Internet of Things in Smart Grid: A Brief Overview

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ABSTRACT:
Two important technologies for smart city development are Smart Grid (SG) and Internet of Things (IoT). A smart grid is a data communication network that is on top of power grids and contributes to its efficiency by collecting and analyzing data from different parts of the grid. The Internet of Things, by connecting things and people to the Internet, provides access to them at any time and any place. The smart grid controls, monitors, and analyzes the power grid by using many devices that are located throughout the power grid. The smart grid, using the Internet of Things, can connect these devices and automate them and track their performance. In this article, a brief review of the architectures, technologies, applications and challenges of using IoT in SG is discussed.

KEYWORDS: Internet of Things, Smart Grid, Smart City.

1. INTRODUCTION

Smart Grid is a solution to the old power grid problems and the problems caused by the growing demand of customers. Problems with older power grids include centralized generation, unidirectional power transmission, inability to quickly monitor the grid, inability to automate and quickly analyze network status .The smart grid uses new communication and information technologies, such as the Internet of Things, in the production, transmission, distribution and consumption of electricity [1], [2].

The Internet of Things, by definition, is a set of objects and people that can be accessed anytime and anywhere by using an Internet connection [3], [4]. The Internet of Things has many applications, for example, it can be used in the infrastructure of the Internet as a connection of objects and smart devices. The concept of IoT is much comprehensive than machine-to-machine connection and includes the connection between various devices, services and systems [5].

Using IoT allows intelligent monitoring and control in the smart grid. Home appliances with internet connection can be controlled remotely and work in non-peak times and reduce the cost of electricity consumed by customers. Customers can balance energy consumption by considering the current price of electricity and using the energy consumption data collected by IoT devices. With the help of the IoT, the manufacturing sector can predict energy needs and distribution conditions. The integration of IoT with Smart Grid leads to the widespread development of Smart Grid.

This paper examines IoT architecture, technologies and applications in SG. The rest of the content is as follows: A brief explanation of the smart grid is provided in Section 2. Section 3 discusses the integration of IoT into smart grids. Section 4 describes the IoT communication technologies in the Smart Grid. Sections 5 and 6 deal with IoT applications and challenges in smart grids, respectively. Finally, in the section 7, the conclusion is presented.

2. SMART GRID (SG)

Smart Grid is a new power grid that solves the problems of old power grids and minimizes the loss of electrical energy. It also solves problems related to efficiency, sustainability, increasing electricity demand, security and reliability [6]. The most common definition of smart grid is that SG is a communication network on top of the power grid that collects and analyzes data from various components of the power grid and uses these analyzes to forecast power supply and demand and power management [7]. Smart Grid can heal itself, improve the quality of electricity, participate users in the production and distribution of electricity, etc. [8], [9], [10], [11].

The SG architecture consists of 3 layers: power system, power flow and information flow. The power flow includes four subsystems: generation, transmission, distribution and consumption. The data flow includes

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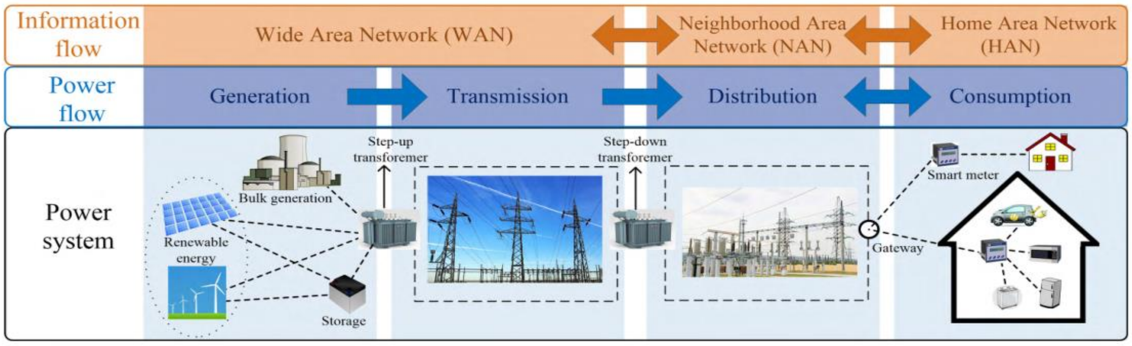

Fig. 1. Smart grid architecture [14].

three networks WAN (Wide Area Network), NAN (Neighborhood Area Network) and HAN (Home Area Network). WAN carries information of generation and transmission subsystems, NAN is located on distribution subsystem. HAN carries consumption subsystem information. The architecture of smart grid is presented in fig 1.

