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A Review on Various Smart Grid Technologies used in Power System

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Abstract – *Electrical infrastructure is expanding day by day due to which smart grid gives better vision for electrical reliability. Various parameters like quality and quantity of power transmitted should be available with the electricity board which can be achieved using smart sensing, metering and communication technologies. If all the above requirements are met in power system then it is called smart grid (SG). SG also helps consumers to manage the load patters and also to manage their expenses. The main component of SG is the communication technology to share data between consumers and grid since grid operators requires real time data to schedule their supply. The Wireless Sensor Network (WSN) uses Aggregation Protocol with Error Detection (APED) to improve the security of data. The SG with SCADA is facilitated by data acquisitions which includes the meter reading, system conditions, etc. that are monitored and transmitted at regular intervals in real time. This paper reviews the modern technologies used in smart grid communication based on IEEE 802.15.4 standard to the SG and how it is modified to ensure effective, efficient and economical and secured communication of the huge real time data from the smart meters.*

Key Words: Smart Grid, smart management, smart networking, distributed generation, smart protection systems

1. INTRODUCTION

The need to modernize the electricity grid gave birth to a new technology which is nowadays called as smart grids. Nowadays utilities are using existing infrastructure and minimizing the need to build new generating stations since SG are more autonomous and enhances the effectiveness and efficiency. The demand of electricity has grown exponentially due to which need of renewable energy resources has been increased which has provided a new dimension to power generation which includes clean energy sources like wind and PV cells in large volumes. Deregulation of power system, financial incentives and awareness towards clean environment and new energy policies have enabled the participation of renewable energy sources. The overall generation from PV solar power plant was about 25% in 2019 of the total demand whereas the electricity generation from wind farm was around 12% [1]. Now since all these latest renewable technologies are dependent on nature, the operation of power system has become very challenging. Therefore the modern power system has to be more reliable, efficient and effective since we have entered in the digital era [2]. These SG gives provision to safely plug-in all the power generated by latest renewable technologies directly to the grid

The wastage of electricity is the key factor of deciding the efficiency of power system. These significant wastages can be minimized with the help of SG technologies by minimizing inefficient distribution of power, ineffective communication and monitoring [3]. And these all disputes can be resolved by the introduction of SG. By choosing modern information and communication technology we can increase the reliability, security, stability and scalability of power system. The balance between supply and demand can be maintained at every instant due to the availability of emerging communication technologies which ensures that the real time data is exchanged [4]. With the advancement in smart metering the real time monitoring of remote electric loads has provided a best possible solution to consumers for economically consuming energy thereby reducing the cost of consumption and suggesting a way to schedule the electricity usage which is directly proportional to the frequency of grid. The advantage is it encourages the generation of energy at the user level and allows end user for participation in energy management [5] [6]. With the help of SG consumers can adjust the consumption according to the dynamic peaks where the consumers gets charged at higher tariff. The utility operator also gets an idea of power consumption of the used and accordingly the power schedule can be maintained.

Smart grid facilitates integrated operation of all entities. The electricity power generation and consumption are closely balanced which improves the efficiency of the power system. The Smart grid also brings benefit to the clean environment as it encourages consumer to generate power from the roof top PV cells [7].

2. SMART INFRASTRUCTURE SYSTEM

The smart infrastructure consists of information, and communication which are the main components of SG. SG can also be seen as a rope where electricity and information flows in both ways. For example in conventional power grid the electricity is being generated by generating units which is further transmitted by transmission grid an then distributed by distribution grid, which is finally delivered to consumers. But in SG, electricity flows in both directions [8], i.e. electricity can be generated on consumer side with the help of renewable energy resources which can be fed back to grid. This backward flow of electricity is of utmost importance, since consumers gets the benefit of generation. For example, it can be very supportive in a microgrid [9], that has been 'islanded' due to power failures. The microgrid can function, even though at a reduced level, with the help of the energy fed back by the customers. Further this paper is divided into three main subsystems:

a. The smart energy subsystem

b. The smart information subsystem

c. The smart communication subsystem

Before discussing about all three subsystem lets have an overview on smart grid (SG).

