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Smart Grid Technologies and Implementation

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ABSTRACT

Deregulation and privatization are posing new challenges on the existing grid system. System elements are loaded up to thermal limits, and power trading with fast varying load patterns is contributing to an increasing congestion. The dramatic global climate developments demand for changes in the way electricity is operated. Utilities across the world are trying to figure out how to bring the convectional network into the 21st century and the digital computer age. However, while modern technologies have transformed much of the economy, the electric industry has yet not embraced and implemented these technologies. This paper reviews works related to smart grid, presents the need for smart grid technologies by identifying its benefits and presenting different areas of its application for the realization of smart grid vision, and implementation of reliable and efficient smart grid. Proper utilization of these technologies could bring improvement to the operation of smart grids and possibly eliminate the challenges it poses.

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INTRODUCTION

Advances in information and communication technology (ICT) have been utilized over the year by utility industry in order to improve power quality, reliability, efficiency and security. Growing concern for environment, increasing complexity in managing convectional grid, energy sustainability and independence, aging asset base, demand growth and search for service quality continue to stress the need for a quantum leap in application of such technologies. This leap towards a smarter grid is now known as smart grid (SG) (Moslehi, K. and R. Kumar, 2010).

The basic expectation of utility industries in this century is to meet growing demand: reliably, cleanly, sustainably and at low cost. That is the principal focus for the definition of SG polices on the global level. European SG concept – EU Smart Grids Technology Platform vision for Europe's Electricity Networks on the future was launched in 2006 (Schmid, J., 2010). The SG vision is targeting for new product, process and services, improving industrial efficiency and use cleaner energy resources. The SG vision is highly essential as a means to support the nation's environmental as well as economical ambitions. There are already a number of various emerging technologies within the transmission and distribution networks which can contribute towards improving system operation and management. In addition, there is increased use of digital communication and control including smart metering and advanced grid wide area real-time monitoring.

The distribution system (DS) is of prime significance since it used to be a passive network with far less automated functions than the transmission system. In this vein, the fundamental objective of any SG implementation on the DS should enable all infrastructures to allow all desirable functions of optimizing the operation of the DS to achieve maximum benefits to utilities and end users alike (Meliopoulos, A.P.S., 2011; Metke, A.R. and R.L. Ekl, 2010). These goals are achievable only via a system that will enable accurate and regular monitoring of the DS.

As far as system planning is concerned, the planning process can be greatly improved by applying the data received from smart grid technologies (SGTs). In fact, expansion plans change under different weighted combination of objective functions and different cases according to the SGTs in the system; while the objective function in itself can also be improved due to the existence of SGTs

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(Tekiner-Mogulkoc, H., 2012). There are indeed some energy-related benefits from deploying the SGTs in the distribution network. Nonetheless, it requires further development of the SGTs and integrating them into the grid structure. This could allow the self-healing functionality of the grid and facilitate the integration of distributed generation technologies. For instance, the SGTs can be employed to expedite reactive power compensation using dynamic VAR devices. Enabling technologies in terms of information and communications can definitely unclog the realization of these SG functions.

The use of SGTs will have a societal impact in the near future (Simões, M.G., 2011), since it will not be only affecting network operators and grid users, but also individual homeowners (Molderink, A., 2010). With the envisioned transition from a hierarchically controlled grid to a distributed controlled one, end users will become increasingly aware of their energy consumption patterns and can accordingly decide to balance their lifestyle and business requirements as an active customer of the grid.

This paper basically provides a review of the different technologies associated with the smart grid and its likely applications on the existing grid system. The main features of the SG are first outlined and the technologies needed to realize a smart system infrastructure is highlighted. The vision for the future grid along with its implementation issues is further articulated. The challenges that may hinder the implementation are spelled out and conclusions are presented.

Smart Grid Concept:

The SG is a compilation of concepts, technologies, and operating practices intended to bring the electric grid into the 21st century.

