Micro smart Grids as a Solution for Energy Distribution and Utilization

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1. Introduction

The majority of the world’s electricity delivery system or ‘grid’ was built when energy was reasonably low cost. While minor upgrading has been made to meet rising demand, the grid still operates the way it did almost 100 years ago—energy flows over the grid from central power plants to consumers, and reliability is ensured by preserving surplus capacity . The result is an incompetent and environmentally extravagant system that is a foremost emitter of greenhouse gases, consumer of fossil fuels, and not well suited to distributed, renewable solar and wind energy sources. Additionally, the grid may not have ample capacity to meet future demand. Continued economic growth and fulfillment of high standards in human life depends on reliable and affordable access to electricity. Over the past few decades, there has been a paradigm shift in the way electricity is generated, transmitted, and consumed. However, fossil fuels continue to form a dominant initial source of energy in the industrialized countries.

The present revolution in communication systems, particularly stimulated by the Internet, offers the possibility of much greater monitoring and control throughout the power system and hence more effective, flexible, and lower-cost operation. The Smart Grid is an opportunity to use new

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information and communication technologies (ICTs) to revolutionize the electrical power system .However, due to the huge size of the power system and the scale of investment that has been made in it over the years, any significant change will be expensive and requires careful justification.

The effective management of loads and reduction in losses and wasted energy needs accurate information, while the use of large amounts of renewable energy generation requires the integration of the load in the operation of the power system in order to help balance supply and demand. Smart meters are an important element of the Smart Grid as they can provide information about the loads and hence the power flows throughout the network. Once all the parts of the power system are monitored, its state becomes observable and many possibilities for control emerge. In the future, the anticipated future de-carbonized electrical power system is likely to rely on generation from a combination of renewable, nuclear generators, and fossil-fuelled plants with carbon capture and storage. This combination of generation is difficult to manage as it consists of variable renewable generation and large nuclear and fossil generators with carbon capture and storage that, for technical and commercial reasons, will run mainly at constant output. It is hard to see how such a power system can be operated cost-effectively without monitoring and control provided by a Smart Grid.

The concept of Smart Grid combines a number of technologies, customer solutions and addresses several policy and regulatory drivers. Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both -in order to efficiently deliver sustainable, economic and secure electricity supplies. The Smart Grid is defined as:

A smart grid uses sensing, embedded processing and digital communications to enable the electricity grid to be observable (able to be measured and visualized), controllable (able to manipulated and optimized), automated (able to adapt and self-heal), fully integrated (fully interoperable with existing systems and with the capacity to incorporate a diverse set of energy sources).Introducing Smart Grid to the electrical power grid infrastructure will:

- ensure the reliability of the grid to levels never thought possible
- allow for the advancements and efficiencies yet to be envisioned
- exerting downward pressure on electricity prices

- maintain the affordability for energy consumers
- provide consumers with greater information and choice of supply
- accommodate renewable and traditional energy resources
- enable higher penetration of intermittent power generation sources
- revolutionizing not only the utility sector but the transportation sector through the integration of electrical vehicles as generation and storage devices
- finally, the Smart Grid will promote environmental quality by allowing customers to purchase cleaner, lower-carbon-emitting generation, promote a more even deployment of renewable energy sources, and allows access to more environmentally friendly central station generation. Furthermore, the Smart Grid will allow for more efficient consumer response to prices, which will reduce the need for additional fossil fuel-fired generation capacity, thereby reducing the emission of CO2 and other pollutants.