The HAN manages the electricity needs of consumers, including homes, workshops, factories and shopping malls. HAN includes smart devices, home appliances, electric vehicles and solar panels. HAN sends electrical appliance information to NAN via smart meters. The NAN collects information from several smart meters located in different HANs and connects them to distribution substations. It then sends the collected information to the WAN. WAN is the main part of communication between network gateways or aggregation points. Using WAN, communication is established between transmission systems, generation, renewable energy sources and control centers [12].

Some of the benefits of a smart grid include: optimal transmission and distribution of electrical power, quick power recovery after system failure, low cost of operation, maintenance, lower electricity tariffs due to reduced peak demand, facilitate the integration of renewables into the network increase the versatility of transmission lines, reduce peak demand, quick recovery after any disturbances and sudden problems in lines and feeders, network protection management in case of emergency, better demand response, improve power quality, reduce greenhouse gases. The development of digital technology in SG ensures the reliability, efficiency and access of consumers to generation, which in turn leads to economic stability [13].

The challenges of smart grids include the following:

- Privacy issues: The biggest concern in a SG is security issues. The smart grid uses smart meters that dynamically establish the connection between generation and consumption. Some smart meters are easily hacked and may control the power source of a building or distribution unit.
- Grid volatility: The SG is smart in terms of generation and final consumption, because it uses smart meters in these areas. But the network does not have enough smartness in the middle to manage switching operations. This lack of development in the network causes it to fluctuate. To date, SGs have focused more on power generation and energy consumption. If a large number of nodes are added to the network before the software intelligence for network control is developed, it leads to smart grid volatility. Smart control systems are required for safe and secure operation of the power system.

3. IOT INTEGRATION INTO SMART SG

The smart grid is highly dependent on data retrieval, transmission and processing. Using various communication technologies and smart devices, IoT provides real-time network communication between users and devices and increases the efficiency of the smart grid [15]. Currently, the SG system integrated with IoT has been launched and implemented, but the big data processing facilities have not been used optimally yet. The implementation of IoT in SG includes several applications: dynamic scheduling for home consumption, monitoring of power production, transmission, distribution and consumption, system maintenance, demand monitoring and management [16]. Fig 2 shows the IoT integration in SG.

3.1. Architecture of IoT Integration into SG

There are different architectures for the Internet of Things integration into the smart grid, which are discussed in this section.

3.1.1. Three-Layered Architecture

There are three layers in this architecture: perception layer, network layer and application Layer [17]. This architecture is shown in fig 3.

The perception layer includes various sensors and IoT devices that collect SG data. This layer consists of two sub-layers: perception control and communication extension. The perception control sub-layer is in charge of processing the information obtained from the devices

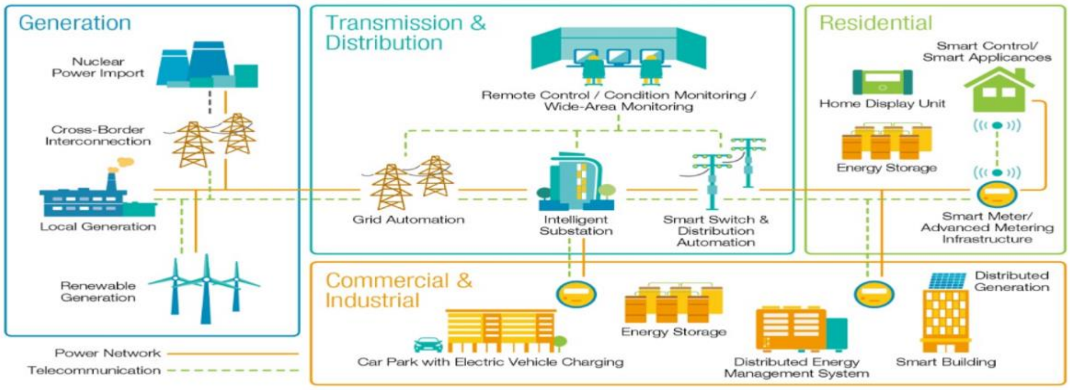

Fig. 2. Integration of IoT into SG [13].

of this layer and controlling and monitoring. The communication extension sublayer is in charge of the communication between the devices of this layer and the upper layer, i.e. the network layer.