There is no single template that defines exactly what the SG will look like or how it will operate in any given area. Without a consensus template everybody tend to construct their own imagine vision of how the technologies, systems, and customers will interact. There is also the reality that customer mix, geography, weather and other factors will almost certainly make the SG in each service area a little unique.

Literature review on (Baumeister, T., 2010) stated different definitions of SG but, The European Commission Task Force on Smart Grid (Petinrin, J.O. and M. Shaaban, 2012; Zhang, Z., 2011) defined SG as “an electricity network that can intelligently (as shown in Fig.1) integrate the action of all users connected to it (producers and consumers of electricity) to ensure economically efficient, sustainable power system with minimal losses and high level of power quality, security and safety”.

Then, SG can be said to be a system of information and communication applications integrated with RG, distribution and consumer technologies (Petinrin, J.O. and M. Shaaban, 2012). This gives opportunity to consumers to manage their electricity usage and select economically efficient offerings; apply automation and alternative resources for delivery system reliability and stability SG is not necessarily a specific combination of parts as much as it is a process for using information and communications to integrate all the components that make up each electric system. SG is system integration with the objective of promoting customer choice; improve reliability and integration of renewables.

The development of smart grid is to be automated, digitalized, widely distributed energy delivery network. SG applies the use of digital technology to improve reliability security, and efficiency (both economy and energy) of the electric system from large generation, through the delivery system to electricity consumers and a growing number of distributed-generation and storage devices (Petinrin, J.O. and M. Shaaban, 2013).

The basic concept of SG is to apply monitoring, analysis, control, information and communication capabilities to the conventional grid system, to maximize the output of the system and minimize the energy consumption. The conceptual model of SG is shown in Fig. 2. The smart grid enable for utilities to interchange electricity around the network as efficiently and economically as possible. It also allows the homeowner and business the use of electricity as economically as possible. It is to accomplish reliability and efficiency, as well as optimisation in operation, planning, and demand side management (DSM), which includes the use of diverse resources (Lo, C.H. and N. Ansari, 2011; Breuer, W., 2007; Mukhopadhyay, S., 2011). The primary concept of a smart grid involves the idea of advanced metering infrastructure (AMI) to improve the DSM and energy efficiency (EE). It has improved to embrace more features such as self-healing, interactive, and strong/security, optimisation, compatibility, and integration.

Features of Smart Grid:

While the initial concept of a SG was with the notion of advanced metering infrastructure (AMI) to improve the demand side management (DSM) and energy efficiency, it has developed to include more features:

Self-healing: One of the required features of the SG is to be self-healing, able to preventive, corrective, emergent and restorative (Giri, J., 2009; Heydt, G.T., *et al*., 2009). It quickly detects and reacts to power disturbances with no or minimum effect on the end-user.

Interactive: It obtains the intelligent interaction between utility grids and end-user to achieve energy flow, information flow and capital flow in bi-directional way.

Strong/Security: The security of the utility grid is its capability to mitigate disturbances and contingencies. It quickly identifies cyber and physical attacks and responds to man-made and natural disasters, protection, information security and other vulnerabilities.

Optimization: Improvement in the use of asset and effective minimization of operation and maintenance cost.