Fig. 1 shows the main component of the Smart Grid

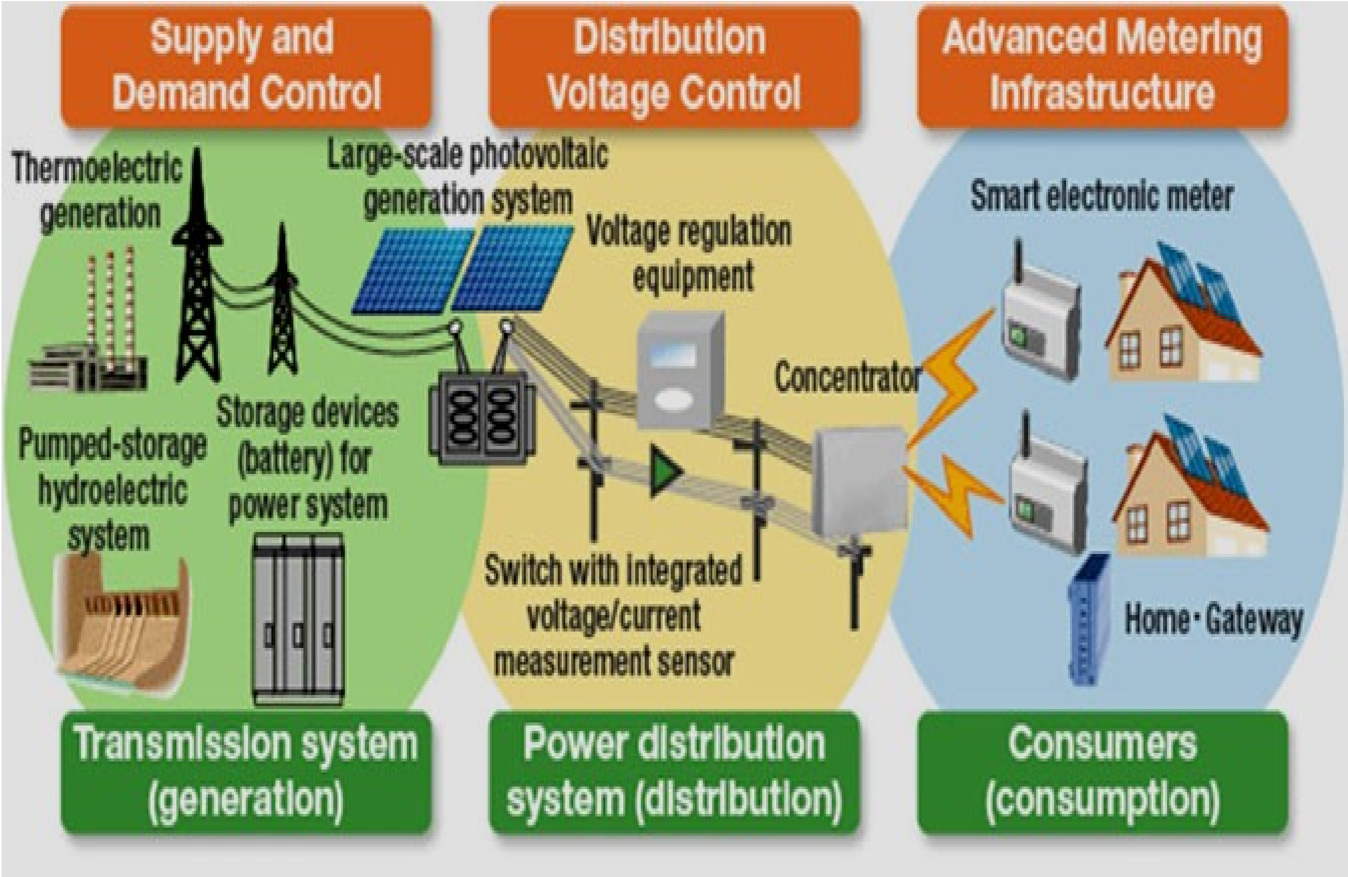

Fig. 1 The main components of Smart Grid

Keywords

ICTs information and communication technologies CO2 carbon dioxide, EV electrical vehicles, SCADA supervisory control and data acquisition PV photovoltaic, AMI advanced meter infrastructure, , PMU Phasor measurement units, High-voltage DC HVDC

2. Characteristics of Smart Grid

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

The smart grid has the following important Characteristics:

Smart Grid allows consumers to play a part in optimizing the operation of the system and provides consumers with greater information and choice of supply. It enables demand response and demand-side management through the integration of smart meters, smart appliances and consumer loads, micro-generation, and electricity storage electrical vehicles (EV) and by providing customers with information related to energy use and prices. It is anticipated that customers will be provided with information and incentives to modify their consumption pattern to overcome some of the constraints in the power system.

- It better facilitates the connection and operation of generators of all sizes and technologies and accommodates intermittent generation and storage options. It accommodates and facilitates all renewable energy sources, distributed generation, residential micro-generation, and storage options, thus significantly reducing the environmental impact of the whole electricity supply system. It will provide simplified interconnection similar to ‘plug-and-play.

- It optimizes and efficiently operates assets by intelligent operation of the delivery system (rerouting power, working autonomously) and pursuing efficient asset management. This includes utilizing assets depending on what is needed and when it is needed.

- It operates resiliently in disasters, physical or cyber attacks and delivers enhanced levels of reliability and security of supplying energy. It assures and improves reliability and the security of supply by anticipating and responding in a self-healing manner, and strengthening the security of supply through enhanced transfer capabilities.

- It provides power quality of the electricity supply to accommodate sensitive equipment that enhances with the digital economy.

- It opens access to the markets through increased transmission paths, aggregated supply and demand response initiatives, and ancillary service provisions.

Moreover, Smart Grid systems, there are four fundamental categories of benefits:

- Economic - reduced costs, or increased production at the same cost, that results from improved utility system efficiency and asset utilization
- Reliability and Power Quality – reduction in interruptions and power quality events
- Environmental - reduced impacts of climate change and effects on human health and ecosystems due to pollution
- Security and Safety - improved energy security (i.e., reduced oil dependence); increased cyber security; and reductions in injuries, loss of life and property damage

