Internet of Things Integrated Smart Grid: The Future of Energy

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Abstract – *Electricity is the key energy source for electronics products are used at all levels of society, from residential to industrial. Around the world, the majority of electrical power grids are operated by fossil fuels, which are becoming increasingly scarce and are supposed to run out in the upcoming years. So, Conventional electrical power grids are being transformed into smart grids (SGs). The smart grid is a transformation of the conventional power system that relies highly on the interaction of energy, control & communication infrastructure. Smart Grid facilitates bidirectional energy flow between service providers and consumers by integrating power generation, transmission, distribution, and utilization systems. Smart Grids make extensive use of a variety of devices to monitor, analyze, and control the grid, which are deployed in large numbers at power plants, distribution centers, and consumers' premises. Although, the Smart Grid requires connectivity, automation, and the tracking of such devices. Utilizing Internet of Things, this can be achieved. The Internet of Things (IoT) is a large dynamic global network infrastructure of Internet-enabled entities with web services. The Internet of Things (IoT) assists smart grid systems to support various network functions throughout the generation, transmission, distribution, and consumption of energy by integrating IoT devices (such as sensors, actuators, and smart meters), and also by providing connectivity, automation, and tracking for such devices. In this article, we have discussed about IoT, Smart Grid and their relationship, IoT integrated Smart Grid Technology, IoT architectures in Smart Grid, IoT applications and services in Smart grid, challenges and future research directions for the IoT integrated Smart Grid.*

***Key Words*: Internet of Things, Smart Grid, AMI, HAN, NAN, WAN.**

1. INTRODUCTION

A conventional electrical power grid comprised of a huge number of loosely connected simultaneous Alternate Current (AC) grids. It performs three main functions: generation, transmission, and distribution of electrical energy, in which electric power flows only in one direction, i.e., from a service provider to the consumers [1]. Firstly in power generation, Numerous power plants generate electrical energy, primarily through the combustion of carbon and uranium-based fuels. Secondly in power transmission, High-voltage transmission lines are used to transport electricity from power plants to distant loads centers. Thirdly in power distribution, Electrical distribution systems provide reduced-voltage electricity to end users. Each grid is centrally maintained and regulated to ensure that power plants generate electrical energy in accordance with the customer demands while adhering to power system constraints. Almost entirely of the generation, transmission, and distribution of electrical energy is owned by utility companies, which provide electrical energy to consumers and charge them appropriately to recover their costs and earn a profit [1]. The power grids endure a significant wastage of energy due to a number of factors, such as consumers' inefficient appliances and lack of smart technology, inefficient routing and dispensation of electrical energy, unreliable communication, and monitoring, and most importantly, lack of a mechanism to store the generated electrical energy. Furthermore, power grids face some other challenges as well, including growing energy demand, reliability, security, emerging renewable energy sources and aging infrastructure problems to name a few [1].

In order to resolve these challenges, the Smart Grid (SG) mechanism has emerged as a promising approach that incorporates a variety of information and communication technologies. Such technologies can improve the effectiveness, efficiency, reliability, security, sustainability, stability, and scalability of the traditional power grid. In numerous ways, the smart grid is different from traditional power grids. For example, the Smart Grid allows for bidirectional communication between service providers and consumers, whereas a traditional power grid only allows for unidirectional communication from the service provider to the consumer. Smart Grid features include Advanced Metering Infrastructure (AMI), smart meters, fault tolerance, unauthorized usage detection, and load balancing, as well as self-healing, which refers to the detection and recovery from faults [11].

Smart Grid reduces energy waste by generating energy that closely matches demand. For example, Smart Grid assists in real-time pricing, self-healing, power consumption scheduling and optimized electrical energy usage [6]. By maintaining a balance between power generation and consumption, such decisions can significantly improve power quality and grid efficiency.

Smart Grid utilizes multiple devices to monitor, analyze, and control the grid. Hundreds, millions or even billions of such monitoring devices are installed at power plants, transmission lines, transmission towers, distribution centers, and consumer premises. One of the primary concerns for the Smart Grid is the connectivity, automation, and tracking of such a large number of devices, which requires distributed monitoring, analysis, and control via high-speed, ubiquitous, and bidirectional digital communications [17]. It requires the distributed automation of the Smart Grid to accommodate such devices or "things". As a result of the Internet of Things (IoT) technology, this is already becoming a reality in the physical world. The Internet of Things (IoT) is defined as a network that connects any object to the Internet via a protocol for exchanging data and communicating among various smart devices in order to accomplish monitoring, tracking, management, and location identification objectives [26]. The Internet of Things (IoT) has gained significant attention in recent years due to its ability to connect various network-enabled devices.

Internet of Things (IoT) is a term that refers to a network of physical objects or things that are connected to the Internet [28]. These objects contain embedded technology that enables them to communicate with both their internal and external environments. Through high-speed and two-way digital communications, these objects sense, analyze, control, and make decisions independently or in collaboration with other objects in a distributed, autonomous, and ubiquitous manner [1]. This is just what the Smart Grid needs. So, IoT technology can assist SGs by supporting various network functions throughout the power generation, storage, transmission, and distribution systems, as well as by integrating IoT devices (such as sensors, actuators, and smart meters), as well as by providing connectivity, automation, and tracking for such devices [21].

The Smart Grid (SG) is widely regarded as one of the largest IoT applications. Although many domestic devices that use electricity are now connected to the Internet, there are still a significant number of domestic devices that are not. For example, the number of microwave ovens and washing machines that are connected to the Internet is significantly less than the number that are not [1]. Essentially, anything that consumes electricity can be enhanced by connecting it to the Internet (such as, microwave ovens and washing machines, that are connected to the Internet can be operated remotely and at off-peak times, thus saving cost, as well as provide comfort to human through automation). So, in the future, we can expect the Smart Grid integrated with IoT to be larger than the Smart Grid today, and the modern and intelligent grid (SG) will not be possible without IoT [1]. By establishing the Internet of Things as a global standard for communications and the foundation for the Smart Grid, new doors for future innovation will be opened.

