Features of Smart Grid Technologies: An Overview

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ABSTRACT

This paper presents an overview of smart grid (SG) technology features such as two-way communication, advanced metering infrastructure (AMI) system, integration of renewable energy, advanced storage techniques, real time operation and control, data management and processing, physical and cyber security, and self-healing, etc. The SG technology allows two-way communications for better reliability, control, efficiency and economics of the power system. With these new SG technologies, consumers have many energy choices, such as use of renewable energy, usage management, flexible rates, electric vehicles (EVs), etc. The requirement of these technologies is the real time operation, and the SG accommodates this real time operation and control. SG technology allows distributed generation through demand response and energy efficiency technologies to shed the load demand. However, it's very difficult to adopt these changes to the conventional grids. Utility companies, governments, independent system operators (ISOs) and energy regulatory commissions need to agree on the scope and time frame of these changes.

Keywords: Distributed generation, smart grid, cyber security, self-healing, renewable energy, electric vehicles.

1. INTRODUCTION

In developing economies with large dispersed population, reliable supply of energy is a good indicator of quality of life. The demand for electricity, in view of growing world population, is expected to rise by about 70% by 2040. This issue can be handled by using the promising technologies that use renewable energy resources (RERs) that have been tested and used worldwide. These technologies can be easily installed locally with low investments, hence the cost related to the transmission lines can be saved. The operational and control methods of such energy systems are different from the conventional energy systems. In this context, the smart grids are emerging in electrical power systems to achieve both economic and environmental objectives while contributing to the reliability of power supply to the customers. These SGs are made up of millions of pieces and parts, such as control, computers, power lines and many real time communication equipment. The smart grid (SG) technology is undergoing improvements and in many cases its operation is under research [1].

The SG technologies offer ways to meet various challenges such as increasing demand, integration of increasing numbers of renewable energy resources (RERs) and EVs, ageing infrastructure, etc.; and to develop a cleaner energy supply that is more affordable, sustainable and energy efficient [2]. The SG technology includes more communication technologies such as smart meters, digital relays, phasor measurement units (PMUs), supervisory control and data acquisition (SCADA), geographical information system (GIS) and demand-side management, etc. when compared to the conventional/existing electrical grid. The SG concept allows remote control and automation through two-way communication. It involves smart meters that allow two-way communication and all the network devices are provided with sensors to gather data [3]. Automation technology allows the utility company and operators to control elements individually. SG is made up of all available advanced technologies such as plug-in electric vehicles, distributed generation, RERs, smart meters, distribution automation and optimized control, etc [4].

The conventional/existing electrical power grid is the largest interconnected machine on the earth [5]. It is complex and an important part of human life. The demand is increasing day-by-day as is its complexity as a network. The increasing demand is due to an increase in population, globalization, latest infrastructural development is higher than the energy infrastructure added. Due to higher demand, sometimes energy companies have to use less efficient or polluting sources of power generation to meet the load demand. As the last option, they have to use emergency shutdown for some areas in order to reduce the voltage of the system, and this is called a *brownout*. The conventional overburdened grid fails very easily and it doesn't have self-healing capability. Therefore, there is a requirement for the development of SG [6].

SG has many advantages such as economical benefits, security benefits, renewable energy integration and optimization, better operation and faster control,

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Manuscript received on April 20, 2018 ; revised on July 7, 2018 ; accepted on July 24, 2019.

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etc. Moreover, the SG also provides more control to consumers to decide to use power when the energy prices are at its lowest value. As the energy demand changes every second, and it is usually lowest during the middle of the night and highest from 9 p.m., but it varies with weather conditions. Consumers can get the information through mobile devices or computers about the energy rate at any moment. Research is also going on to set up an alarm system that will alert consumers about the lowest price and highest price. On the other hand, it will also benefit the energy company as it can shift the peak demand curve and the distribution of demand will be more even; finally, infrastructure for the generation capacity will also be economical. With the available real time pricing tools, the consumers can decide their best time to use energy. The SG has a number of advantages compared to conventional grid and some of them are two-way communication, self-healing and self restoration capabilities, better renewable energy penetration and optimization, improved grid reliability and security, reduced energy cost, improved energy efficiency and better power quality, reduced losses and better environmental conditions, higher customer involvement and satisfaction, etc [7].