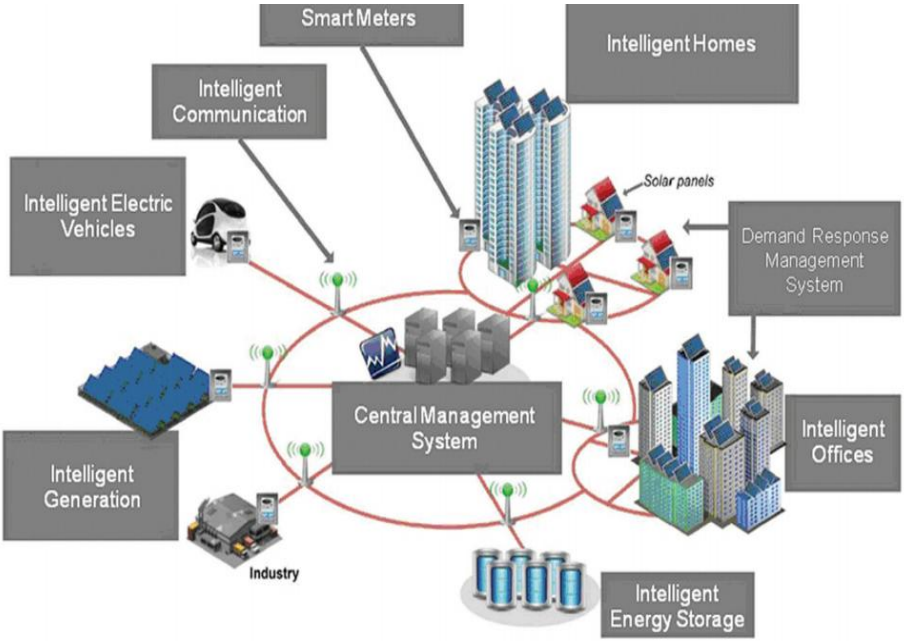

Fig. 1: Intelligent energy systems.

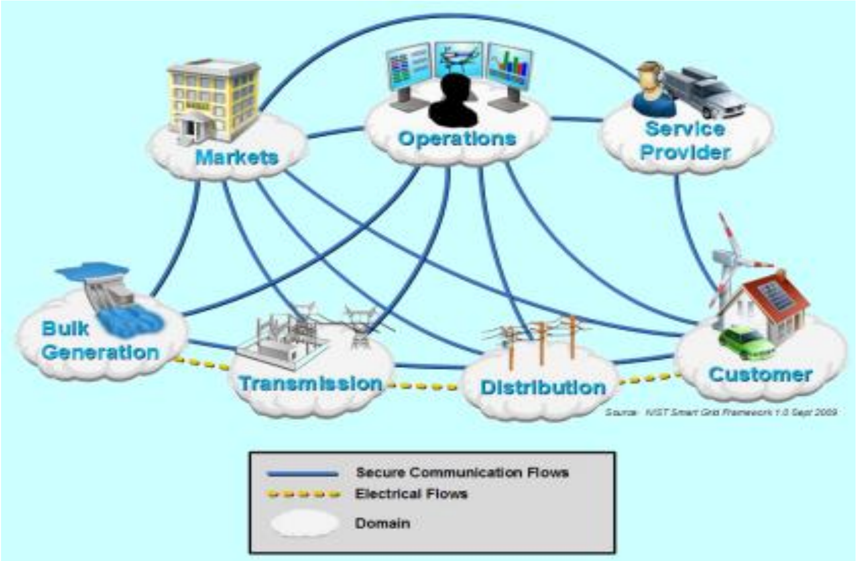

Fig. 2: Smart grid conceptual model (FitzPatrick, G. and D. Wollman, 2010).

Compatibility: Provision of centralized power generation, distributed power generation and energy storage unity is compatible.

Integration: It involves optimization, information integration and the standardization and refinement of the management. Different functions of SG is illustrated in Fig. 3.

There are lots of benefits to a wide range of constituencies in fully implemented SG. There will be a quantum improvement in monitoring and control capabilities that will in turn enable grid operators to deliver a higher level of system reliability, even in the face of ever-growing demand. There will be reductions in peak demand, the proliferation of renewable generations, and a corresponding reduction of carbon dioxide emission, as well as pollutants such as mercury.

Utility companies will experience lower distribution losses, reduce maintenance costs and defer capital expenditure. Customers will have greater control over their energy usage and costs, including generating their own power, while realizing the benefits of a more reliable energy supply.