2.1 OVERVIEW OF SMART GRID

A typical smart grid structure is shown in Figure 1. The main structure of SG consists of the following subsections, which are:

a. Generation

b. Transmission

c. Distribution

d. Control network

Each subsection is interconnected at various locations and information is exchanged and communicated by means of smart communication subsystem such as an access point with wired or wireless communication. Raw information of the network like health of system or performance is obtained from a subsystem known as information subsystem which consists of smart meters, sensors and phasor measurement unit (PMU) [10]. Real time monitoring, management and control are performed at control network subsystem. Alongside an individual network via distribution network can be dispersed as generation station condition is and renewable energy resource generation is taking on consumer side. The benefits of smart grid are as follows:

a. Getting better power reliability and quality;

b. Optimizing capability utilization and prevention Construction of back-up (peak load) power plants;

c. Enhancing capability and efficiency of live electric power networks;

d. Getting better resilience to interruption;

e. Enabling analytical maintenance and self-healing responses to system turbulence;

f. Facilitating extended use of renewable energy sources;

g. Cooperative distributed power sources;

h. Automating safeguarding and operation;

i. Reducing greenhouse gas emissions by enriching electric vehicles and new power sources;

j. Reducing oil expenditure by reducing the need for wasteful generation during peak usage periods;

k. Presenting opportunities to improve grid security;

l. Enabling change to plug-in electric vehicles and new energy storage options;

m. Rising consumer choice;

n. Enabling fresh products, services, and markets.

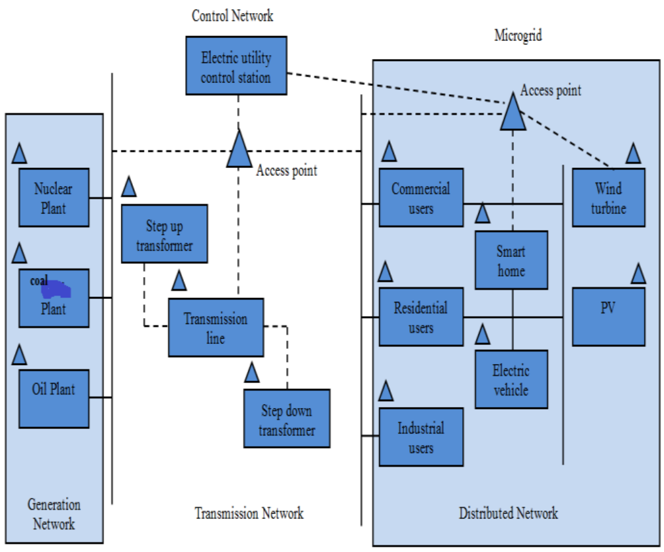

Figure -1: Structure of Smart Grid

2.2 SMART ENERGY SUBSYSTEM

The bidirectional flow of information and energy takes place at the information place of infrastructure base of smart grid. In this subsection of review paper the existing works on smart energy subsystem is explored and summarized indicating the challenges faced. As we look back in history the conventional power grid is only one way i.e. the power flows from generation to distribution, electricity was conventionally produced at a central power plants by electromechanical generators which were driven by mechanical force developed by the flow of water or heat engines. In order to take benefit of the economies of size, the generating plants are generally quite large and situated away from heavily populated areas. The generated electric power is stepped up to a higher voltage for transmission on the *transmission grid*. The transmission grid moves the power more than long distances to substations. Upon coming at a substation, the power will be stepped down from the transmission level voltage to a distribution level voltage. As the power exits the substation, it enters the *distribution grid*. Lastly [11], ahead arrival at the service location, the power is stepped down again from the distribution voltage to the essential service voltage(s). Figure. 2 shows an example of the conventional power grid. In compare with the conventional power grid, the electric energy generation and the run pattern in a Smart Grid

are suppler. For example [12], the distribution grid may too be competent of generating electricity by using solar panels or wind turbines.