At the same time, the SG standards have also been recognized as a national priority since the Energy Independence and Security Act that is proposed in 2007. The administration has further accelerated the process through the American Resource and Recovery Act. However, the standards development can take a long time. Within each industry, there are groups of experts who come together to discuss, develop, and update the standards. These groups are called standards development organizations (SDOs). For the SG, there are over 25 SDOs involved in updating current standards and the developing new standards. These include organizations such as IEC, IEEE, ITU, NAESB, SAE, etc [8].

The features, benefits and costs of SG technologies are described in [9, 10]. SG scientific assessment is presented in [11] and it is directly related to the layout of construction, the direction of investment, technology route and the implementation effect and other key issues. Reference [12] focuses on the SG technology, which lets us dream about the solutions to maximum power problems. A detailed review of SG technologies for renewables, including their costs, technical status, applicability, communication technologies and market maturity for various uses is presented in [13, 14]. An overview of SG concepts and state-of-the art technologies that highlight SG experiences in Asia, North America, South America, Africa, Australasia and Europe is presented in [5, 15, 16]. Reference [17] presents the emerging technologies of SG infrastructure, and highlights the behavioral science to enhance their impact on energy savings.

References [18, 19] address the critical issues for SG technologies in terms of information and communication technology issues, opportunities and fundamental standards of SG. Reference [20] examines a set of concepts, technologies, and operating practices of SG. The key characteristics of traditional grid and SG, and the reasoning behind the transition to the SG and the key concerns the transition raises are described in [21]. SG requires more sophisticated models to analyze options, refine market performance, and design new market components. The basic design and applications of SG are presented in [22, 23]. The processes and features of SG, Micro Grid and Super Grid in South Korea are presented in [24]. The present paper describes an overview and features of SG.

The remainder of this paper is organized as follows. Section 2 describes the comparison of various features of smart grid in comparison with the conventional/existing electrical grid. The detailed architecture of SG is presented in Section 3. Various features of SG are described in Section 4. Section 5 presents the development of SG around the world. Finally, Section 6 presents the conclusions of this paper.

2. COMPARISON OF FEATURES OF SMART GRID WITH CONVENTIONAL GRID

Smart grids (SGs) include the conventional and the renewable energy resources (RERs), and they will gain significance for their sustained growth and development without impacting the environment. An overview of SG with its general features, functionalities and characteristics are presented in [25]. It presents the SG fundamental and related technologies and identified the research activities, challenges and issues. The conventional technologies such as fossil fuel based power generation cause unwanted emissions and threaten the future of the world. The conventional grid is not capable enough to handle the increased penetration of RERs. The SG technologies are promising as they use RERs and they have been tested and used throughout the world. Such technologies can be easily installed locally with low investments, and hence saving the cost related to transmission lines. The conventional grid is not capable of meeting the increasing demand. Therefore, there is a requirement for an advanced grid that can accommodate not only an increase in demand but also provide better control and optimization [26]. The comparison between the conventional/existing electrical grid with the SG is presented in Table 1 [27].

3. SMART GRID ARCHITECTURE

The efficient SG environment allows lower energy cost for consumers and is environmentally friendly. SG architecture is effective for any enterprise including production facilities, factories, retail stores, warehouses and hospitals. It should be combined with energy management software, so that various businesses can manage their energy consuming equipment [28].

Table 1: *Comparison of features between the conventional grid and the smart grid.*