2. INTERNET OF THINGS

The Internet of Things (IoT) is a network of devices that connects people and things at any time, in any location, with anyone and anything, via any network and service. In 1999, members of the community developing Radio Frequency Identification (RFID) proposed the Internet of Things concept. In 2005, the International Telecommunication Union (ITU) published an annual report on the Internet of Things, which expanded the concept of the Internet of Things even further [2]. The Internet of Things (IoT) is defined as a network that connects any object to the Internet via a protocol for exchanging data and communicating among various smart devices in order to accomplish monitoring, tracking, management, and location identification objectives. Thus, IoT is a huge dynamic global network infrastructure of Internet-enabled physical and virtual objects/entities with web services which contains embedded technologies and all types of information devices such as global positioning system (GPS), infrared devices, scanners, radio frequency identification (RFID) tags/devices, sensors, actuators, smartphones, and the Internet to sense, identify, locate, track, connect, monitor, manage, communicate, cooperate, and control of objects/ things in physical, digital and virtual world [2]. Thing-oriented, Internet-oriented, and semantic-oriented are the main concepts of IoT implementation. Smart devices, such as RFID tags, sensors, actuators, cameras, laser scanners, the Global Positioning System (GPS), and Near Field Communication (NFC) are all part of the things-oriented concept. The Internet-based concept allows smart devices to communicate with each other via ZigBee, Wi-Fi, Bluetooth, and cellular communications. The semantic oriented concept realizes a variety of applications with the help of smart devices [1].

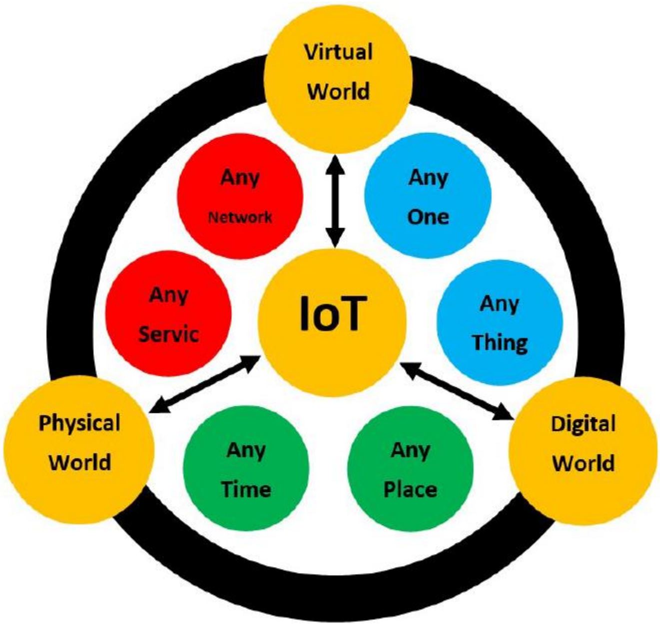

Fig -1: IoT with its connections & associated entities [2]

The Internet of Things is an integration of different hardware & software technologies. The Internet of Things combines information technology, which includes hardware and software used to collect, store, and process data, and communication technology, which includes electronic systems used to communicate between one or more objects. The combination of heterogeneous communication technologies must be adjusted to meet the reliability, speed, security, and energy efficiency requirements of IoT applications [3]. The implementation of the Internet of Things allows for more extensive communication with various objects in our environment through the Internet. In order to implement the Internet of Things, a wide range of technology enablers must be used, including sensor networks, GSM, GPRS, 4G / 5G, WI-FI, GPS, RFID, microcontrollers, and so on.

The Internet of Things (IoT) has gained significant attention in a variety of applications in recent years, allowing the Internet to be connected to a variety of network-embedded devices used in daily life. The term "Internet of Things" refers to devices and services that are more advanced than traditional machine-to-machine connectivity and support a wide range of protocols and applications [2]. In the future, connectivity will take on a completely new dimension as it will include not only humans and devices, but also a wide range of other objects. Physical items can connect to the virtual world, be controlled remotely and act as physical access points to Internet services [6]. The Internet of Things has automated the operation of a variety of systems, including health care, transportation, the military, home appliances, security, surveillance, agriculture, and power grids. The Internet of Things (IoT) implementation in Smart Grids can be divided into three categories. First, IoT is applied to gather information from equipment through various communication technologies. Second, the Internet of Things is being used to monitor the condition of equipment through the use of various smart devices. Third, the Internet of Things (IoT) is utilized to control the Smart Grid through an application interface [2].

3. SMART GRID

Smart Grid is a modern electrical grid concept that has been planning, developing, and researching since 2007. Smart Grid is defined as a communication network on top of the electricity grid to gather and analyze data from different components of a power grid to predict power supply and demand which can be used for power management. It is a smart electricity network that use two-way information technology, secure cyber communication technology and intelligence of computing integrated in the entire spectrum of electrical energy systems ranging from generators to consumers [3]. The Smart Grid has been promoted as a promising solution for reducing electrical energy waste and for resolving the issues associated with traditional power grids, enabling advancements in efficiency, effectiveness, reliability, security, and stability, as well as meeting the increasing demand for electrical energy. The key characteristics of the Smart Grid are self-healing, improved electricity quality, distributed generation and demand response, cooperative operation and user participation, and efficient asset management [19].

The following are some of the functionalities that are required for the deployment of the smart grid:

1.Communication networks: Public, private, wired, and wireless communication networks that can be used as the communication infrastructure for smart grid [2].

2.Cybersecurity: Determining measures to guarantee availability, integrity, and confidentiality of the communication and control systems which are required to manage, operate, and protect smart grid infrastructures [2].

3.Distributed energy resources: Using different kinds of generation (e.g., renewable energies) and/or storage systems (batteries, plug-in electric cars with bi-directional chargers) that are connected to distributed systems [2].

4.Distribution grid management: Trying to maximize the performance of components in distribution systems such as feeders and transformers and integrate them with transmission systems, increase reliability, increase the distribution system efficiency, and improve management of distributed renewable energy sources [2].