2.1 The synthesis of smart grid

Figure. 2.shows the existing electricity grid is a strictly hierarchical system in which power plants at the top of the chain ensure power delivery to customers' loads at the bottom of the chain. The system is essentially a one-way pipeline where the source has no real-time information about the service parameters of the termination points. The grid is therefore over-engineered to withstand maximum anticipated peak demand across its aggregated load. And since this peak demand is an infrequent occurrence, the system is inherently inefficient. Moreover, an unprecedented rise in demand for electrical power, coupled with lagging investments in the electrical power infrastructure, has decreased system stability. With the safe margins exhausted, any unforeseen surge in demand or anomalies across the distribution network causing component failures can trigger catastrophic blackouts. To facilitate troubleshooting and upkeep of the expensive upstream assets, the utility companies have introduced various levels of command and- control functions. A typical example is the widely deployed system known as supervisory control and data acquisition (SCADA).Given the fact that nearly 90 % of all power outages and disturbances have their roots in the distribution network; the move toward the Smart Grid has to start at the bottom of the chain, in the distribution system. Moreover, the rapid increase in the cost of fossil fuels, coupled with the inability of utility companies to expand their generation capacity in line with the rising demand for electricity, has accelerated the need to modernize the distribution network by introducing technologies that can help with demand-side management and revenue protection.

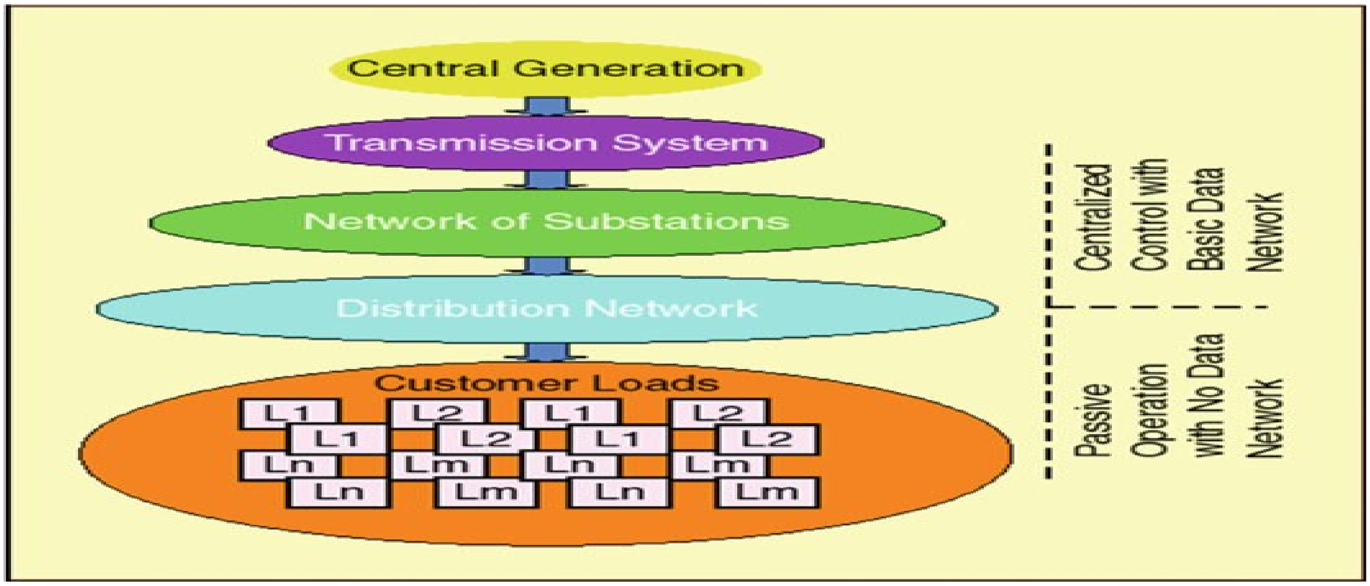

Fig. 2 Electrical Network Hierarchical System

2.2 Components of Smart Grid

For the generation level of the power system, smart enhancements will extend from the technologies used to improve the stability and reliability of the generation to intelligent controls and the generation mix consisting of renewable resources. Figure. 3 show Smart Grid returns on investments