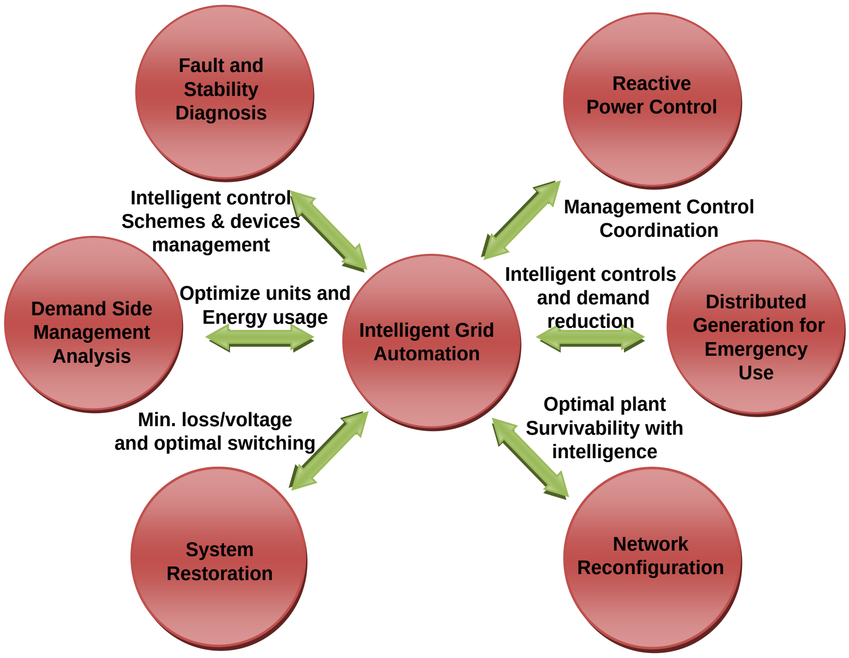

Fig. 3: Functions of smart grid.

Smart Grid Technologies:

Smart grid incorporates many of the already existing technologies on conventional grid and involves the application of communication and control skills to optimise the operation of the whole electrical grid. Some of the SG technologies in use today are: 1) Real time situation awareness and analysis of the distribution system that can drive improve system operational practices that will, improve reliability. 2) Fault location and isolation that speed recovery when necessary outage does occur by allowing work crew to drastically narrow the search for a down line. 3) Substation automation enables utility to plan, monitor, and control equipment in a decentralized way, which makes better use of maintenance budgets and boost reliability. 4) Smart meter allow utility customers to participate in time-of-use pricing program and have greater control over their energy usage and cost. 5) SCADA/DMS put more analysis and control functions in the hand of grid operators. 6) Voltage control, through reactive power compensation and the broader application of power electronics, increase transmission capacity of existing lines and improve the resilience of the power system as a whole.

For the existing power grid to be transformed into a smart grid there is need for power engineering technologies to meet energy demand and strategies to control it. Smart Grid is positioned to take advantage of new technologies, such as plug-in hybrid electric vehicles, various forms of distributed generation, solar energy, smart metering, lighting management systems, distribution automation, and many more. For the proposed smart grid to be the real smart it supposes to be, these enabling technologies must be involved and utilized.

Power Electronics:

Power electronics is essential in the implementation of smart grids because of the integration of renewable energy sources which requires highly developed power converter system. According to (Phadke, A., 2009; Tiwari, A. and V. Ajjarapu, 2011; Zhang, X., 2008), flexible alternating current transmission system (FACTS) and high voltage direct current (HVDC) provide fast dynamic voltage, power flow and stability control of the power grid, it improves efficient use of transmission assets. The installation of FACTS devices helps the power grid in adjusting voltage and power flow dynamically and flexibly. Also, it militates against network congestion and blackout. Power electronic also includes an emergency command system and advanced distribution automation (ADA) and related technologies. ADA system includes system monitoring and control, power distribution system management functions and interaction with the user (such as load management, measurement and real-time pricing).

Distributed Energy Access:

It is a small unit of electricity resources. It is connected to the low voltage side of the distribution system at different locations close to the end user (Kumar, R., 2011). It is an intelligent network system including intelligent judgment with adaptive ability and distributed management which monitor, collect and convey information of the network for the end-user to make sure that there is optimal allocation and utilization of energy. This brings improvement to grid operation and energy efficiency.