Features	Conventional/Existing Grid	Smart Grid (SG)
Two-way communication	Not possible in conventional grid	Involves efficient two-way communication through the advances in real time devices
Complexity	Less complex compared to SG	More complex as it continuously generates data though a real time device that needs to manage same time
Self-healing capability	Doesn't have this capability as it corrects the system after occurrence of fault	Has self-healing capability as it automatically identifies the faults and takes the corrective measures immediately
Self-restoration capability	Doesn't have this capability	Can self-restore through better control techniques
Plug-in Hybrid Electric Vehicles (PHEV)	Doesn't accommodate PHEVs	Can accommodate PHEVs
Consumer involvement	Doesn't allow consumer involvement	Allows consumer involvement and helps the utility to better manage energy demand every minute
Real time/dynamic pricing	Doesn't allow real time pricing (RTP)	Allows RTP through real time devices and has better management of energy demand
Cyber attacks and security	Less prone to cyber-attacks	High risks of cyber-attacks and cyber security needs to be tightened
Wide area control and measurement	Doesn't have these capabilities	Has this capability through real time devices such as PMUs and GIS
Telecommunication devices	Very few telecom devices incorporated	It is dependent on too many telecommunication devices
Storage	It has installed conventional storage	New generation of storage technologies are incorporated and research is going on for better storage technology
Penetration of renewable energy resources (RERs)	RERs are incorporated but they don't operate efficiently compared to SG	Efficient operation and optimization of RERs
Distributed generation (DG)	Allows DG but they don't operate efficiently compared to SG	Allows efficient operation of DGs
Visualization and monitoring capabilities	Has conventional visualization and monitoring devices that gives alert to the operator	Has advanced visualization and monitoring devices that will trigger control itself in case of abnormal situation
Advanced metering infrastructure (AMI) system	Doesn't have AMI system	Has AMI system
Geographical information system (GIS)	Doesn't have GIS facilities	Incorporates GIS for better operation and control
Advanced control	Doesn't have advanced control	Has latest automation involved through distributed intelligence, analytical tools and operational applications
Advanced sensors	Doesn't have advanced sensors	Gives real time line information through advanced sensors and helps to maintain better power flow
Power quality	Has poor power quality as main emphasize is on power outages	Has better power quality due to advanced automation and control
Resiliency	It's not resilient to natural disasters and other fault conditions	Has better resiliency compared to conventional grid

A global effort has been made towards an energy efficient network that reduces energy dependence and global warming. As energy prices are usually high during peak hours and low during off peak hours, the businesses with an efficient energy management system can reduce the energy cost drastically. Architecture puts a technical framework around the key relationships such as regulators, government agencies, standards and user group communities, product vendors, industry projects and R&D, utilities and energy companies, and the energy consumers [28]. The smart metering and communication methods used in SG are being extensively studied owing to widespread applications of SG [29].

Efficient communication architecture must consider power outage as a possible challenge and to resolve this issue, remedies should be handily and easily available such as conventional batteries, solar recharging and other storage options. The SG architecture should also focus on cyber security, interoperability and standards to be adaptable to new technology and new environments. Data should be available centrally as well as locally for better analysis. Once data has been received through the sensors, it is communicated to the control devices and operators. This data is then modeled, scrutinized and analyzed, and this outcome should be applied to business optimization. Hence, the SG data obtained will be mixed with the existing applications [30]. The SG architecture should include the following basic functionalities:

- Ability to identify grid problems and resolve them immediately through automatic control action.
- Efficient consumer participation in energy usage and management.
- Better energy forecasting and control through latest optimization tools such as evolutionary programming and adaptive dynamic programming.
- Replace conventional generation through distributed generation (DG) and storage, whenever and wherever is possible.
- Optimum use of transmission system.
- Efficient data handling capabilities.

SG offers challenges to all the sectors, i.e., generation, transmission and distribution. Even though some of the companies are already leading this field successfully, still it requires many changes. There is a need for global collaborative effort to educate all stakeholders about the benefits of SG compared to the conventional/existing electrical grid for successful adaption and operation. International cooperation can make the global SG concept successful as it is an evolutionary process. There is a need for constant communication among regulators, technologists, researchers, utility operators and business leaders globally to share knowledge and experience [31]. According to the Department of Energy (DOE)/Electric Power Research Institute (EPRI) framework, the cost benefit analysis of SG should have the following requirements [32]:

- It should be adaptable to all SG demonstrations.
- It should provide consistent and fair comparison of alternative SG technologies and systems.
- Adaptable to new technology and environment.
- Identify all pros and cons.
- Minimize redundancy in benefit attribution.
- Benefits should be distributed by level, distribution and timing.

4. FEATURES OF SMART GRID

Various features make it possible to differentiate the SG from the conventional/existing electrical grid in different manners. The features of SG that make the grid smart are presented next.