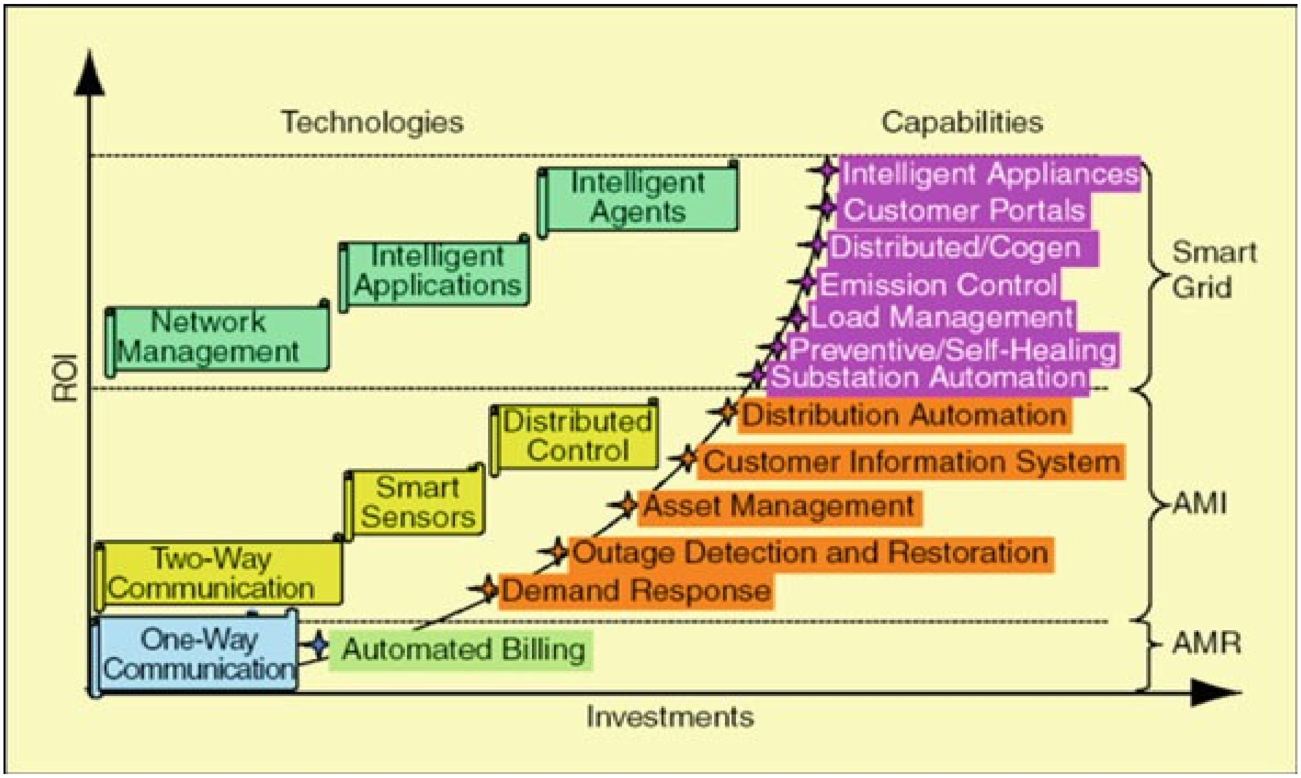

Fig. 3 Smart Grid returns on investments

2.2.1 Monitoring and Control Technology Component

In a conventional power system, electricity is distributed from the power plants through the transmission and distribution networks to final consumers. Transmission and distribution networks are designed to deliver the electricity at the consumer side at a predefined voltage level. Photovoltaic power generation is in general connected at the distribution level of the power system. For this reason, it is possible for the power produced by the photovoltaic (PV) to cause a ‘counter’ power flow from the consumer side to be delivered to other consumers through the distribution network. This phenomenon may present two challenges: an increase in the voltage in areas with high PV production and voltage fluctuation throughout the system due to the intermittency characteristics of the PV production. Intelligent transmission systems include a smart intelligent network, self-monitoring and self healing, and the adaptability and predictability of generation and demand robust enough to handle congestion, instability, and reliability issues. This new resilient grid has to resist shock (durability and reliability), and be reliable to provide real time changes in its use. Taking these issues into consideration, voltage control systems that incorporate optimal power flow computation software are developed. These systems have been designed to rapidly analyze power flow to forecast the voltage profile on the distribution network, and, in some cases, control voltage regulation equipment to ensure the appropriate voltage. The optimal control signal is developed through optimal power flow calculation.

2.2.2 Intelligent Grid Distribution Subsystem Component

The distribution system is the final stage in the transmission of power to end users. At the distribution level, intelligent support schemes will have monitoring capabilities for automation using smart meters, communication links between consumers and utility control, energy management components, and advanced meter infrastructure AMI. The automation function will be equipped with self-learning capability, including modules for fault detection, voltage optimization and load transfer, automatic billing, restoration and feeder reconfiguration, and real-time pricing. Electrical companies are accelerating efforts to develop an (AMI) to improve customer services and reduce meter reading costs. An essential element in this AMI is the smart meter. A smart meter is a device that not only measures the electricity consumption but also able to communicate with a center. Developing the communication network between the meter and the center presents several challenges, including costs and reliability.AMI technologies and systems need to be developed to ensure reliability and flexibility in measuring and controlling electricity meters through next-generation wireless mesh networks. Wireless mesh networks provide a transmission method that links electrical meters to relay data by each meter through other meters, using a multi-hop network scheme. This network is helpful reduce the time required to acquire data while at the same time curtailing costs. While wireless mesh networks present cost benefits, some challenges have to be overcome to ensure practical application. Simultaneous transfer of data between meters at the same frequency can cause signal collision, preventing reliable data collection. Figure .4 represents the advanced metering infrastructure those are being used in present days for electrical power companies