5.Electric transportation: Integrating plug-in electric vehicles in a large-scale [2].

6.Energy efficiency: Providing mechanisms for different kinds of customers to modify their energy usage during peak hours and optimizing the balance between power supply and demand [2].

7.Energy storage: Using direct or indirect energy storage technologies such as pumped hydroelectric storage technology [2].

8.Wide-area monitoring: Monitoring of power system components over a large geographic area to optimize their performance and preventing problems before they happen [2].

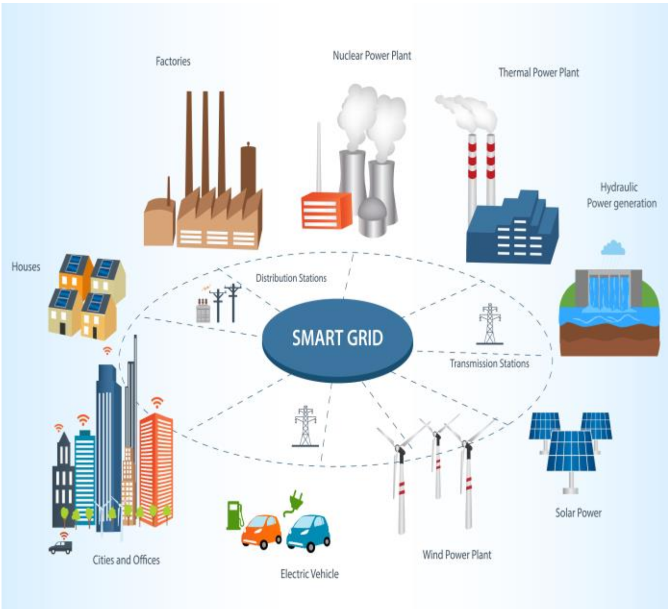

Fig -2: Smart Grid Architecture

Smart Grid (SG) is envisioned to be the next-generation electric power system. Smart grid can be considered a particular case of Machine to Machine (M2M) communications. SG completely revolutionizes the energy generation, transmission, distribution, and consumption in four sub-systems. Smart grid is consist of three types of networks namely Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN) [24]. HAN is the first layer; it is responsible for managing the on-demand power requirements of consumers. It is comprised of smart devices, home appliances (such as washing machines, televisions, air conditioners, refrigerators, and ovens), electrical vehicles, and renewable energy sources (such as solar panels) [13]. The HAN network connects electrical appliances to smart meters in residential units, industrial plants, and commercial buildings. The NAN, alternatively referred to as the Field Area Network (FAN), is the second layer of an SG and is made up of smart meters that are connected to multiple HANs. NAN supports communication between distribution substations and field electrical devices for power distribution systems. It collects the service and metering information from multiple HANs and transmits it to the data collectors which connect NANs to a WAN [21]. WAN is the third layer of an SG, and it serves as a backbone for communication between network gateways or aggregation points. It facilitates the communication among power transmission systems, bulk generation systems, renewable energy sources and control centers [1].

4. IoT INTEGRATED SMART GRID

The Smart Grid has already gained effective implementation in the sensing, transmission, and processing of data, and IoT technology is now playing a significant role in grid construction. The initiative behind Smart Grid is to improve planning, maintenance, and operations by ensuring that each component of the power grid can 'listen' and 'talk' to one another, as well as to enable automation in Smart Grid. For example, in a traditional power grid, the utility company knows about a service interruption only after customers notify them [11]. In Smart Grid, the utility company will automatically know about the disruption of service because certain components of Smart Grid (such as smart meters in the affection region) will cease sending the collected sensor data. Here, the Internet of Things plays the key role in enabling this scenario because all the components of the grid must have IP addresses and should be capable of two-way communication. The Internet of Things has made this possible. IoT technology enables interactive real-time network connectivity between users and devices via various communication technologies, power equipment via various IoT smart devices, and the collaboration required to achieve real-time, two-way, and high-speed data sharing across multiple applications, thereby increasing the overall efficiency of a Smart Grid. The application of the IoT in SGs can be classified into three types based on the three-layered IoT architecture. Firstly, IoT is applied for deploying various IoT smart devices for the monitoring of equipment states. Secondly, IoT is applied for information collection from equipment with the help of its connected IoT smart devices through various communication technologies. Thirdly, IoT is applied for controlling the Smart Grid through application interfaces [1].

IoT sensing devices are generally comprised of wireless sensors, RFID (Radio Frequency Identification), M2M (machine-to-machine) devices, cameras, infrared sensors, laser scanners, GPSs, and various data collection devices. The Internet of Things (IoT) technology has the potential to significantly enhance and support information sensing in Smart Grid [10]. The IoT technology also plays a key role in the infrastructure deployment of data sensing and transmission for the Smart Grid, assisting in network construction, operation, safety management, maintenance, security monitoring, information collection, measurement, user interaction etc. Furthermore, the Internet of Things (IoT) enables the integration of information flow, power flow, and distribution flow in the Smart Grid environment [34].

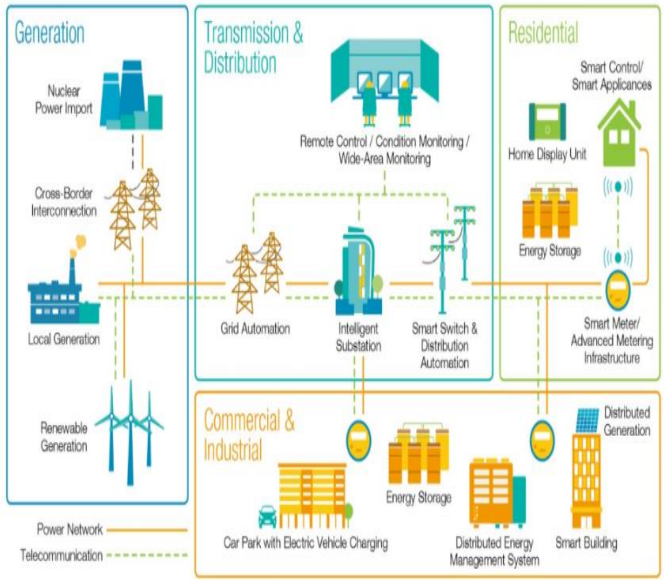

Fig -3: Integration of IoT into Smart Grid [3]