4.1 Integration of Renewable Energy Resources (RERs) into the Grid

A concern about climate change and carbon emissions has injected pressure on the use of RERs as a primary source for generation. Renewable energy is generated through natural resources other than fossil fuels, i.e., wind, solar, hydro, geothermal, tidal wave energy, bio-mass, etc. They are all environmentally friendly, sustainable and economic sources of energies. Along with these advantages, they also have some disadvantages such as stochastic behavior of these resources. The standards must be created and followed for integration of RERs into the SG. Several researchers have diverted their efforts toward RERs and SG combination and control of the same. A significant challenge associated with SGs is the integration of renewable power generation. The main challenge is to develop a sustainable solution space which can handle RERs, new pricing schemes, communication methodologies, optimal controls, real time monitoring and uncertainty issues. The national needs for efficient and flexible power grids encourage the development of advanced communication, computation and optimization technologies for RERs integration to promote sustainability [33].

In SG networks, sustainability requires the use of RERs [34], communication technologies and the controls to improve environmental security as well as the ability to minimize the cost of the system's capacity and planning. For the modern grid, several computational technologies are required to design and study the long-term and short-term energy independence based on RERs [34, 35]. To achieve this in a timely manner, research activities are needed to provide adequate modeling and optimization techniques that account for the variability and randomness in the future grid. The current models are inadequate for handling the RERs based networks because of the randomness and stochastic nature of the system. The research is developing in innovative technologies considering the stochasticity and adaptive nature. Optimal allocation and control decisions of different types of renewable energy penetration into the grid minimizes the losses and operating costs, thus increasing the efficiency and sustainability of SGs.

Modeling, optimization, and control issues are crucial for developing the SGs. Hence, with the help of probability density functions (PDFs), the RERs can be modeled, and the optimization and control can be applied through the latest techniques such as stochastic programming, mixed integer programming, heuristic method, evolutionary programming or adaptive dynamic programming [36–38]. The increasing use of RERs/DGs will be an important feature of future distribution systems. Generally, the distribution system operator controls the distribution system remotely. Communication infrastructure to exchange information between the substations and a central distribution management system (DMS) therefore should be in place [37].

4.2 Two Way Communication

Communication infrastructure needs to be in place between the generating facilities and the system operator, electricity market and the transmission system [38]. Smart devices like smart meters, different monitors, sensors, and many other electronic devices collect information of various power system parameters and transmit it to controlling and monitoring equipment centrally or distributed. These smart de-

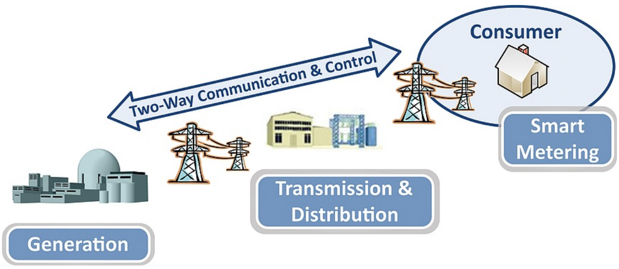

Fig.1: *Two Way Communication in Smart Grid [41].*

vices transmit the information over a two-way communication path. The communication medium may be power line carrier (PLC) communications, radio frequency communications, internet through Wi-Fi networks, cellular communication, satellite, fiber-optic, etc or a hybrid network. The intelligent software applications process the stacks of the data collected from all the devices either centrally or locally. Some of these applications are like a backbone in the SG. Some others assist in billing, service and other customer related activities [39]. A review of integral components of emerging grid and communication infrastructures enabling the SG applications is described in [40]. The schematic diagram of two-way communication used in the SG is depicted in Fig. 1 [41].

Smart devices perform measurement and monitoring activities. SG is adaptable to smart devices as well as advanced software. The real time information received through the software and smart devices is helpful for the system operator to predict, diagnose and mitigate the issues that may damage the system and result in blackout. Moreover, with this new technology, the end users will have more control over their energy consumption and cost.

A robust communication network is very important for reliable operation of a power grid. Different types of communication media available for the SG are power line carrier (PLC), pilot wire, optical fibres, satelite, distribution line carrier (DLC), UHF/VHF radio, coaxial cables and radio relay link (micro wave), etc. Among them, the PLC communication systems are widely used in the SG. The description of PLC communication system is presented next.