The network layer includes various telecommunication networks and the Internet. It maps the information obtained from the perception layer into the information required by telecommunication protocols. It then transmitts the mapped information to the upper layer, i.e. the application layer. This layer performs routing, information transmission and control and management of data obtained from IoT devices

The application layer provides a large number of IoT applications in SG using IoT and industrial technologies. This layer, by processing the information obtained from the network layer, monitors and diagnoses the smart grid. Also, it provides information security and the possibility of sharing information.

3.1.2. Four-Layered Architecture

In this architecture, IoT integration into the smart grid includes four layers: the terminal layer, the field network layer, the remote communication layer, and the master station system layer. As mentioned in previous subsection, the other IoT architecture, has three layers: the perception layer, the transport layer, and the application layer. In IoT integration into SG, these layers are combined as follows: the terminal layer and the field network layer form the perception layer, the remote communication layer is considered as the transport layer, and the master station system layer is the application layer [18]. Fig 3 shows this layering.

The terminal layer includes devices that have IoT technology, such as remote terminal units, data collection devices, smart meters, and various intelligent electronic devices. The terminal layer sends information from IoT devices to the field network layer.

The field network layer can be wired like optical fiber or wireless like WiFi and ZigBee. This layer sends the collected data to the remote communication network layer.

3.1.3. Web-Enabled SG Architecture

The web-based architecture of an SG is shown in fig 5 [19]. The Web of Things provides web services on top of the Internet of Things using a web browser. In this architecture, using digital meters, household energy consumption data is collected. Then this information is transferred to the server through IoT gateways. The web services provided by the server include house location, meter information, power source scheduling and power source switching. The user can use these services through the Internet.

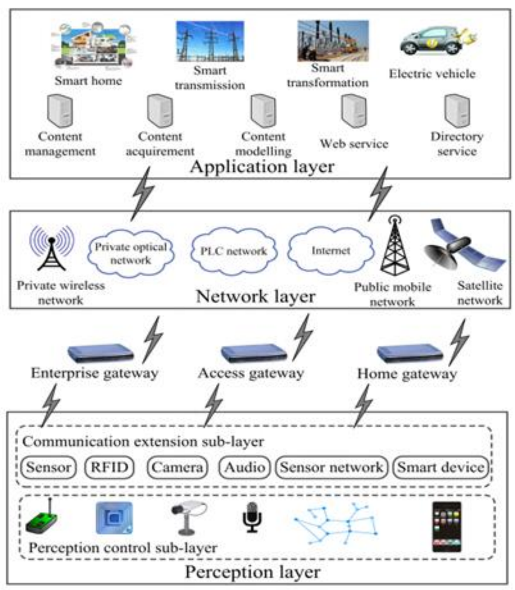

Fig. 3. 3-Layered Architecture of IoT in SG [17].

4. IOT COMMUNICATION TECHNOLOGIES FOR SG

There are several communication technologies for smart grids. The communication technologies of IoT used in

SG for data transmission include ZigBee, 6LowPAN, Z-wave and more. The choice of communication technology depends on such things as the cost of implementation, implementation time and environment. In the following, these technologies will be introduced.

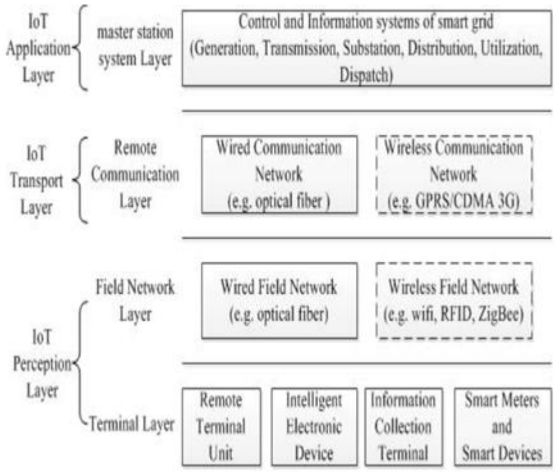

Fig. 4. 4-Layered Architecture of IoT into SG [18].