Energy Measurement and Demand Side:

Measurements and signals coming from different networks through sensor can be utilized by controllers to give self-healing in sub-second time frame (Kumar, R., 2012; McBee, K.D. and M. Simoes, 2011) of the system under disturbances or fault condition. The use of bi-directional smart meter accompany different applications such as measurement of energy use at different time in a day, it is cost effective and it informs the user rates of energy consumption most especially during the peak period (Carpinelli, G., 2013) so that consumer can take adequate decision by changes in electric usage from normal consumption patterns in response to changes in the electricity overtime. The smart meter through its power quality can identify system and consumer voltage deficiency, harmonic distortion, and on-set equipment failure.

Energy Storage:

Energy storage facilities relieve congestion and constrains, it provides easy connection of renewable sources and make islanding possible, and allows load leveling and peak shaving (Wen, S., 2015). The application of energy storage is shown in Fig. 4. Energy storage such as battery, thermal, hydrogen, superconducting magnetic energy storage (SMES) devices, and ultra-capacitors play an important role to minimized the impact of sudden load changes and fluctuations in solar and wind generation, as well as to shift energy consumption from peak hours by providing energy balancing, load following, and increased supply redundancy and system reliability.

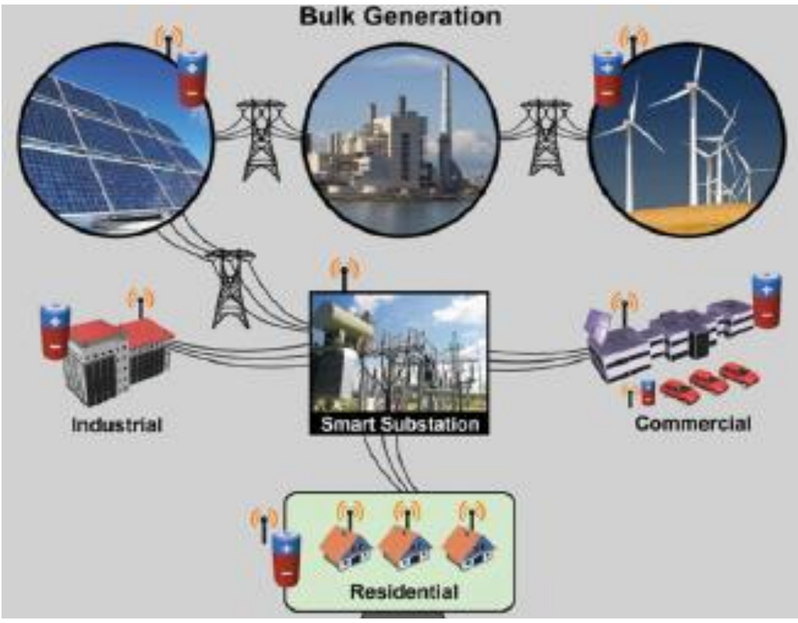

Fig. 4: Application of energy storage and future smart grid (Crossland, A.F., 2014).

The capability of distributed storage to store non-despatchable energy from renewable energy sources can certainly improve system reliability (Yang, Z., 2010). Energy storage such as battery, thermal, hydrogen, superconducting magnetic energy storage (SMES) devices, and ultra-capacitors play an important role to minimized the impact of sudden load changes and fluctuations in solar and wind generation, as well as to shift energy consumption from peak hours by providing energy balancing, load following, and increased supply redundancy and system reliability.

Information and Communication Technology:

Smart grid makes use of information and communication technology (ICT) to take care of the reliability impact of the SG resources such as renewable energy, demand response, energy storage and electric transportation (Peterson, M. and B.N. Singh, 2010). A SG communication platform as depicted in Fig. 5 is a step to SG realization. The SG must be connected with a flexible power secured communication network with energy management strategies which is essential for a very number of sensors and actuators nodes. Communication network is the key enabler needed for the achievement of SG. The communication provides advance control and monitoring including support the involvement of generation, transmission, marketing and service provision to new concerned groups.