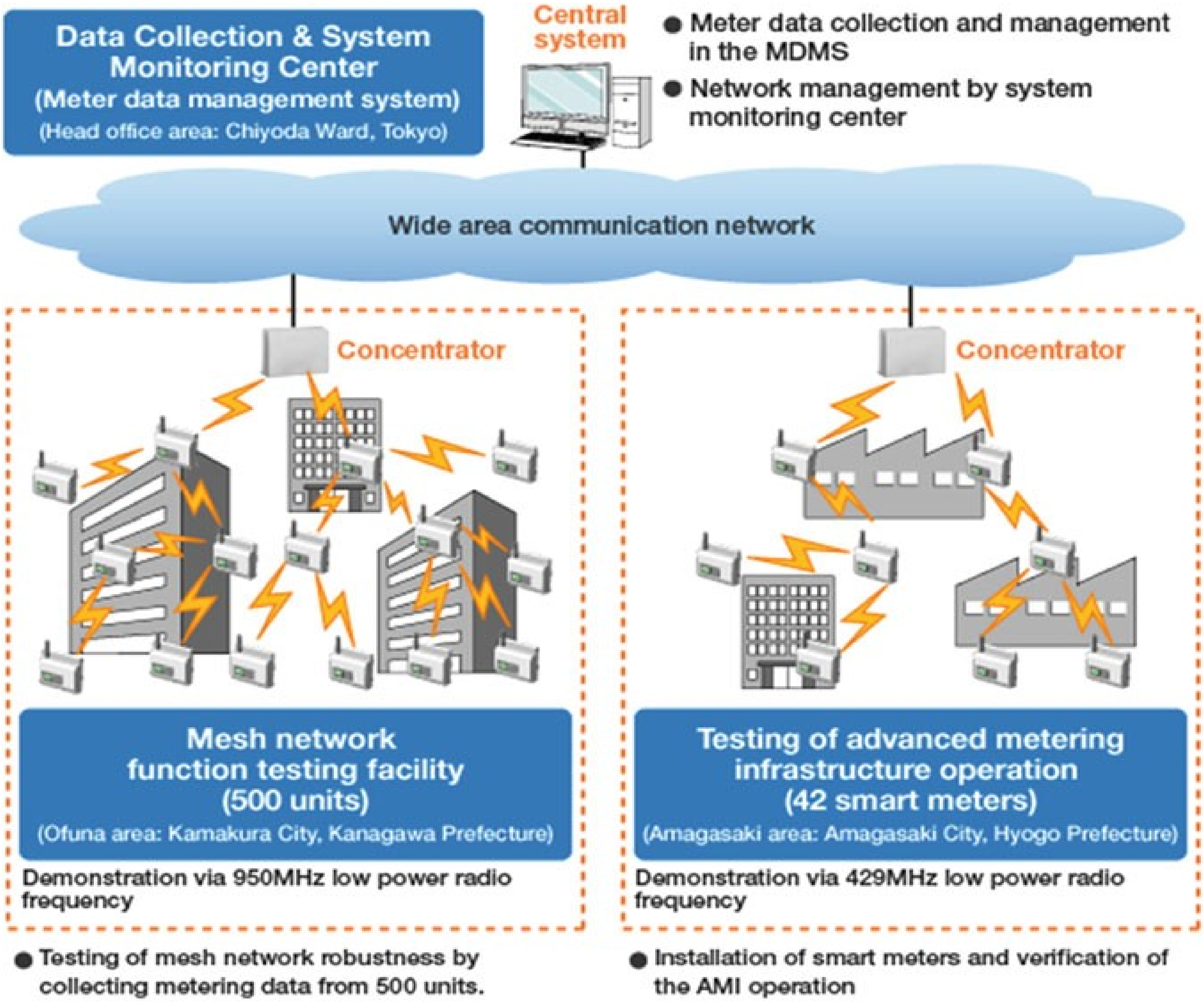

Fig.4 The advanced metering infrastructure AMI used in power system

2.2.3 Storage Component

Due to the unpredictability of renewable energy and the disjoint between peak availability and peak consumption, it is important to find ways to store the generated energy for later on use. Options for energy storage technologies include pumped hydro, advance batteries, flow batteries, compressed air, super-conducting magnetic energy storage, super-capacitors, and flywheels. Associated market mechanism for handling renewable energy resources, distributed generation, environmental impact, and pollution has to be introduced in the design of Smart Grid component at the generation level.

3. Smart Grid Analysis and Properties

There are three major participants in the Smart Grid ecosystem: consumers, utilities and third party service providers, each with a different perspective on privacy and security requirements. Here, we discuss how these stakeholders interact with the Smart Grid software architecture deployed on Clouds, and identify security and privacy concerns arising from those interactions. These are summarized in Figure 5