4.1. 5G

5G is a new generation of wireless communications that has been implemented in some countries since 2020. 5G has less latency, higher rate, higher bandwidth and higher reliability than previous generations. 5G provides wide coverage and can serve a large number of users, and also works in different bands [20].

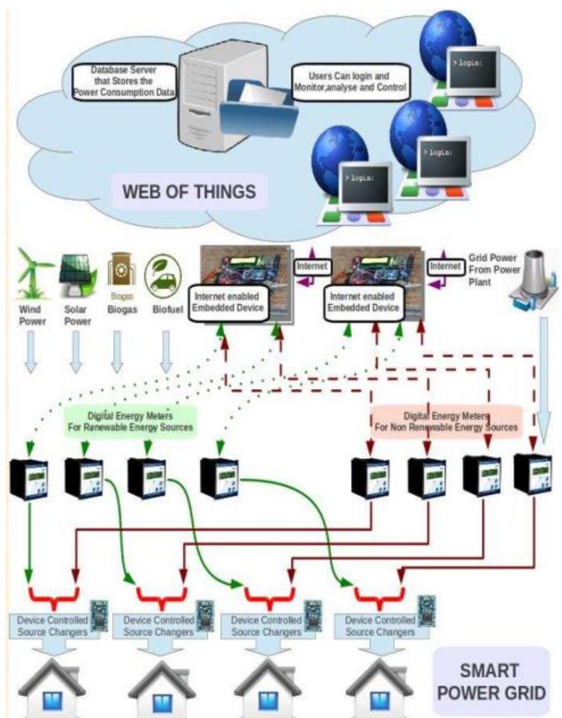

Fig. 3. Web-Enabled SG Architecture [19]

Using 5G, we can control and monitor sensitive infrastructure such as SG. 5G radio access technology (RAT) is designed to meet the needs of SG applications. 5G is therefore a good technology for monitoring and distributed controlling of SG [21], [22].

4.2. Z-Wave

Z-Wave is a low-power, short-range communication technology suitable for home applications [23], [24]. Z-Wave does not interfere with other short-range technologies such as WiFi, ZigBee and BlueTooth. It also has good scalability and can connect more than 300 devices [25].

4.3. 6LowPAN

6LowPAN (IPv6 over Low-power Wireless Personal Area Network) is a short-range, low-rate communication technology suitable for home applications and smart metering [26]. This technology is very powerful and low consumption and has high scalability and can work in different frequency bands [27].

4.4. LoRaWAN

LoRaWAN is a low-power WAN communication technology used for IoT devices and suitable for SG NAN and WAN applications [28]. This long-range communication technology has low consumption and low data rate. Using LoRaWAN and the adaptive data rate (ADR) method can increase the network capacity and battery life of IoT devices [29].

4.5. ZigBee

ZigBee is a low-consumption, reliable and inexpensive communication technology with low data rates and low complexity. This technology is a good choice for metering management and automatic meter reading. Due to its low complexity and cheapness, it is suitable for implementing smart grid in home network [30], [31].

4.6. WirelessHART

wirelessHART is an extended version of the HART protocol used for industrial automation. WirelessHart is a low-power protocol for monitoring and controlling industrial processes [32]. In Smart Grid, this technology can be used in power generation to deploy sensors. WirelessHART is compatible with older systems and has no ZigBee limitations [33].

4.7. Bluetooth Low Energy (BLE)

BLE is the latest version of Bluetooth that is low consumption, short range, simple, and cheap communication technology and has a high data rate [34]. BLE can be used for low battery IoT devices. BLE is suitable for home smart grid applications and online substation monitoring [35].

4.8. Narrow Band IoT (NB-IoT)

NB-IoT is an LPWAN technology that is very simple, inexpensive and low power and can be widely used. NB-IoT uses existing cellular infrastructure, so it can be very cost-effective to implement. This technology in SG is very suitable for home automation and advanced metering infrastructure (AMI) [5].

5. IOT APPLICATIONS IN SG

There are several applications for IoT in SG, some of which are covered in this section [14], [36].

5.1. Smart Home

The smart home is where devices connect to the Internet and can make independent decisions based on information received from sensors. Smart home devices and systems are expected to interact regularly with their surroundings, including all smart devices connected to the Internet and home appliances and the external environment, such as smart grid entities [37]. The smart home is an important factor in the development and use of smart grids. By creating instant interaction between users and the network, IoT improves the quality of services (QoS) and increases the capacity of integrated grid services. The Internet of Things can control smart home appliances, collect energy consumption data, and monitor and control loads [38].