Power generation, transmission, distribution, and utilization are the four main subsystems of the Smart Grid. IoT can be applied to all these subsystems and appears as a promising solution for enhancing them, making the IoT a key element for Smart Grid [29]. In the area of power generation, the IoT can be used for the monitoring and controlling of energy consumption, units, equipment, gas emissions and pollutants discharge, power use/production prediction, energy storage and power connection, as well as for managing distributed power plans, pumped storage, wind power, biomass power and photo-voltaic power plants. In the area of power transmission, the IoT can be used for the monitoring and control of transmission lines and substations, as well as for transmission tower protection. In the area of power distribution, IoT can be used for distributed automation, as well as in the management of operations and equipment. In the area of power utilization, the IoT can be used for smart homes, automatic meter reading, electric vehicle charging and discharging, for collecting information about home appliances' energy consumption, power load controlling, energy efficiency monitoring and management, power demand management and multi network consumption [1].

5. IoT INTEGRATED HOME AREA NETWORK(HAN)

The first layer is the HAN; it manages consumers' on-demand energy requirements and is comprised of smart devices, home appliances (such as washing machines, televisions, air conditioners, refrigerators, and ovens), electric vehicles, and renewable energy sources (such as solar panels) [9]. The HAN network connects electrical appliances to smart meters in residential units, industrial plants, and commercial buildings. HANs can be organized in a star topology or a mesh topology, depending on their purpose. The preferred communication technologies for HANs are powerline communications (wired technology), ZigBee, Bluetooth, and Wi-Fi (wireless technologies) [14]. A HAN consists of a variety of Internet of Things (IoT) smart devices, such as a home gateway, smart meters, sensor and actuator nodes, smart home appliances, and electric vehicles. A home gateway establishes a connection with smart meters and collects data on the power consumption of household appliances on a periodic basis [1].

Fig -4: IoT Integrated Home Area Network

HANs have two distinct functions: commissioning and control. The commissioning function is responsible for identifying new devices and managing them. The control function facilitates communication among smart devices by establishing links, and it ensures that the various Smart Grid layers operate in a reliable manner [35]. A HAN is a two-way communication system that provides demand response management services. In the forward communication direction, the smart meters' load and real-time power consumption information of the home equipment, connected to IoT smart devices, are collected by home gateways and transmitted from the consumer side (the HAN) to the NAN to be forwarded to a utility center. In the backward communication direction, the home gateway serves as a central node, receiving dynamic electricity pricing information from the NAN and relaying it to smart meters or Internet of Things smart devices, which in turn trigger the necessary action for home appliances to be turned on [7].

5.1 Smart Home

The Internet of Things (IoT) technology plays a significant role in the Smart Grid, enabling the creation of smart homes and appliances such as smart TVs, home security systems, smart refrigerators, washing machines, fire detection, lighting control, and temperature monitoring. Sensor and actuator nodes for environmental monitoring are integrated into the smart home, which transmit surveillance data to the control unit. Users can monitor and control their appliances remotely from any location and at any time using the control unit [1]. The smart home is thus a key element of the Smart Grid to realize real-time interaction between users and the grid, improve the quality of services and enhance the capacity of integrated grid services, as well as to fulfill users' energy demands in a most efficient possible way. Optimizing daily power consumption makes broad use of smart home services. For example, users can activate heaters or air conditioners prior to arriving home, allowing them to immediately enjoy their desired environment. Aside from that, users can save money by running their energy-intensive electrical appliances such as their washing machine in the middle of the night when the cost of electricity is lowest. The control unit also uses surveillance data to detect suspicious activities and inform users to take appropriate actions. The IoT is applied to various aspects of the Smart Grid in smart homes, for instance, in a smart home's sensor LAN protocol to control smart appliances, multi-meter reading, information gathering of power consumption (including electricity, water and gas), load monitoring and control and user interaction with smart appliances. Additionally, IoT technology provides services to NANs by connecting a group of smart homes in a neighborhood via a NAN to form a smart community. Thus, smart homes within a smart community can share the results of outdoor surveillance cameras in order to detect accidents or suspicious activity and notify the appropriate emergency centers [1].

5.2 Advanced Metering Infrastructure(AMI)

Advanced metering infrastructure (AMI) is an essential component of Smart Grid. It establishes a bidirectional communication network between smart meters (SMs) and the utility system for the purpose of collecting, transmitting, and analyzing consumer energy consumption data. AMI meters (also known as smart meters) are enhanced and digital versions of conventional electric meters [16]. AMI performs a variety of functions, including self-healing, adaptive power pricing, demand-side management, energy efficiency enhancement, enhancing the reliability of the Smart Grid, interoperability with other systems, monitoring and control of power quality, outage management, providing communications between the central system and SMs, reducing energy consumption, and updating the software on SMs [2].

A central system, two-way communication networks, data concentrators, and smart meters are all components of AMI. SMs are installed at customers' locations or other points in the smart grid to collect data on consumption and transmit it to the central system via communication networks for billing, informing consumers about their consumptions, and so on. In direct load control, SMs can provide energy consumption reports and schedule times for turning on and off devices to balance the load in the Smart Grid. Also, direct load control can add distributed energy resources to SG to supply higher load when the power grid produces extra power [2]. Hence, in this manner, the consumers can adjust their energy usage based on the energy and pricing information received through AMI, and hence can save their money. The importance of this system lies in the timeliness, efficiency, and accuracy in the power consumption data. By utilizing this system, IoT technology can assist users in saving money by adjusting their electricity usage behavior in response to an analysis of their energy consumption [1].