SG includes data sensing, collection, transmission, communication and storing. A large number of sensors based and intelligent electronic devices (IEDs) are deployed in electric components, substations, homes, and premises. The data collected from the devices are aggregated and sent to control centers for operators or automated system to measure, analyze, and execute the process of planning - protection – prevention (Lane, T.W. and J.C. Rounds, 2007). The successful operation assists to facilitate monitoring and control to increase the workload efficiency and strengthen the security protection of the grid. Synchronous phasor measurement units (PMUs) which amass data frequently in a power cycle are being deployed to assist in development of a much more detailed picture of the grid dynamic for system planning, control, and post incident analysis.

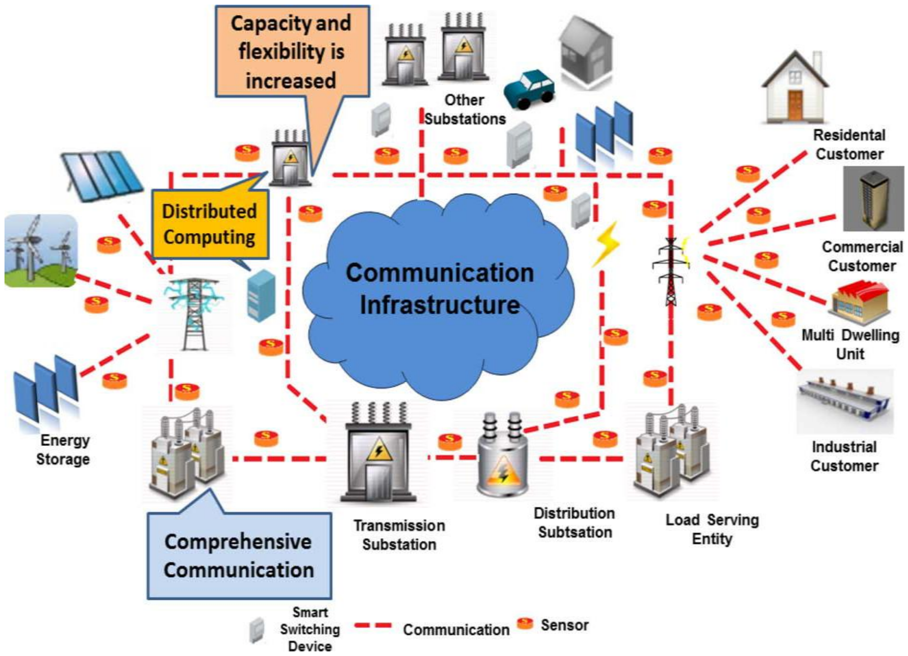

Fig. 5: A smart grid communication platform (Gungor, V.C., *et al*., 2011).

The SG communication infrastructure comprises of four network sectors: core (or backbone, metro), middle-mile (or back-haul), last mile (or access, distribution), and homes and premises. These four monitoring sectors interconnecting with one another supported by various technologies fundamentally assemble the communication infrastructure of the SG.

The integration of heterogeneous network will assist to facilitate efficiency communication for the SG. The use of different technologies for the SG communications will certainly rely on the associated network characteristics. The geographical needs, task objectives, including utilization and services to customers will affect the choices of technologies development of the SG communications. The fundamental component for making the SG work will be a robust and dynamic communications network, providing the utility the ability of real time, two-way communications throughout the grid and enabling interaction with each component from fuel source to end user.

Control, Automation and Monitoring:

These are technologies essential to offer advanced protective relaying, measurements, fault records and event record for the power system as security of the power system must be ensured by using phase measurement unit (PMU) and Wide Area measurement system (WAMS). Also there should be adequate integrated sensors. measurement, control and automation system with information technology for fast diagnosis and timely response to any occurrence in any part of the power system, management and efficiency operation, minimization of congestion and potential outages, and to work autonomously when the situation required fast restoration. Monitoring and controlling are essential to make the smart grid self-healing, self-organizing and self-configuring.

I. Vision of Future Smart Grid:

Modernization of the existing grid has been generally accepted globally. Due to policy and regulation initiatives, the momentum for the SG vision has increased recently. Therefore each country has developed beautiful plans and strategies, with vision for transition from existing grid to SG with the available SGTs.