5.2. Advanced Metering Infrastructure (AMI)

AMI is a very significant part of the smart grid. AMI can use the IoT to collect data, monitor measurements and exchange information between smart meters. Also, IoT can be used to obtain user consumption patterns [39].

5.3. Integration of Distributed Energy Resources (DERs)

Today, renewable energy resources have been considered in the development of smart grids. Electricity generation patterns of renewable energy resources depend on location and weather conditions, thus creating problems in predicting grid energy status and reliability. IoT technology can solve these problems by providing interoperability and seamless connectivity. IoT technology can be used to estimate and control the status of renewable energy resources [40].

5.4. Costumer Side Applications

The Internet of Things can be used in smart meters to measure various parameters. IoT can be used in intelligent management of power consumption according to the cost of electricity at different hours. Using IoT, interoperability between different networks, charging and discharging electric vehicles, energy efficiency management is possible [41].

5.5. Smart Distribution

The IoT-based smart distribution grid is a significant part of the Smart Grid. Smart distribution grid has high reliability, high power quality. The distribution grid is directly connected to SG customers. IoT can be used to collect various data and help monitor and safe operation of the distribution network, as well as fault detection and repair [42].

5.6. Transmission Lines Monitoring

Online monitoring of transmission lines is a main IoT application in Smart Grid. Various sensors that measure ambient and transmission lines conditions can be used for real-time online monitoring of transmission lines [43].

6. CHALLENGES OF USING IOT IN SG

The use of IoT in SG faces several challenges. In this section, the most important of these challenges will be examined.

6.1. Energy Supply for IoT Devices

In using IoT in SG, a large number of devices must be connected to the network, providing energy for these devices is an important challenge. Traditional energy sources are very limited, while, using renewable energy sources can have better performance. On the other hand, new devices perform better in terms of energy consumption. IoT devices and sensors used in SG should be able to continue working for a long time without needing a new battery.

6.2. Big Data Management

Using the IoT in SG generates a huge amount of data that must be managed, processed and stored. Collecting data on a regular basis leads to the creation of a very large volume of data. Since different data are generated by multiple sensors, the variety of data is very high. On the other hand, these data must be collected and processed at high velocity. The three characteristics stated for the data, i.e. very high volume, variety and velocity, put the data of using IoT in SG in the category of big data.

Two methods are used to manage big data: MapReduce and Stream Processing [44]. The MapReduce method is appropriate for non-real-time and static applications. It can also be used to analyze historical data. Its working method is that it divides large data sets into smaller data sets. Then, simultaneously, it processes small data sets on several machines. The Stream Processing method is proper for both real-time and non-real-time applications. Currently, this method has a very good performance for sensor data flow and big data. The Stream Processing method has high scalability and tolerates the error well.

6.3. Standardization

The use of IoT in SG creates a complex system that has various data. Data management and processing of this system requires a specific standard. Meanwhile, each of the big companies uses their own unique method to manage and process data. Therefore, achieving a uniform standard is associated with difficulties. Although, each of the different components of this system have standards, but they are not interoperable. In other words, the telecommunication standardization of this system should be such that different components of the smart grid such as devices, meters and protocols achieve interoperability.

6.4. Security

Using IoT in SG can be associated with security challenges [45]. Monitoring and control in this system is done through the Internet, which is vulnerable to cyber-attacks. Attackers can manipulate the data of Internet of Things devices and cause damage to power companies and their facilities by affecting the real-time balance between production and consumption.

Internet of Things devices usually have little computing and storage capacity and complex security algorithms cannot be implemented on them. On the other hand, IoT devices may provide more information than what is required by the smart grid, such as when people are at home. This violates the privacy of users. Therefore, security is a very important challenge in smart grid.

7. CONCLUSIONS

This paper discusses the use of the Internet of Things in smart grids. After explaining the architecture of integrated IoT into the smart grid, some of the existing IoT applications in the smart grid and a number of communication technologies used in the smart grid were mentioned. In the following, the challenges of using the Internet of Things in the smart grid, which include the problems of IoT devices, managing large volumes of data, standardization and security, were stated. IoT can help with SG productivity. The generation, transmission, distribution and consumption of electricity can be managed, controlled and monitored with the help of the Internet of Things.

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