastructure that integrates advances in communications,computing, and electronics to meet the energy needs of the future. At present, the IntelliGrid portfolio is composed of five main projects: IntelliGrid architecture, fast simulation and modeling, communications
11	**Large-scale demonstration of**	ChoosEV A/S	DK	2011- 2013	Its main investigation is whether it is possible to move the charging of electric vehicles to a more environmental friendly time and whether the electric vehicle
12	**Model City Manheim**	MW Energie	DE	2008-2012	It concentrates on an urban conurbation in which distributed renewable energy resources are used to a large extent. Within the framework of the E-Energy project, a representative large-scale trial is being conducted both in Manheim and in Dresden to demonstrate that the project can be applied and translated to other regions.
13	**More Microgrids**	ICCS/National Technical University of Athens	ES, GR, PT, NL, IT, DK, MK, DE	2006-2009	It aims at: 1) implementing sophisticated control techniques for distributed generators; 2) integrating microgrids into operation and development of the power system; 3) conducting field trials to test control strategies on actual microgrids; and 4) quantifying microgrids effects on power system operation and planning.
14	**Pacific Gas and Electric Company's SmartMeter Program**	Pacific Gas and Electric Company	US	From 2006	It is part of a statewide effort driven by the California Public Utilities Commission to upgrade California's energy infrastructure with automated metering technology. This technology will enable new programs that help California energy customers use less energy and save money.

15	**Pacific Northwest Smart Grid Demonstration Project**	Bonneville Power Administration	US	2010-2014	It aims at 1) validating new smart grid technologies and business models; 2) providing two-way communication between distributed generation, storage, and demand assets and the existing grid infrastructure; 3) quantifying smart grid costs and benefits, and 4) advancing standards for interoperability and cyber security approaches.
16	**SmartGridCity, Boulder, Colo**	Xcel Energy	US	2008-2010	SmartGridCity is a technology pilot that explores smart-grid tools in a real-world setting. The goal of this pilot is to help determine: 1)Which energy management and conservation tools customers want and prefer; 2) Which technologies are the most effective at improving power delivery; 3) How best to incorporate SG technology into the business operations to improve efficiency, reduce carbon emissions and modernize the energy delivery system; 4) How to roll out the most promising SG components on a wider scale. Xcel Energy has installed approximately 23,000 smart meters in Boulder as part of a new era in electricity grid management.
17	**Smart Grid Demonstration Project in Sino-Singapore Tianjin Ecocity**	Tianjin Electric Power Company	CN	2010-2011	The project aims at building a smart power supply network with 220kV and 110kV transmission grid, 10-35kV distribution lines, and 380V/220V low voltagedistribution grid.

***Country Codes: AT-Austria, BE-Belgium, CA-Canada, CN-China, CY-Cyprus, CZ-Czech Republic, DE-Germany, DK-Denmark, FI-Finland, FRFrance, GR-Greece, ES-Spain, HU-Hungary, IL-Israel, IT-Italy, LV-Latvia, MK-Macedonia, NL-Netherlands, RO-Romania, PL-Poland, PT-Portugal, SE-Sweden, SI-Slovenia, TR-Turkey, UK-United Kingdom, US-United States**

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