An image of the future is revealed through SG vision. The vision defines the expectation for what SG looks like, how it operates, and the cost. The vision of the power system require for the future is essential for today's' grid modernization. The understanding of the vision will create alignment necessary to inspire passion, investment and progress towards the SG for the 21st century (Xie, K., 2008). Vision of SG should be a fully network-connected system that reorganizes all elements of the power grid and communicates its status and the effect of consumption decisions (including economic, environmental and reliability effects) to automated decision making system of the network.

A SG vision has shown in Fig. 6 is required to set the foundation for a transition that aim in achieving that the SG must be reliable, secure, economical, more effective, more environmental friendly, and safe. Transformation of the existing grid starts with building a vision, followed by the deployment of enabling technology platform and the integration of SG application that will support the vision. The SG vision must be expressed from different perspective: its value, characteristics as shown in Fig. 6, and the milestones for achieving it.

Fig. 6: Smart grid vision (Li, F., 2010).

II. Implementation Strategies:

Important changes must be incorporated into the nature of electricity supply, as demand increases and traditional resources are exhausted. Major stakeholders have come together to define a clear vision of the future, but these must be translated into practical solutions (Orecchini, F. and A. Santiangeli, 2011).The implementation of SG requires quick action for optimal value improvement delivery and reliability, and to have impact on the nation's energy security through DGs and RESs. But to successfully realize the benefits of SG depends on implementation factors, including the ability of utilities and consumers to make use of IT advances utilize interoperability strategies and improve on transmission efficiency. According to Lisa Wood, the Executive Director of the Institute of Electric Efficiency, I quote, "Over 58 million smart meters will be deplored to mass market customers over the next 5 to 7 years". The full benefit of SG realization goes beyond smart meter and delivery improvement. It lies on the capability to transmit electricity across the globe to make use of RESs.

The implementation of SG needs many steps in each domain. The success of the implementation start with consumer acceptance of SG implementation to commercial investment and to separate three tiers of government roles in devising long-range plans and formulating the right regulatory policies. Presently, some consumers are not interested in SG because of increase in electricity bill to offset the cost of investment. From the survey carried out by Parks Associate as part of its Residential Energy Management Service (REMS) to know consumers response to energy management solution; 35% do not want utilities to control systems in their homes regardless of the saving potentials (Ablondi, B., 2010). From the survey, there is need for public awareness and campaigns that explain the benefits of SG and put it in terms of consumers appreciate and use.

The SG promise to combat climate change and improve energy policy, but intimate details of customer's life can be revealed to utility through their vast amount of data. Therefore, with its provision of lower energy cost, increased utilization of environmentally-friendly power sources, and enhanced security against attack and outage, there is new privacy threat through the enhanced collection and transmission of data-to-data that can reveal details about activities within the home and that can easily be transmitted from one place to the other (Ipakchi, A., 2007; Järventausta, P., 2010).

Introduction of SG comes with prospects and problems. Utilization of internet to link data flow between consumer and utilities create cybersecurity and vulnerabilities on the grid. Therefore, the SG requires special protection through a more private network and not internet. SG utilizes IT to control supply and demand based on numerous amount of data to determine the strategy to peak power loads and when to briefly "ON" or "OFF" power. The internet that carries the data creates more potential vulnerabilities. Another problem is the easy to use smart meter that introduces vulnerabilities. Smart meter provide direct access to consumers about their power usage and means of managing it, but that bi-directional meter also give room for the grid to be attacked from outside. Customers hacking into data to roll the meter back on the utility bill is a serious attack. Vulnerabilities may permit an attacker to penetrate a network, gain access to control software, and change load conditions to destabilize the grid in unpredictable manner. Therefore, compromise of data should not be the only concern but SG technologies need to look into governing the grid operation too. Finally, there is required to secure the information flow on the SG which is a key determinant of success. In addition, there must be resilience and guarantees built in from the ground up to avoid a new risk on the SG. In spite of introducing new vulnerabilities, SG basically makes the electric system more secure (Mukhopadhyay, A.R., 2011). Security comes just in the form of increased reliability as it does from cyber protection.