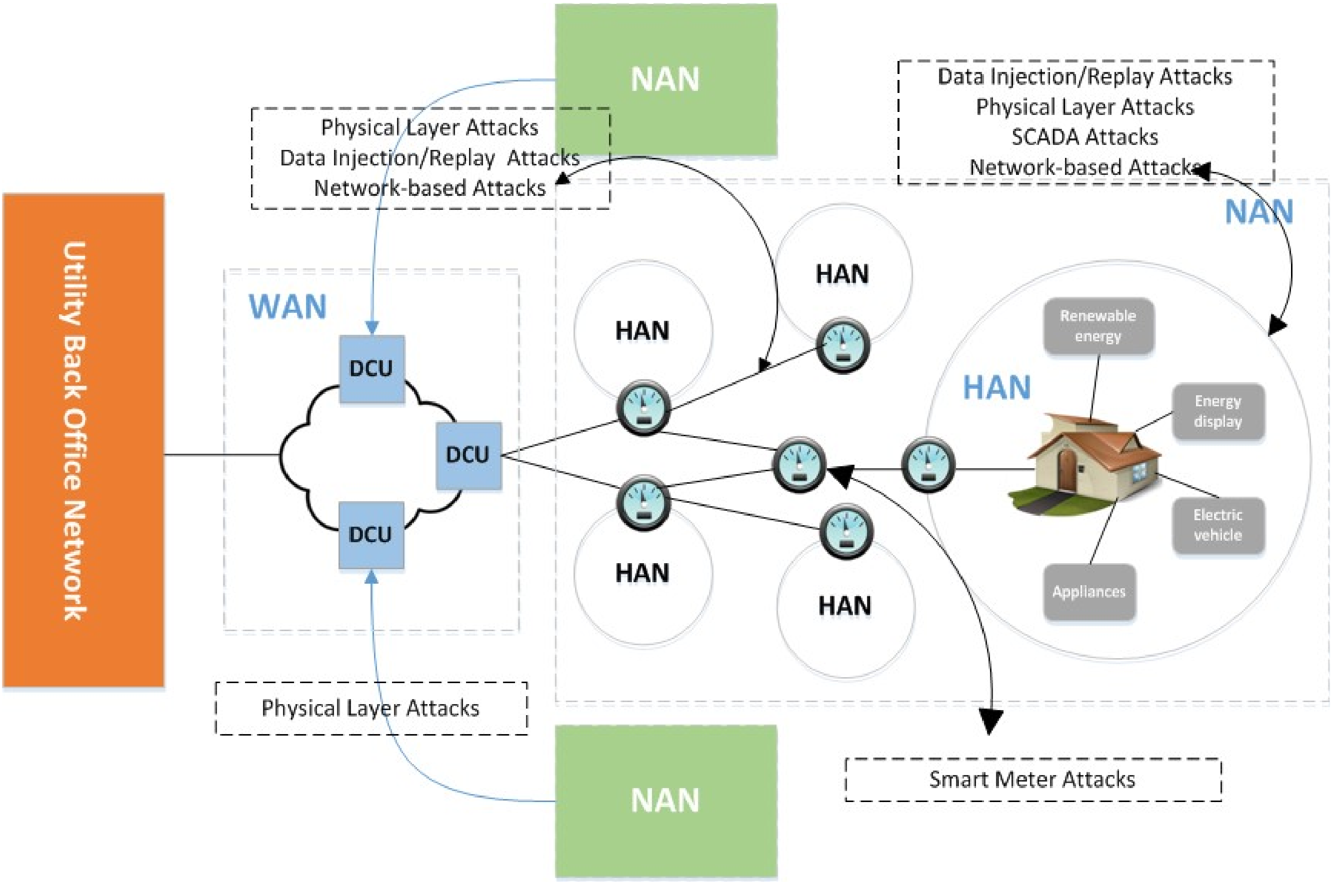

Fig 5. Smart grid communication architecture with attacks illustrated

A. Electricity users

Electricity users include residential, commercial and industrial consumers. Residential consumers, such as single or multi-dwelling residential units, may provide limited access to utilities to directly control their appliances, and voluntarily curtail their power usage when notified of real time pricing or other incentives by the utility. Industrial consumers include large scale manufacturing units which usually have significant power requirements and are willing to pay more than the residential consumers for power quality guarantees. Commercial consumers encompass businesses, shopping malls, university campuses, restaurants, retailers and so on. Industrial and commercial consumers are typically more willing than residential consumers to participate in demand optimization through direct control, given appropriate pricing incentives. Smart meters installed at the consumers' end communicate with various smart appliances within the home and building area network (HAN and BAN) to gather power usage data as well as send control signals to these appliances and equipment within the facility.

B. Smart Grid Utility

Utilities are central to the Smart Grid ecosystem and have several responsibilities such as stable grid operations including generation, transmission and distribution of power, maintaining customer satisfaction, and complying with various regulatory norms. Moving from the traditional electric grid to a Smart Grid raises several concerns for the utility providers, particularly in a Cloud environment. The utilities use the Cloud infrastructure to store and process large quantities of data collected from Smart meters and appliances as well as sensors deployed across the Smart Grid. This raises regulatory compliance issues since the data will potentially be stored and processed in a distributed manner across geographical boundaries. It also increases the exposed attack surface that can affect grid operations. It increases concerns over data leakage during data movement and sharing that can compromise consumer trust. It also exposes various forecast and pricing algorithms used by the utility to the Cloud provider. The utilities may also provide an infrastructure for third party services to run their applications in the Cloud and access consumer and other data available in the Cloud. This further adds to the security and privacy concerns such as unauthorized access to the Cloud resources.