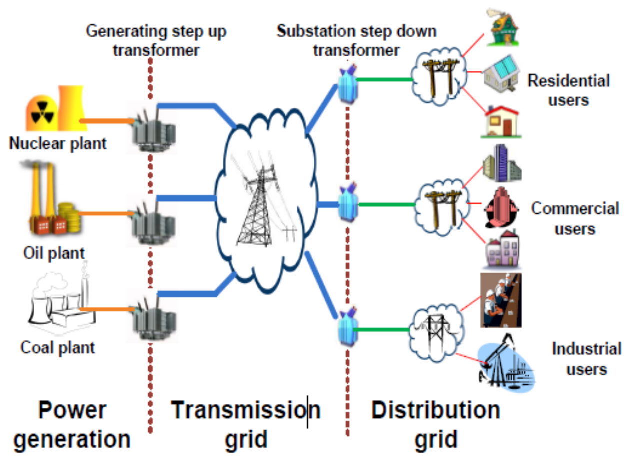

Figure -2: Conventional Power Grid

2.3 POWER GENERATION

Generation of electricity is the practice of generating electricity from other forms of energy such as natural gas, coal, nuclear power, sun and wind. Early in 1800 Michael faraday first discovered the principle of electricity generation electricity can be generated by the motion of a loop of wire or a disc of copper between the poles of a magnet [12] . There are other various energy sources which generate electric power and since most of the non renewable energy resources are getting eliminated most of the countries have started opting to renewable energy resources. In comparison to the conventional power grid a smarter power generation where the flow of power and information is bidirectional is recommended in SG applications. A microgrid, which is a localized assemblage of electricity generators and loads, can cut off from the macrogrid so that distributed generators carry on to power the users in this microgrid without obtaining power from outer. Thus, the trouble in the macrogrid can be isolated and the electric power supply quality is enhanced. A review of diverse distributed energy technologies such as micro turbines, photovoltaic, fuel cells, and wind power turbines can be found. However, implementing DG(s) in practice is not an easy plan due to a number of reasons. *First*, DG involves bulky scale deployments for generation from renewable resources, such as solar and wind, whose yield is, though, subject to wide fluctuations [13]. In general, the generation patterns ensuing from these renewable and the electricity demand patterns are distant from being equal. Therefore, efficient utilization of the DG in a way that is aware of the variability of the yield from renewable sources is significant. Even though it can only see a limited saturation of DG in today's power system, the future SG is expected to approve a large number of distributed generators to form a much more decentralized power system. It may develop from the present system in three stages [14]:

a. Accepting DGs in the present power system;

b. Introducing a decentralized system of DGs cooperating with the centralized generation system;

c. Supplying largely power by DGs and a partial amount by central generation.

2.3 SMART COMMUNICATION NETWORK

The biggest challenge faced by smart grids is too integrate the wireless communication with traditional power system. As it is clear that efficiency of power system increase if the flow of power and information is bidirectional. Therefore the key component of SG is the communication network which should provide real time, accurate, reliable and huge volume of information [15]. The smart meters at the consumers end with information management and control system are connected to the communication network. Thus the development of SG communication technology has taken a giant leap from wired fiber optic cable and power line communications (PLC) to wireless cloud computing.

2.4 DATA MANAGEMENT SYSTEM

In order to extract maximum information from smart meters data management systems are required. These systems should be able to process large amount of real time data. The several subsystems of data management system are billing system, customer information system, distribution management, geographic information system, outage management system [16]. These several subsystem serve the purpose to send and receive data and control signals to update the load patterns which eventually makes billing easier and transfers energy efficiently. Further this system helps the utilities and grid operators to maintain all the records like voltage levels at load end, inclusion of reactive power compensations for maintaining stability and reactive power of the system.

The communication system includes communication between the several layers, a protocol to enable communication among the entities.

a. Identification of different communication technologies which is suitable for different parts of the system.

b. Ensuring security of data transfer between different parts of the network.

3. WIRELESS SENSOR NETWORK IN SMART GRID

Wireless Sensor Networks (WSN) will be one of the dominant technology advancements in monitoring various applications in most of the scenarios [17]. The distribution energy generation has an advantage of customers being independent of the grid and helps in reducing the emission of greenhouses gases. But in case of faults due to reverse power flow, voltage rise or any other cause the distributing generating units are to be isolated from the gird using electronic converters and inverters. So, the control has to be done in three phases such as sensing, data communication and control. The Wireless Sensor Nodes (WSN) is implemented for enabling the sensing part more effective. A combination of ultra-low power RF signals using WSN transceiver module is designed for data communication

Zigbee is best suited technology for SG because Zigbee has short-range, low data rate, energy-efficient that is based on IEEE 802.15.4 standard. In Zigbee sensor nodes are either organized in star, mesh, and cluster topology [18]. But mesh topology is the top most among all the topologies. Figure 3 shows a typical application WSN in smart grid technology.