5.3 Electric Vehicles (EVs)

Electric Vehicles are considered as an effective tool for reducing the gas emissions and oil demands, as well as for increasing the energy conversion. The evolution of smart grid technology has created new opportunities for Electric Vehicles. Electric vehicles are now used to exchange energy with the grid. They not only consume energy from the power grid, but they also distribute energy back to the power grid through the use of their bidirectional charger. There are three main emerging concepts which are based on the capability of charging/discharging of EVs: Vehicle-to-Grid (V2G), Vehicle-to-Vehicle (V2V) and Vehicle-to-Home (V2H) [1]. In V2H, the Electric vehicles supply energy to the homes. The electric vehicles (EVs) charge their batteries from the grid at a low cost during off-peak hours. Then at on-peak hours, when the energy price is higher, the houses consume energy from EV batteries fulfilling the whole or partial demand of the house and avoids buying the expensive energy during on-peak hours [6].

Electric Vehicles represent an incredible opportunity for Internet of Things-enabled Smart Grid systems. A charging system for an electric vehicle is comprised of three components: a power supply system, charging equipment, and monitoring. The power supply system is responsible for the output and management of electricity. The charging equipment, which includes both AC and DC chargers, charges and discharges the EVs. Charging with an alternating current (AC) is slow and is commonly used in the home [22]. Rapid EV charging necessitates the use of direct current (DC) chargers, which are typically found at public charging stations. Both charger types include a billing feature. The monitoring system is in charge of the charging system's security and monitoring it in real time. IoT technology plays a leading role in this monitoring system, providing an information management system that integrates different components of the charging system [15]. Electric Vehicles are equipped with GPS, which let the IoT to help drivers to manage their batteries more efficiently by locating the nearest, most suitable charging station with the shortest waiting time, as well as providing traffic and parking information [1].

5.4 Distributed Energy Resources (DERs)

Renewable energy sources such as solar cells, photovoltaic cells, and wind turbines are gradually being integrated into the modern power grid. They have recently attracted considerable attention in Smart Grid studies due to climate changes and environmental pressures. Renewable energy has a beneficial effect on the global environment because it generates electricity without emitting carbon dioxide [1]. Recently, many countries have installed a substantial number of solar cells and wind turbines to satisfy part of their power requirements. Power generation patterns of renewable energy sources (solar and wind), which are distributed over the grid, are intermittent in nature and dependent on location and climate, so they pose significant challenges for the predictability and reliability of the power supply. Such problems are addressed using the seamless interoperability and connectivity provided by the IoT technology. Furthermore, the IoT technology uses sensors to collect real-time weather information which helps in forecasting energy availability in the near future. Utilizing the IoT technology and Wireless Sensor Networks, SGs sense, estimate and control the states of DERs [1].

5.5 Power Demand Management

Power demand management, also known as demand-side energy management, is defined as the change in the energy consumption profiles of consumers according to the time-varying electricity prices from utility companies. It is used to reduce the consumer's electricity bill, as well as the power grid's operational costs and energy losses, as well as to shift demand load away from peak periods [6]. IoT devices collect the energy consumption requirements of various home appliances and transmit them to the home control units. Subsequently, the Smart Grid control unit schedules the energy consumption of home appliances based on the users' defined preferences so that each consumer's electricity bill is minimized. Demand-side energy management can be performed at different levels of the Smart Grid. For instance, it can be performed at a home-level to maintain consumers' privacy. It can also be performed at higher levels to not only benefit the consumers but also the utility companies by generating a more effective scheduling plan [1].

6. IoT INTEGRATED NEIGHBORHOOD AREA NETWORK(NAN)

NAN is the second layer of Smart Grid and consists of smart meters belonging to multiple HANs. For power distribution systems, NAN facilitates communication between distribution substations and field electrical devices. It collects service and metering information from multiple HANs and transmits it to the data collectors that connect NANs to a wide area network (WAN) [1]. The communication technologies for NANs need to cover a radius of a thousand meters. The communication channels between smart meters and data aggregation points therefore must be interference free. A gateway in the NAN collects consumers' energy consumption data from smart meters in HANs and transmits the collected data to the utility companies through either private or public WANs. Essentially, the topology of a NAN is made up of two types of gateways: NAN gateways and HAN gateways. A NAN gateway connects various HAN gateways and acts as an access point, allowing a single hop connection to HAN gateways in a hybrid access mode. The HAN gateways transmit their energy consumption data to NAN gateways through either wired (PLC, DSL) or wireless (cellular, mobile broadband wireless access or digital microwave technology) communication technologies [1].

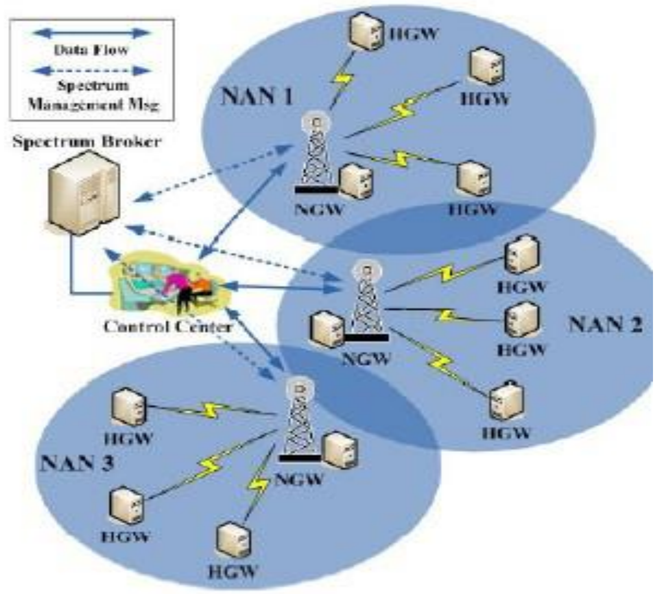

Fig -5: IoT Integrated Neighborhood Area Network

6.1 Smart Distribution

The smart distribution grid is introduced and is defined by its high reliability, improved power quality, increased compatibility, enhanced interaction capability, increased utilization rate of power grid assets, and visualization management platform. Its primary functional requirements include a robust and adaptable grid structure, operational control, an open communication architecture, and a software component. Smart distribution grid is based on advanced automated IoT technology and is one of the important component of Smart Grid [1]. It is the component of the smart grid that is directly connected to users. Smart distribution grid consists of communication system, power distribution remote unit, master unit and station unit. With the help of IoT technology, the smart distribution grid can immediately identify the faults in case of any disorder and can overcome the fault instantly. The Internet of Things enables a smart distribution grid by providing various types of sensors for collecting data about temperature, humidity, and noise, which enables the distribution grid to be monitored and operated securely [1].