4.2.1 Power Line Carrier (PLC) Communication System

The PLC communications utilize the existing electrical infrastructure, which will provide the natural upgrade from simple electricity conductors to hybrid and bi-directional electricity and data communication solutions. PLC communication systems operate by impressing a modulated carrier signal on the wiring system. PLC communication technology is required to cope with the increased size of power grid, to avoid dependence on busy telephone lines and also need for economic and reliable means of interconnection between various generating stations, substations and control rooms. Different types of PLC communications use different frequency bands, depending on the signal transmission characteristics of the power wiring used. Power line technologies can be grouped into narrowband PLC (NB-PLC), which operates between 3 kHz to 500 kHz, and broadband PLC (BB-PLC), operates at frequencies above 1.8 MHz [42]. The NB-PLC has a low band data collection; however, the distance that it can be transmitted is up to several kilometres. NB-PLC is available at a low cost with high reliability.

PLC employs a high frequency signal injected into the transmission circuit. PLC communication (PLCC) is used in all power utilities as a primary communication service to transmit speech, telemetry, data transferring and protection tripping commands. It also used for the line protection. This is economical and reliable for inter grid message transfer as well as low bit rate RTU signals. Main applications of PLCC include multi-purpose transmission (operational telephone and low speed data in SCADA), back-up systems and protection signalling. PLCC allows the integration of renewable energy to sell power to the electric grid. Current challenges for PLC communication include the collection of data from RESs to predict future power generation such as wind and solar because of their uncertain and variable nature. Another challenge is the data collection faces delay in receiving the required information [43].

4.3 Advanced Metering Infrastructure (AMI) System

Smart metering systems are considered as the next-generation power measurement systems, that are revolutionary and evolutionary versions of existing power grids [44]. AMI is an integrated system of smart meters, data management systems and communications networks which enables two-way communication between the utilities and the customers. Hence, by using the AMI system, the issuance or communication of commands or the price signal from utility to meter or load controlling devices are also possible. The customer systems include home area networks, in-home displays, energy management systems, and other customer-side-of-the-meter equipment that enable the SG functions in residential, industrial, and commercial facilities. AMI system is a platform that supports measurement, collection and analysis of energy usage and communicates the same with the energy metering device. Various benefits associated with AMI deployment are broadly classified as the system operation benefits, financial benefits and customer service benefits [45]. The vital element of AMI system is smart meters, and they support

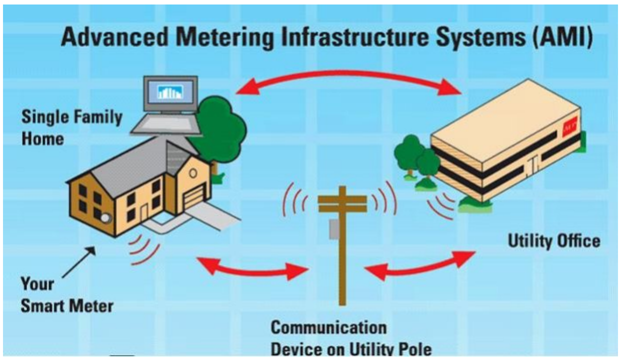

Fig.2: *Advanced Metering Infrastructure System [47].*

various functions such as measuring electricity consumption of customers on 5, 15, 30 or 60 minute intervals, monitoring the on/off status of electricity and measuring the voltage levels. The smart meters communicate these data to the utility companies for processing, analysis and billing [46]. Various functionalities of smart meters include the quantitative measurement, communication, control and calibration, power management, synchronization and display. Fig. 2 depicts the schematic diagram of AMI system [47].

The AMI system is a major contributor to the outage management, voltage monitoring, and the service restoration. By using the AMI system, one can get improved customer service and reduced operational costs. AMI system enables the utility companies to isolate outages faster and dispatch the repair crews to a more precise location, which in turn reduces the outage duration [46]. AMI system data integration with other information and management systems, including the geographic information and outage management systems, enables the utilities to create detailed outage maps; this helps the public to know about the service restoration progress.

4.4 Advanced Energy Storage Technologies

Efficient and innovative storage technologies are required for the SG, especially when the RERs are integrated to the system. Most of the existing storage resources are hydro and pumped storage. However, the growth potential for these resources is much smaller than the need for storage necessary to counter growing net demand variability presented by the RERs such as wind and solar resources. Various storage technologies are emerging to fill this gap. Battery storage is undergoing improvements in technology as well as economies of scale. Storage resources tend to make the net demand profile flatter and, they are expected to improve reliability. In addition, most of the battery storage devices can respond in sub-second time scales [48].