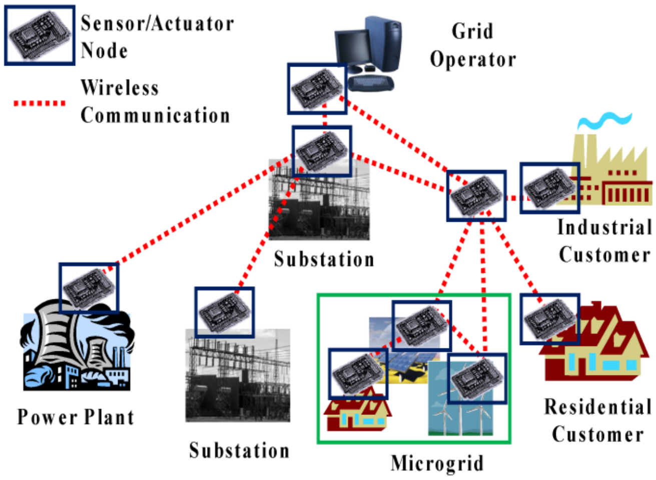

Figure -3: Wireless Sensor Network based Smart Grid

An aggregator is proposed in between the user and the trusted authority. To ensure privacy of data transfer between customer and smart grid control centres a protocol with error detection (Aggregation Protocol with Error Detection APED) is proposed. This protocol has three main phases namely, 1) data encryption and reporting, 2) aggregation with error detection and 3) dynamic Join and leave. The DG-APED provides error detection and reduced communication overhead. The advantages of WSN in smart grid are:

a. Enhancement in electric power systems and its infrastructure is less nature.

b. Remote System Technology for Monitoring and Fault Diagnostics

Whereas the challenges faced by wireless sensor network in smart grid applications are:

a. RF interference due to Harsh environmental conditions

b. Assured Service quality and reliability.

c. Packet errors and variation in link capacity

d. Resource constraints Energy, memory, and processing are constraint of WSNs.

4. SCADA (SUPERVISORY CONTROL AND DATA ACQUISITION) IN SMART GRID

The SCADA to SG collects and communicates smart meter readings and the sensor statuses at regular intervals to enable real time monitoring. The data transferred is sent to the RTU for further processing and also to a human controller to override settings whenever necessary. There are open software packages like Wonderware and Citect for SCADA systems [19]. Asset management can also be integrated in SCADA system but may result in security issues. The SCADA to the SG have a two-layer communication model with a back bone structure and a local area network. The back bone network should have the infrastructure nodes which carries the routers across the nodes of the smart grid as shown in figure 4.

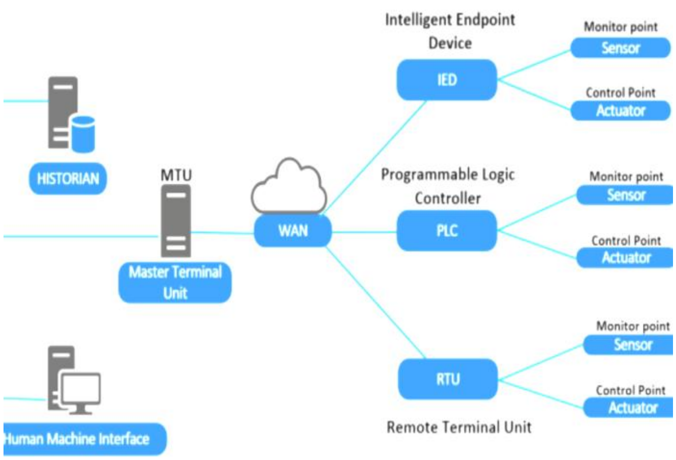

Figure -4: SCADA system at smart grid

Data security is essential as each node is dealing with huge amount of data. The data is encrypted to overcome this major drawback. Asymmetric and symmetric encryptions are the two major encryptions used. Symmetric encryption is slower and costlier but provides more functionality than symmetric encryption. Symmetric encryption is cheaper but provides data security. The Cross Crypto graphic algorithm is proposed which combines the best features of both the symmetric and asymmetric encryption techniques. The cipher test of the message and that of the key are sent to the SCADA assets. The cipher text is decrypted by the SCADA Masters and is compared with the computed digest. The message is accepted only when both digests matches otherwise rejected.

4.1. SCADA NETWORK

SCADA is a communication network which supports two level tree topology networks. It consists of wireless radio links and dial up lines and modem connections. Though the newer substations connected to the smart grid may be capable of handling the excess volume of data, the existing links between the generating stations, load centers and control center are incapable of handling this volume of data. So, there must be an assurance of handling the huge amount of data whenever a smart grid is developed. So, the communication network should evolve a structure of an internet but with some differences. With the availability of off the shelf products like Wi-Fi and Zig bee also reduced the complexity of the communication of the smart meters, home area network devices.

4.2. SCADA CONTROL

The periodic monitoring of electrical devices results in a huge amount of data flow. Some distribution companies use broadband internet access or data transmission through a reserved band of frequency [20] [21]. The control is done in three levels based on the different voltage levels of the power system such as low voltage at load end, medium voltage at generation and high voltage at transmission. Different technologies are adapted for communication and control at these levels whichever is suitable. Power line communication (PLC) is used at low voltage levels to transfer load data and control signals inside the buildings. The advantages of SCADA system to smart grids are:

a. Mitigates and stands resilient to physical and cyber attacks.

b. Assure power quality as required by the 21st century consumers.

c. Enables participation of every element in the competitive markets with lower transaction costs and real time information communication.