6.2 Smart Patrol

The patrolling of power generation, transmission and distribution used to be mainly a manual task, performed regularly at specific time intervals. However, due to climate conditions and both human and environmental factors, patrolling quality and quantity are not always as desired. Additionally, patrolling unattended substation equipment is not always easy for power workers [1]. The IoT technology offers a promising solution to this problem by introducing Smart patrol. Smart patrol is comprised of WSN and RFID tags which are connected to the power substation with the help of IoT technology and are used to locate the power equipment in order to improve the quality of patrolling, as well as to enhance the stability, efficiency and reliability of a power system and its supply. Smart patrol can be used for a variety of purposes, including patrol personnel location, equipment status reports, environment monitoring, state maintenance, and standard operations guidance [1].

7. IoT INTEGRATED WIDE AREA NETWORK(WAN)

The wide area network (WAN) is the third layer of the Smart Grid, and it serves as a backbone for communication between network gateways, NANs, distributed grid devices, utility control centers, and substations. It facilitates the communication among power transmission systems, bulk generation systems, renewable energy sources and control centers. It is consists of two interconnected networks, core networks and backhaul networks [1]. The core network provides communication to utility control centers with low latency and high data rate through fiber optics or cellular communications. The backhaul networks provide broadband connections and monitoring devices to NANs through wired (e.g., optical networks, DSL), wireless (e.g., cellular network, mobile broadband wireless access) or hybrid fiber-wireless networks [1].

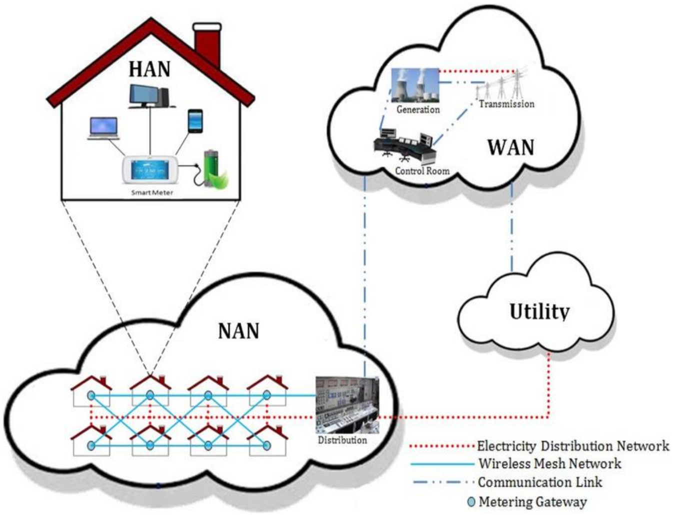

Fig -6: IoT Integrated Wide Area Network

7.1 Online Monitoring of Power Transmission Line

The online monitoring of power transmission lines is one of the most important applications of the IoT in the Smart Grid, specifically for disaster prevention and mitigation. Natural disasters in recent years have highlighted the inherent challenges of high voltage power transmission lines in terms of security, reliability, and stability. Traditionally, high voltage transmission line monitoring has been performed manually. Sensors measuring conductor galloping, wind vibration, conductor temperature, micro-meterology and icing can now be used to achieve real-time online monitoring of power transmission lines [1]. This new online power transmission line monitoring system is comprised of two parts. In the first part, the sensors are installed on the power transmission lines between transmission towers to monitor the states of power transmission lines. The second part has sensors installed on the transmission towers in order to monitor their states and their environmental parameters. IoT enables the communication between the power transmission line sensors and the transmission tower sensors [1].

8. RENEWABLE ENERGY RESOURCES INTEGRATION WITHIN SMART GRIDS

Renewable energy sources are highly diverse in terms of scalability and type. Geothermal, biomass, wind, hydroelectric, and solar energy are among the sources of renewable energy. The renewable generation has the advantage of enhancing sustainability, minimizing hazardous gas emissions, minimizing dependency on the imported and local remnant sources, and enhances energy security by diversifying energy resources. The SG approaches can lessen barriers and facilitate the penetration of renewable resources such as: solar, hydro, wind, geothermal, and biomass energies. Accordingly, the importance of SG within the plants that are driven on the aforementioned resources is inevitable [8].

Renewables with SGs have the following characteristics:

1) The SG technology balances the demand and supply of electricity. This is accomplished through the use of distributed storage devices, advanced sensing, control software, market signals, and data structures [8].

2) The automated SG technology is capable of utilizing feedback regarding dispersed storage and demand, enabling a more seamless and cost-effective integration of renewable energy generation hosting [8].

3) Implementations of SG technologies reduce the impediments to the penetration of RERs [8].

4) Through the application of SG technology relative to RE, the grid operator has the capability to control and coordinate the system in reaction to grid characteristics [8].

5) SGs enables diversified management and distributes integration mechanism for RE through the utilization of communication software along with converters and inverters [8].

RE sources are capable of operating on both large and small scales and can be designed and controlled as an aggregated energy source. The design and development of the SG require modelling of RERs and technologies such as solar, wind, biomass, and fuel cells, as well as an examination of their penetration levels and impact valuations on the inherent systems for upgrading and innovation [8].

9. IOT IN SMART GRID INTEGRATION ARCHITECTURES

The Smart Grid has a broad implementation in terms of information retrieval, transmission, and processing, as well as network functions. Through a variety of communication technologies and IoT smart devices, IoT technology enables real-time network connections between users and devices, enabling data sharing in two directions, in real time, and at a high speed, thereby increasing the efficiency of the Smart Grid. The Smart Grid system that is integrated with IoT has been regulated and implemented, but the full capabilities of instant knowledge and sustainable large-scale data processing have not been exploited optimally [2]. IoT implementation covers several areas such as Adjusting home consumption with dynamic scheduling, electricity monitoring, system monitoring and maintenance, demand and management, charging and parking of electric vehicles. Several IoT architectures have been proposed to be integrated into Smart Grid namely three-layer architecture, four-layer architecture, Cloud based architecture, Web enabled architecture and so on [3].