There are several research projects going on for different storage technologies such as flywheels, supercapacitors, pumped hydro storage, storage batteries etc. Storage integration also helps to improve the system reliability and removes the requirement to use electric power as soon as it is created on the power grid. This added flexibility allows the creation, delivery and use of electrical energy to be optimized, enabling better efficiency across the grid, emissions reduction, reduced maintenance and capital costs, more seamless integration of RERs and more effective implementation of advanced SG operating regimes. Dynamic storage for the SG is also undergoing research [49].

The integrated storage and energy sources systems are generally not allowed to draw energy from the grid, hence this policy cannot be applied unless the energy stored in the reservoirs is produced by the local energy sources themselves. This difference in the management strategy is defined as generation strategy; since it is not an increase of load when the price is low (as a consequence of a general decrease of power demand), but a shift in power production. Although the intermittent nature of RERs is considered a problem, the regulatory rules slightly penalize bad forecasts and slightly incentivize good practices [50].

Energy storage can be useful in many applications for power system operations, such as voltage support, transmission and distribution upgrade deferral, improved power quality, etc. Further, depending on their characteristics such as power rating and energy storage capacity, different storage technologies can be more effective in certain applications over others. For example, flywheels can respond quickly and reach their rated power output in a few seconds, but they cannot store large amounts of energy. Hence, they are more suited for applications where speed of response and power levels are favoured, such as frequency regulation. In order to fully assess the operational value of energy storage service across technologies and market operations, an operational value index of energy storage in electricity market operations becomes necessary [48].

4.5 Data Management and Processing

Data management and processing mainly involves four stages, i.e., creation, collection, management and utilization of data. The SG information processing has the following stages:

- Creation of data: Real time devices and sensors are used to capture the information.
- Collection of data: Equipment is used to transmit the information to business applications (through intelligent gateways/networks using the Internet).
- Management of data: Different software and analysis tools are used to monitor devices and collect data.
- Utilization of data: Analysis, scrutinization and software applications that adds value to the information.

Nowadays, many electric utilities are in the process of replacing their existing electro-mechanical meters or non-interval digital meters with interval, digital meters to support dynamic pricing and demand response and to enable energy consumption management by customers. The amount of data is growing dramatically, and data management is no longer an option, but rather an important necessity. When we receive the bulk data from the meters, the following steps need to be followed:

- Recognize smart data classes and characteristics.
- Some data may support multiple outcomes.
- Consider distributed data and analytical architecture.
- Avoid stranded investments or capability impediment.
- Design data architecture to match data classes.
- Use of new tools involving complex event processors to handle new classes of data.
- Develop business process transformation plans.

4.6 Real Time Operation and Control

SG involves many smart devices at all levels of the energy supply chain such as smart meters, PMUs, GIS, advanced visualization tools, SCADA, energy management system (EMS), demand management system (DMS), etc. Researchers are also verifying real time operation and control schemes for SG. The real time operation and control scheme provides the SG a self-healing capacity [51]. SCADA systems become more integrated and connected with existing enterprise resource planning systems and other non-SCADA or external applications but require new, tailored architectural approaches to guarantee continuous operation of critical resources [52].

SCADA is the combination of telemetry and data acquisition. SCADA encompasses the information collection via a RTU, transferring it back to the central site, carrying out any necessary analysis and control and then displaying that information on the operator screens. The required control actions are then conveyed back to the process. A communications protocol is a standard rule for data representation and data transfer over a communication channel. Usually, IEC60870, DNP3 and IEC61850 protocols are used for SCADA [53]. DNP3 and IEC60870 are specifically developed for SCADA; both can be used in applications where there is a need to communicate outside the substations, such as connecting substation devices by controlling a circuit breaker through a remote control in a network control centre [54]. IEC61850 is a global standard for communication networks and systems in substations. IEC61850 is a communication protocol and also defines how data is sent and received but also describes how data is executed and stored [53]. IEC61850 is used for Generic Object Oriented Substation Event (GOOSE) messaging, as it is less expensive, is more secure, is interoperable, has improved reliability, is easy to use, is bench tested and allows faster deployment [55, 56].