C. Service Providers

We envision a Smart Grid ecosystem where, in addition to the primary application of optimized demand response, various other applications will be developed and deployed by third party providers offering a range of value added services to the consumers. However, regulatory norms may restrict Smart Grid data to flow out of the utility infrastructure and hence require the third party providers to deploy their services within the sandboxed environment provided by the utility in the Cloud. This raises security and privacy concerns for the application providers. For example, it can potentially expose various proprietary algorithms as well as intellectual property including data from private sources used by the third party to provide different services to the consumer. Another major challenge is the integration of the utility Cloud infrastructure with internal infrastructure including legacy security and privacy software. This makes it difficult to prove regulatory compliance since the required features will be distributed across private and utility’s public infrastructure. To accomplish the diverse necessities of the Smart Grid, the following enabling technologies must be developed and implemented:

- Phasor measurement units (PMU) and wide area monitoring, protection and control (WAMPAC) to ensure the security of the power system.

- Intelligent electronic devices (IED) to provide advanced protective relaying, measurements, fault records, and event records for the power system, integrated sensors, measurements, control and automation systems, and information and communication technologies to provide rapid diagnosis and timely response to any event in different parts of the power system. These will support enhanced asset management and efficient operation of power system components, to help relieve congestion in transmission and distribution circuits and to prevent or minimize potential outages and enable working autonomously when conditions require quick resolution.

- Smart appliances, communication, controls, and monitors to maximize safety, comfort, convenience, and energy savings of homes.
- Smart meters, communication, displays, and associated software to allow consumers to have better choice and control over electricity use. Those will provide consumers with accurate bills, accurate real-time information on their electricity use, and enable demand management and demand-side participation.

Information and communications technologies: These include

- Two-way communication technologies to provide connectivity between different components in the power system and loads.

- Open architectures for plug-and-play of home appliances; electrical vehicles, and micro-generation.

- Communications and the necessary software and hardware to provide customers with greater information enable customers to trade in energy markets.
- Software to ensure and maintain the security of information and standards to provide scalability and interoperability of information and communication systems.

Power electronics and energy storage: These include

- High-voltage DC (HVDC) transmission and back-to-back schemes and flexible
- Different power electronic interfaces and power electronic supporting devices to provide efficient connection of renewable energy sources and energy storage devices.
- Series capacitors, unified power flow controllers (UPFC) and other FACTS

devices to provide greater control over power flows in the AC grid.

- HVDC, Flexible Alternating Current Transmission Systems(FACTS), and active filters together with integrated communication and control to ensure greater system flexibility, supply reliability, and power quality.
- Power electronic interfaces and integrated communication and control to support system operations by controlling renewable energy sources, energy storage, and consumer loads.
- Energy storage to facilitate greater flexibility and reliability of the power system.

4. Smart Grid Applications

The primary objective of any power network within the Electricity Sector is to produce reliable and stable energy to all paying customers without obstruction. Achieving such goals will require considerable amount of attentiveness, engineering effort and constant monitoring of fluctuating energy parameters. Even so, accomplishing 100% energy efficiency is still seen as close to impossible. This comes as the current centralized power systems architecture contains many technical, operational and economical limitations within its infrastructure. On account of these limitations, the general public especially during summer periods witnesses numerous blackouts within their municipality. These blackouts are the most serious type of power outage and are triggered by numerous factors such as strong winds, flooding, fire, individuals leaving there air conditioners running for immense periods of time and even constant viewing of particular television events that occur randomly. Because of these causes, engineers are required to anticipate the occurrence of such events and ensure that the base load is adjusted to cope with the peak in demand. This implies that a utility company must provide the least amount of electricity to its customers Nevertheless, to tackle the issue of energy efficiency in the years to come it is fundamental that the current centralized power systems architecture be replaced by decentralized power systems architecture. This decentralized power systems architecture will have many ad-vantages, one being that electricity can be accumulated via several storage devices located near the utility system or at an isolated site disconnected from the power grid

This accumulated electricity will take immediate effect in multiple directions once a fault occurs, thus ensuring the event of a blackout will be unnoticed. Correspondingly, these storage devices will behave like a back-up generator where power is provided to the customer via renewable energy technologies and smart grid concepts. This benefit will allow engineers to repair the actual fault site without bringing about customer dissatisfaction.

4.1 Generation Distributed Systems

Generation Distributed is also referred to as “Decentralized Generation” in parts of Asia and Europe, “Embedded Generation” across the United States and “Dispersed Generation” in North America. The technology incorporates wind turbines, micro turbines, photovoltaic systems, fuel cells, energy storage and synchronous generator applications to supply active power to distributed systems connected close to the consumers load. This section of the paper provides a brief outline of general types of generation distributed technologies and key issues facing integration of the grid.

A. Wind Turbines

Wind power generation harnesses the energy of wind to drive electric power generators. This is achieved using some form of wind turbine which is operated either at variable or constant speed [7]. The advantage of using wind turbines compared to many other devices comes as there is no fuel charge, no pollution, potentially a 24 hour source of energy and units are modular with fairly linear power vs. cost relationship for large-scale installations. Disadvantages include high initial cost, unpredictability of energy production and greater environmental impacts compared to solar.

On the other hand, vertical-axis wind turbines have several advantages over horizontal axis wind turbines. The majority of their mechanical and electrical machinery is located on the ground rather than 40 - 90 m in the air.