9.1 Four Layered IoT in Smart Grid Architectures

The four-layer architecture for IoT in the Smart Grid system consists of the terminal layer, field network layer, remote communication layer, and master station system layer. According to the three-layered IoT hierarchical model, the terminal and field network layers in this architecture correspond to the IoT perception layer, the remote communication layer corresponds to the IoT network layer and the master station system layer corresponds to the IoT application layer [1].

The terminal layer is comprised of IoT devices deployed in various SG functions, such as power generation, transmission, distribution and utilization. The IoT devices include remote terminal units, information collection devices, smart meters, smart devices and intelligent electronic devices. This layer collects information from IoT devices and transmits the collected data to a field network layer. The field network layer can be wired or wireless. Depending on the type of IoT devices, the appropriate communication network is used to transmit the collected data to a remote communication network layer. The remote communication network layer can also be wired or wireless. It is comprised of various communication networks which provide connectivity to the Internet, such as 2G, 3G, and LTE as wireless networks, and optical networks as a wired network. This layer serves as a middleware between IoT devices and the master station system layer. The master station system layer is the control and information system of a SG. It controls and manages all the SG functions. It can also be considered as an interface to the IoT-aided SG applications [1].

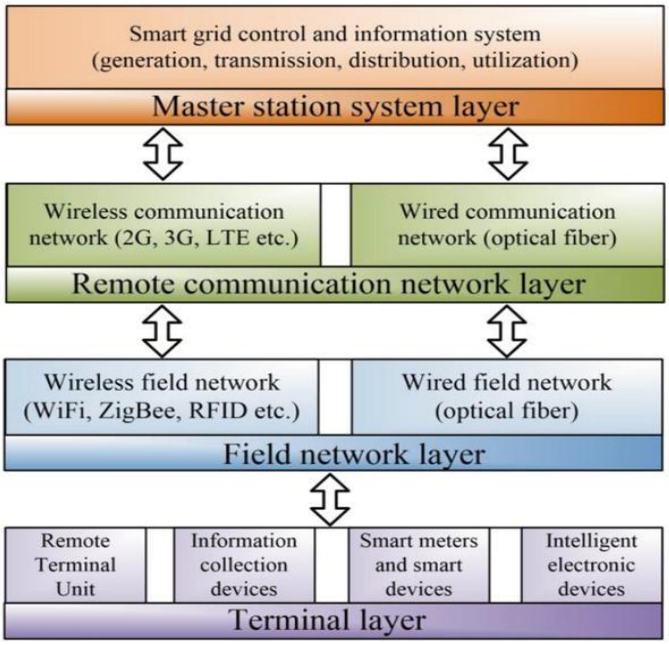

Fig -7: Four-layer architecture for IoT into SG[1]

9.2 Web-Enabled Smart Grid Architectures

In Figure 8, an architecture for IoT-aided SG systems is proposed in based on the web of things. The web of things is comprised of a number of web services provided on top of the IoT devices in which the web browser acts as an interface to these web services. There are two types of energy sources, non-renewable and renewable energy sources. Non-renewable energy sources include thermal power plants (combusting coal or oil) that release carbon emissions to the environment, as well as nuclear power plants. The renewable energy sources are environmentally, friendly and are comprised of hydropower, wind farms, solar, biogas plants and biofuel sources, as well as geothermal and tidal/wave sources [3].

The energy sources in this architecture are connected to individual digital energy meters. These digital energy meters are responsible for collecting household energy consumption data. The meter readings from energy meters of non-renewable and renewable sources are collected by separate IoT gateways which communicate regularly with these meters. The collected data from IoT gateways are updated to the server periodically, and the server provides web services on top of these IoT devices. These web services include the locations of houses connected through the SG, and the meter information. Moreover, for each home, the scheduling of power sources and the controlling of the energy sources by switching the source controllers remotely through IoT devices are provided as web services. Through the Internet, by connecting to any device, a user can access these services. The energy sources for each household are switched through source changers which are controlled through IoT devices; these IoT devices switch the energy sources upon receiving instruction from the user via the server [3].

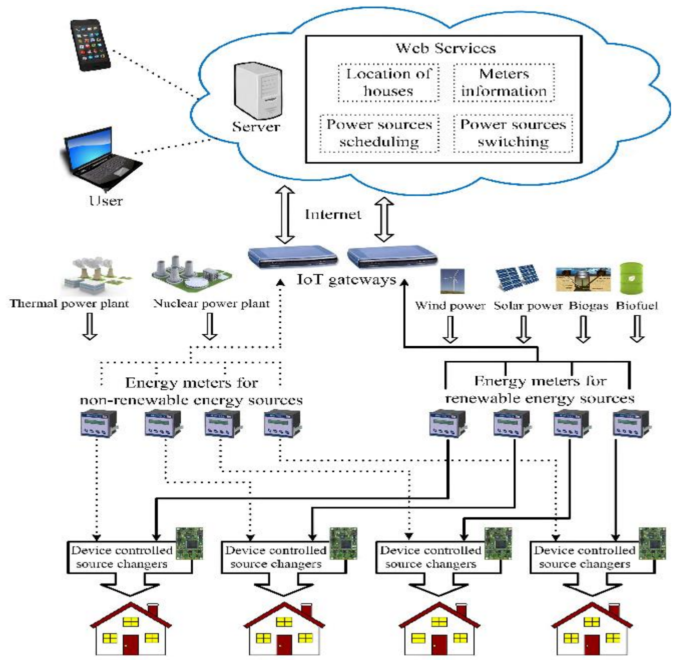

Fig -8: Web Enabled Smart Grid Architecture[3]

9.3 Big Data & Cloud for IoT Integrated SG

The integration of IoT technology and smart grid technology necessitates the management of extremely large volumes of data through regular processing and storage. Consumer energy demand, energy consumption, advanced metering, blackout management records and forecasts, network component status, and power line faults are all included in this data. This requires electricity companies to invest in hardware and software capable of effectively storing, managing, and processing data collected from IoT devices [3].