4.6.1 Self-healing

The security and stability calculation and development of emergency plans of current power grids are still off-line analysis; hence, the results are comparatively conservative [57]. However, the SG has better self-management and self healing ability. With real-time monitoring, the problems can be automatically detected and corrected. With the incorporation of micro grids, the affected areas can be isolated from the main networks limiting the disruption. If an overhead power line has an error, there is an inevitable power loss. Usually, the self-healing process has three steps:

- Step 1: Using AMI, the utility company collects the real-time usage data.
- Step 2: It analyzes the data to identify a potential power failure during a high power demand period.
- Step 3: Then, the utility redistributes the power across its service area and sends a radio signal to turn on or off the smart applications.

With self-healing function, the power grid is able to maintain its stable operation, estimate weak stage, and deal with an emergency problem. Even though the SG involves many advanced devices, it is not recognized by these advanced devices. The specialty of SG is that it has two-way communications to as many points of the distribution network as possible. The SG should be adaptable to all new and old devices that are part of the distribution framework. They are needed for devices in the substation, down the feeders, at the metering points and even into the extended grid into home or captive power plants for a business. The smart devices are useful only through the business applications as they support using the communication and control capability.

4.7 Cyber-Physical Security of SG

The cyber security of power grid, encompassing attack prevention, detection, mitigation, and resilience, are among the most important R&D requirements for the emerging SG. One of the important goals of future research is to develop a comprehensive cyber security risk modeling framework that integrates the dynamics of the physical system as well as the operational aspects of the cyber-based control network. The models are needed to quantify the potential consequences of a cyber-attack on the power grid in terms of load loss, stability violations, equipment damage, or economic loss [58].

The SG cyber security is also vulnerable to different physical attacks such as sabotage, terrorist, theft, mal practice of different devices, etc. In such situations, the SG should be capable of self healing. As a critical infrastructure, the electric power grid is vulnerable with respect to malicious physical and cyber attacks. Indeed, the importance of physical and cyber security of SGs has been highlighted by recent intrusion incidents around the world. Various types of sensors, instrumentation, information and communications technology (ICT), computational methodologies, and security controls have been developed to enhance the physical and cyber security of SG [59]. The tight coupling between the information and communication technologies and physical systems introduces new security concerns, requiring a rethinking of the commonly used objectives and methods. Providing a cyber-enabled sustainable pathway towards deep integration of intelligent decision making in smart distribution grids using distributed intelligence techniques, leads toward an overall cost-effective and environmentally benign utilization of a future energy system portfolio.

Distribution intelligence is the part of SG that applies to the utility distribution system, i.e., wires, switches, and transformers that connect the utility substation to the customers. The power lines that run through people's back yards are one part of the power distribution system. Most of the utility companies are only starting on the road to true distribution intelligence, but the market is expected to boom in the coming years. Also, the stochastic behavior that comes through the integration of RERs and random load can be solved through the probability distribution functions (PDFs) and the advanced optimization methods.

5. SMART GRID DEVELOPMENT AROUND THE WORLD

The SG has many advantages and at the same time has many security risks. Protecting the privacy of customers and the energy generators must be given highest priority. To achieve the benefits of SG, there is a requirement for developing a network solution with high reliability and security [35]. Even though the SG is able to resolve many issues prevailing with traditional electric networks, it still faces several challenges [51]. Some of the challenges include: inadequate infrastructure, efficient management of SG and its integration into the existing grid, data management, storage concerns, socio-economic issues, lack of awareness, design of demand-side management models to capture the customer behaviour, integration and interconnection of distributed energy resources to the power grid (due to the uncertain nature of renewable energy resources), cyber-security challenges of SG due to the diversity of components and contexts where the SGs are deployed, communication challenges, regulatory policies (i.e., lack of policy and regulation to the SG applications) and grid operation, etc. Reference [60] presents the challenges and requirements of SG system development, planning and operation in China. The SG development, implementation and practices in various parts of the world is presented next.