5. CLOUD COMPUTING TO SG COMMUNICATION

Cloud computing is a technique which enables the rapid access of networks servers and storage of a collective pool with a minimal management effort or service provider interaction. The smart grid environment deals with huge amount of data. The security of data becomes an important constraint which is effectively handled by the cloud computing.

a. Cloud Owner: It is the authority who defines and responsible for the attributes of data access policy. It's about the data apprehension. And in SG the cloud owner is the electricity company.

b. Cloud User: It is the entity which needs to access the data of others when the security parameters are satisfactory. In SG the consumers and the system operators are the cloud users.

c. Cloud server: It is the element which stores data, facilitates sharing services, providing retrieval and revocation services. The electricity company owns the cloud server.

d. Key Administration Center: It communicates with the entities and the cloud server by creating and managing the keys for secured communication. The data management center will hold the position of administration center.

The efficiency of the SG can be improved by providing addition cloud services such as AWS Inspector, AWS Cloud Watch, AWS Cloud Trail, and AWS Config to automate compliance controls. Researchers are now focusing on how to apply cloud computing to smart grids. Researchers are still ongoing where to apply the cloud computing technique to augment the efficiency of the smart grid. The demand response optimization using cloud platform has been analyzed in [22]. The cloud platform has been used for host address centric communications for large scale smart metering resulted in a faster reply time. The power flow analysis is added to smart grid to formulate routing of the service requests in cloud computing for smart grids [23]. Security issues like voltage and load angle at various nodes of the smart grid are focused [24] [25] and some new security mechanisms were introduced for a better integration of smart grids and clouds. Figure 5 shows smart grid with cloud communication

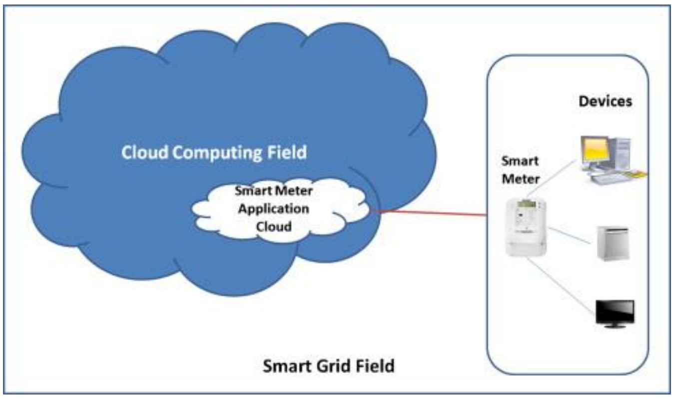

Figure -5: Smart Grid with cloud communication

Energy consultants, energy consumers and transmission service providers and modern web-based communication technology have brought together by cloud computing along with a decision support system [26]. Application of cloud computing in information management in smart grid has resulted in several advantages [27] and it is proved that cloud computing is fit for SG. Cloud computing network for SG includes security, consistency, fault tolerant services, real-time assurances and ways to protect the privacy of sensitive data. The security of data transfer is assured by the introduction of improvised Ciphertext Policy_ Attribute Based Encryption (CP-ABE) is used to achieve the security parameters like confidentiality, integrity, and availability.

[28][29][30]. The advantages of cloud communication in SG are:

a. Ensured security and reliability.

b. Privacy of data transferred is preserved.

c. Vulnerability to attack can be rectified by proactively classifying information and apply access control.

d. More guaranteed flexibility when Pay-as-yougo cloud services are chosen.

Whereas the challenges faced by cloud communication in smart grid are:

a. The Downtime of the network is the major drawback of cloud computing.

b. Cloud computing transfer's only minimum control to the customer.

c. Vendor lock-in is another challenge of cloud computing. Migrating from one cloud platform to the other is difficult and would involve additional cost and configuration complexities.

6. CONCLUSIONS

This paper has given a wide view of various communication technologies used in smart grid. The WSN for SG has reduced the size, operation and maintenance cost and resulted in more throughput per $ investment. The data acquisition is done by the SCADA software and the security of data is ensured by the cross crypto graphic encryption. SCADA to SG resulted in increased resilience of power system. Cloud computing is proved suitable for SG with the efficient real time transfer of meter readings and sensor control signals with assured security. Block chain to SG doesn't need any major architectural changes which has improved the scalability of the power system.

With assured faster real time data transfer with the block chain technology we want to extend this work towards applying an artificial intelligence technique for scheduling the dg sets along with the roof top PV generation.

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