III. Implementation Challenge:

Some of the challenges in implementation of SG are investment, regulations, business models, consumer education, cybersecurity and even weather in space are leading factors. The SG comprises some discreet but overlapping elements. SG challenge is divided into seven domains which are consumers, markets, operators, service providers, bulk generation, transmission and distribution.

The development of SG is a revolutionary technological change in the electricity market that involves many stakeholders. Every stakeholder embraces the transition from existing grid to SG because of its assumed features such as clean, cost effectiveness, flexibility, reliability, efficiency and security. The European commission submits that with SG, energy consumption will be reduced by 10% while carbon emission by 9%. International Energy Agency noted that many countries have developed plan, but there is lack of concrete project implementation. IEA once called for coordination and cooperation on implementation of SG, but IEA cannot do more than appealing to countries to take action. The DSO may be in the best position to implement SG, but government policies and regulations may regulate them purely on the basis of financial standard that they may not be able to do what is expected, Another challenge before DSO when it comes to SG implementation is that staff is getting older, there is a shortage of technical staff and at the same time, there is need for investment on technological skill. The worst of it is that, SG involved the use of ICT which has not been in the existing grid.

The existing grid is a centralized with ultra-high voltage transmitted through a very thick cable from generation down to the end-user (one way traffic) with expanded connection and the demand in the market could not be influenced. The transition to SG now comes with two major changes. From centralized to decentralized power production both mix together make it somehow complex. While there will be variable supply as a result of intermittency and fluctuant RESs, the demand will become responsive to price changes. In addition, the SG will have to allow the penetration of electric vehicles (EVs) which make demand on the grid, but it also provide storage of electricity in car batteries which it may sell to utility. All these could only be achieved by adding intelligence to the existing system from the accomplishment of flexibility on the demand side and accept the penetration of DG into the system.

Let's assess the cost of not transition to SG; having increasing energy consumption going forward, of an ageing electric grid that's pushed to the breaking point. Lost revenue associated with outages, environmental impacts. The cost of manual operations is not linear but going forward. With an ageing workforce, the cost of manual operation of the system is exponential (Isom, P., 2010). Remarkable things happen when the economics of certain conditions and available technology come together. This happen with computer system and telephone when the economics and technology come together, they cause a transformation in the way things are done because those two came together drive substantial change. The SG technologies and infrastructure designed to be in place are more than enough to take care of all the challenges (Bose, A., 2010), milestone and vulnerabilities on the SG. Detailed relationship between existing grid and smart grid was discussed by and stated that whatever may be the challenges on the smart grid, it should not be an obstacle to upgrading the existing grid to smart grid.

IV. Conclusion:

Smart grid is the modernization and automation of the current power delivery systems, both transmission and distribution. From a design perspective, a SG will incorporate elements of traditional and advanced power engineering, sophisticated sensing and monitoring technology, information technology and two ways communication. One of its objectives is to update the power system automation which includes transmission, distribution, sub-station, individual feeder and customers using latest technologies. The only way to fully implement the SG is to utilize the modern technologies. To realize an extensive SG is to develop a vision for the ultimate design of a SG and then make a short term decisions that incrementally transform existing grid system into this future vision. Proper utilization of SGTs will bring a tremendous improvement to the efficient operation of SG and eliminate the challenges pose before it.

Through the integrated use of these technologies, SG provide self-healing, high reliability and power quality, be resistant to cyber-attacks, operate with multi-directional power flow, increase equipment utilization, operate with lower cost and offer customers a variety of service choices. The SGTs and infrastructure designed to be in place are more than enough to take care of all the challenges, and vulnerabilities on the SG. The technical feasibility however is not in doubt and the cost of not achieving the SG vision is higher than the technologies and infrastructure needed. Therefore, SG needs to be implemented quickly enough to provide optimal value, improving delivery and reliability, and also contribute to the nation's energy security by tapping more domestic and renewable providers.

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