5.1 Europe

The European Technology Platform for Electricity Networks of the Future (SmartGrids ETP) is the key European forum for the crystallization of policy, technology research and development pathways for the SG sector. The European Union (EU) aims to get 20% of its energy from RERs by 2020 and cut down greenhouse gas emissions, and rely less on imported energy. In 2007, the European Council adopted the 20:20:20 objective, reducing the greenhouse gas emissions by 20%, increasing renewable energy to 20% and making 20% energy efficiency improvement by 2020 [61]. EU members are required to implement smart meters in 80% of households by 2020 based on the cost-benefit analysis. The electricity sectors of the member states vary, so the roll out and their costs have to be individually dealt with. The European Commission also established the European Electricity Grid Initiative, a 9 year research and development program for the SG technology and market innovations [61]. An overview of the current status of SG development in Great Britain is presented in [62].

5.2 United States (US)

US has invested in RERs and initiated modernization of its energy infrastructure. The Global SG Federation Report of 2012 states that the US has a non-binding target of around 17% below 2005 levels by year 2020 under the Copenhagen Accord. It has also noted that in 2010, 663 US electric utilities had installed 20,334,525 smart metering infrastructure and that the national penetration rate for smart meters was already 14% a year. Some consumers reacted negatively to the deployment of smart meters because they recovered the cost of smart meters back through the consumers, and also health and privacy concerns [63]. With the formation of the SG Consumer Collaborative (a non-profit organization) facilitating cooperation among utilities, consumers, advocates, and technology providers, the sustainable benefits of the SG can be appropriately managed. The US Department of Energy formed the Office of Electricity Delivery and Energy Reliability for electric grid modernization and resiliency in the energy infrastructure. The office has produced "GRID 2030" which articulates a national vision of electricity for 100 years [61].

5.3 China

The SGs development in China is considered as one of the priorities of China's energy policy. It includes increasing renewable energy mix, reducing carbon intensity and improving energy efficiency. The Chinese government has different agencies for the development of SG, and they are

- State Electricity Regulatory Commission (SERC): Its objective is to supervise the daily operation of power generation companies and power utility companies.
- National Development and Reform Commission (NDRC): Its objective is to oversee SG development plans, approval of SG projects, controlling the pricing of electricity.
- China Electricity Council (CEC): It is developed to assist in formulation of power policies and lobby national SG plans.
- National Energy Agency (NEA): Its goal is to formulate and implement national energy policy and development plans.

China has given substantial attention to the development and emergence of smart grids [61].

5.4 India

India is developing various SG initiatives, such as "National Smart Grid Mission", "Smart Grid Vision and Roadmap for India", "Nehru National Solar Mission", etc. in order to enhance reliability and performance of the grid and to support economical, technical, and social development [59]. During the last decade, the installation of RERs has grown at an annual rate of 25%. POWERGRID corporation of India has taken an initiative to develop a SG pilot project at Puducherry. The objective of this project is to demonstrate the technology efficacy, policy advocacy and regulatory framework for tariff design, provide input for standardization and interoperability framework of various technologies, net metering, electric vehicle deployment with charging through renewables, etc. [64].

5.5 South Korea

South Korea has committed to a voluntary emissions reduction target of 30% by 2020 and plans to replace all old meters by 2020. South Korea's Jeju SG demonstration project shows its leadership in SG. The coordination between industry and government in achieving Korea's green innovation objective is remarkable. South Korea has targeted to generate 11% of its energy from renewables from 2.1% in 2012, by 2030, by eliminating 230 million tonnes of greenhouse gas emissions, to create 50,000 jobs annually, and to generate 64 billion USD worth of domestic demand for new technologies [65].

Future research must develop suitable models for tracking SG security threats by source classification for desired resiliency and developing a robust simulation tool for threats sensing and response for a stabilized SG system [66]. There is an immense potential for the future research in SG. Some of them include: advanced forecasting techniques for SGs, reliability and power quality studies, power flow optimization, battery systems, cloud computing and the integration of practical large scale RERs.

6. CONCLUSIONS

This paper has described an overview of smart grid (SG) and presented the detailed review of features of SG. This study has provided the information about each aspect of SG as well as the information about their interconnection. It also detailed the necessity of SG and its specialties compared to the conventional/existing electrical grid. The detailed description of various features of SG technologies, i.e., two-way communication, advanced metering infrastructure, integration of renewable energy, advanced storage techniques, real time operation and control, data management and processing, physical and cyber security, and self-healing, etc. are presented in this paper. An overview of development of smart grid technologies around the world is also presented in this paper.

ACKNOWLEDGEMENT

This research work has been carried out based on the support of "Woosong University's Academic Research Funding - (2018–2019)".

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