The Supervisory Control and Data Acquisition (SCADA) System is a major component of decision-making in the Smart Grid. SCADA collects data from distributed IoT devices and monitors and controls them online and in real time. Additionally, it facilitates in the management of power flow throughout the network, thereby increasing consumption efficiency and ensuring the reliability of the electricity supply. SCADA systems are typically located throughout an electricity company's various locations. With the growing size of SG, electricity companies face challenges in maintaining a continuously updated and upgraded SCADA system. To overcome this problem, cloud computing is one of the best solutions for hosting a SCADA system. Cloud computing enables on-demand access to a pool of shared computing resources, including storage, servers, networks, processing, applications, and services [3].

Fig -9: SCADA System Control Center

10. REQUIREMENTS FOR APPLYING IoT IN SG

To utilize IoT in Smart Grid, there is some technologies and requirements which are listed as follows:

1.Communication technologies: Communication technologies can be used to receive and transmit acquired information about the state of SG's devices. We have short-range and long-range communication technology standards. ZigBee, Bluetooth, and ultra-wideband technologies are examples of short-range communication technologies. For long-range communications, power line communications, optical fiber, wireless cellular networks such as 4G,5G and satellite communications can be used [2].

2.Data fusion techniques: Since the resources of IoT terminals (such as batteries, memory, and bandwidth) are limited, it is not possible to send all information to the destination. Thus, to increase the efficiency of information gathering, data fusion techniques can be utilized to collect and combine data [2].

3. Energy harvesting process: Since most of the IoT devices use battery as one of their primary power sources, energy harvesting process is very important for IoT applications, e.g., using different sensors and cameras to monitor different parts of a smart grid [2].

4. Operating in harsh environments: IoT devices which are installed in high-voltage transmission lines and substations must work in harsh environments. Thus, to extend the lifetime of their sensors in these conditions, we should have sensors should be high or low temperature resistant, anti-electromagnetic, or waterproof [2].

5.Reliability: IoT applications in different environments need to satisfy different requirements such as reliability, self-organization, or self-healing. Thus, based on the actual environment, suitable IoT device must be selected to overwhelm environmental issues. For example, when some devices cannot send data due to lack of energy, a new route for the data must be found so that the network reliability remains at the required level [2].

6. Security: Security methods must be implemented in all IoT layers to transmit, store, and manage data, avoid information leakage and losses, and protect data [2].

7.Sensors: Sensors measure quantities such as current, voltage, frequency, temperature, power, light, and other signals and deliver the raw information for processing, transmitting, and analyzing. Recently, nanotechnology is used to provide high-performance material which covers different sensor applications and enhances the growth of sensor industry [2].

11. CHALLENGES AND FUTURE RESEARCH STUDY

To achieve technical goals in applying IoT in Smart Grid, there are many challenges which must be addressed in future research directions. Since IoT devices must work in different environments that may have harsh conditions (e.g., high or low temperatures, high voltages, exposure to electromagnetic waves, working in water, etc.), therefore, they must satisfy requirements at those conditions such as reliability or compatibility [2].

In many applications, IoT devices and sensors operate on batteries (e.g., different types of sensors which are used to monitor transmission lines), so suitable energy harvesting techniques should be used or designed. As there are multiple communication networks throughout the SG, IoT devices should support the necessary communication protocols to ensure that data transfer from smart meters to the central system is possible and secure [2].

Since IoT devices in Smart Grid have limited resources and capabilities such as batteries, processing power, storage, or bandwidth, so data fusion processes should be used to compress and aggregate useful data so that SGs have more efficient energy and bandwidth usage and data collection [2].

Since the smart grid contains many different gateways and IoT devices with different specifications and resources, interoperability between these devices to exchange information is very critical. One solution to achieve interoperability is to use IP-based networks. Another solution is that IoT devices should support different communication protocols and architectures [2].

Sensors, smart meters, and other similar devices that measure and collect information in a smart grid create big data that can consume a lot of energy and other resources and create a bottleneck. The scientists should design the smart grid in such a way that can efficiently store and process this huge amount of collected data [2].

There are many separate standards for IoT devices, but there is no unified standard for IoT devices in the smart grid. This may cause security, reliability, and interoperability issues for IoT devices in SG. Therefore, standardization efforts should be unified [2].

To monitor and control IoT devices in Smart Grid, the scientists should use the Internet which is very vulnerable, and attackers can manipulate measured data by sensors and smart meters and cause a lot of financial losses. Therefore, the scientists should develop secure communications for IoT devices in the smart grid by considering resource limitations of IoT devices and determine some security measures for these devices. For example, IoT devices have limitations in computation and storage. Thus, the scientists should design or use security solutions so that IoT devices are able to run them. From the collected data by smart meters, it is possible to extract some information about consumers' habits (e.g., wake up times, etc.), therefore it must be guaranteed that this private information will not be used without consumers' permission. Also, suitable mechanisms for security measures such as trust management (between IoT devices which are owned by different parties, e.g., customers and utilities), authentication, authorization, data integrity, maintaining confidentiality, and detecting identity spoofing should be devised [2].

12. CONCLUSION

Smart grid is a future electric grid based on sensing technology, communications, digital control, information technology (IT) specifically the Internet of Things (IoT) and other field equipment's that function that solves the various problems such as information flow, energy wastage, growing energy demand, reliability, and security in the conventional power grid. The Internet of Things (IoT) enables Smart Grid operations by utilizing smart devices or IoT devices such as sensors, smart meters, and actuators to monitor, analyze, and control the grid, as well as to connect, automate, and track various devices. We have discussed the Internet of Things, the Smart Grid, and the integration of the Internet of Things into the Smart Grid in this paper.

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