This makes maintenance and operation simpler and reduces structural needs. Furthermore, vertical-axis wind turbines do not need a yaw control.Figure 5, illustrates a variable speed induction generator connected to a rectifier and inverter.

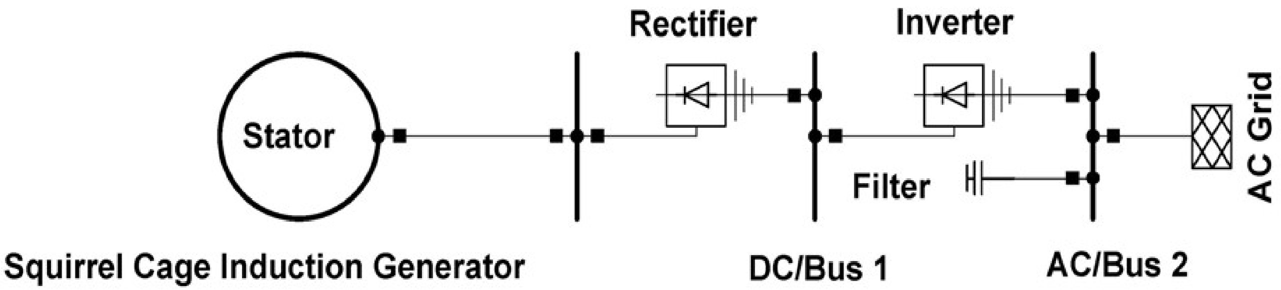

Figure 5. Variable speed induction generator.

An additional method used to operate wind turbines is by connecting the stator directly to the AC grid and the rotor through power electronic devices.

B. Photovoltaic

Photovoltaic systems convert solar energy into electric power using an array of solar cells. Solar cells are semi-conductor devices that generate DC electric power at low voltages, typically less than 0.5 Volts. A single cell may be less than a square centimeter in size and produce only a small amount of power. For this reason, many cells are connected in series to produce higher voltages and in parallel to produce higher currents. To achieve Maxi-mum Power Point Tracking (MPPT) using photovoltaic cells a DC/DC converter must be used at the output end of Figure 7. This will extract the maximum available power through a given insulation level, meaning the voltage level will be maintained as close as possible to the maximum power point. PV systems do not have any moving parts therefore less maintenance is required

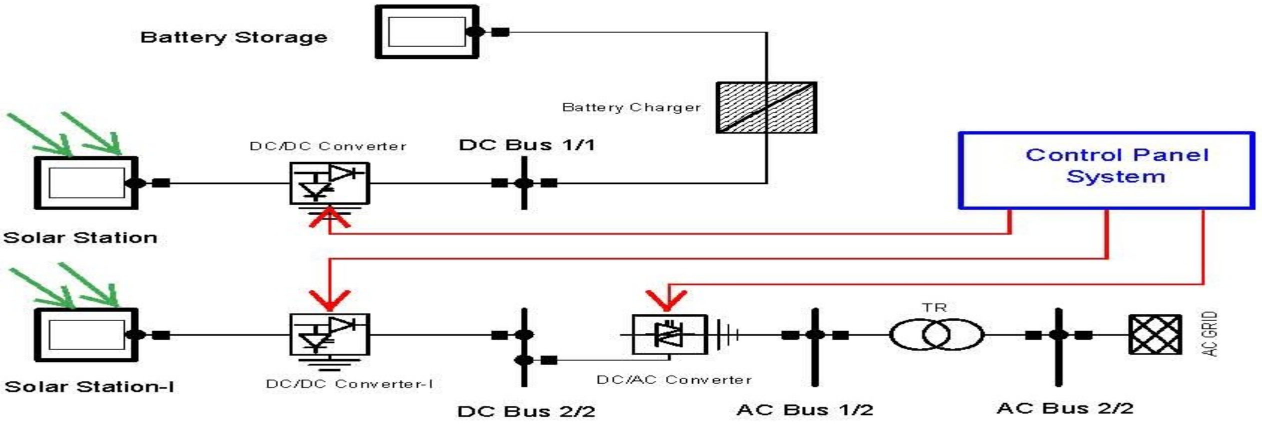

Fig 6. Photovoltaic system connected to a grid

5. Conclusion

The Characteristics of Smart Grid and comparison between traditional or existing grid and Smart Grid are also included in this paper. Afterward the history of the evolution of Smart Grid and the specific components of prospective Smart Grid function were provided. Environmental impact of implementing Smart Grid, particularly the way it can be used to reduce greenhouse gas emissions, and the overview of the technologies required for Smart Grid are discussed. For the generation level of the power system, smart enhancements will extend from the technologies used to improve the stability and reliability of the generation to intelligent controls and the generation mix consisting of renewable resources. The distribution system is the final stage in the transmission of power to end users. At the distribution level, intelligent support schemes will have monitoring capabilities for automation using smart meters, communication links between consumers and utility control, energy management components. The energy systems from the complex systems approach has been given, underlining the importance of viewing the energy system as such, especially for its future development. Modeling the energy system at system level is crucial to help us understand the interactions of the single units, and be able to observe system phenomena such as emergence and the behavior of the system as a whole.

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