Applications of Internet of Things on Smart Grid in China

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***Abstract*—Smart grid can apply Internet of Things (IoT) technologies for creating various intelligent services. In this paper, the basic requirements of the smart grid in China are reviewed. The development of most aspects of the smart grid would be enhanced by the applying the technologies of IoT. The architecture of IoT for the smart grid in China is introduced, which can be expressed as three layers: the perception layer, the network layer and the application layer. Various information and communication techniques of IoT applied on smart grid is discussed. Particularly, the IoT application solutions are provided in detail for power transmission line monitoring, smart patrol, smart home and electric vehicle management.**

***Keywords*— Power system and automation, smart grid, Internet of Things, wireless sensor network, RFID**

I. Introduction

Usually, an IoT system can be divided into three layers: the perception layer, the network layer and the application layer[1]. The sensing devices of IoT[1, 2] is usually composed of radio frequency identification (RFID) devices, infrared sensors, Global Positioning System (GPS), laser scanners, etc. Based on the power transmission and communication network, the information processing and data mining can be realized by IoT. The transferring data includes the exchange information of human-thing and thing-thing, and seamless linkage of information flows. Real-time control, accurate management and scientific decision-making of the physical world would be accomplished through IoT.

It has been widely recognized that smart grid is one of the most important applications of IoT[3]-[5]. Since information perception, transmission, and processing widely exist in smart grid, IoT technology would play a significant role in power grid construction, safety control, security monitoring, data collection, and interaction, etc. The scope of data sensing for most aspects of smart grid can be greatly improved, thus the integration of information flow, business flow, and power flow of smart grid system would be supported rigorously. In this paper, the integration of IoT with Chinese smart grid is discussed in great detail, including the hierarchical structure, the key technology and the applications of IoT in smart grid.

The rest of the paper is organized as follows. In Section II, the requirements of IoT in smart grid are analyzed. Section III presents the architecture of IoT. Section IV discusses key technologies of IoT in smart grid. The information and communication network of IoT in smart grid is studied in Section V. The typical applications of IoT in smart grid are outlined in Section VI. Finally, Section VII concludes the paper.

II. Application Requirements of IoT in Smart Grid

Deployed as the infrastructure of information sensing and transmission for smart grid, IoT technology will play a significant role in smart grid, such as network construction, network safety management, operation and maintenance, information collection, security monitoring, measurement and user interaction, etc. The terminals of IoT can be applied to all aspects of power system, including electricity generation, transmission, transformation, distribution and utilization. The integration of information flow, service flow, and power flow would be realized by the applications of IoT.

In order to extend the application of IoT to smart grid, it is crucial to utilize new materials technology, information technology and communications technology and etc. Based on these new technologies, the devices of IoT are developing towards smaller, lower power consumption, longer battery life, ubiquitous communication, wider bandwidth, stronger calculation ability, decision-making and intelligent control. The intelligent level, safety and reliability of smart grid would be greatly improved by the above trends of IoT.

III. Architecture of IoT

The architecture of IoT can be expressed as three layers[3], which is shown in Figure 1.

The perception layer consists of two-dimension code tags and readers, RFID tags and readers, cameras, GPS, sensor networks, M2M terminals, and sensor gateways, etc. Perception layer is usually divided into two sub-layers: perception control sub-layer and communication extension sub-layer. The perception control sub-layer realizes intelligent perception of the physical world, including recognition, information acquisition, processing and automatic control. With the help of communication module in the communication extension sub-layer, physical entities can be connected to the network layer and the application layer.

The network layer is composed of all kinds of communication networks and the core network. The communication networks are usually considered as the access network, while information transmission, routing and control are usually implemented in the core network. The concept of network layer has been widely accepted due to its mature technologies. Besides, the IoT management center and information center belong to the network layer. This fact means both network operation ability and information operation ability can be realized by the network layer.

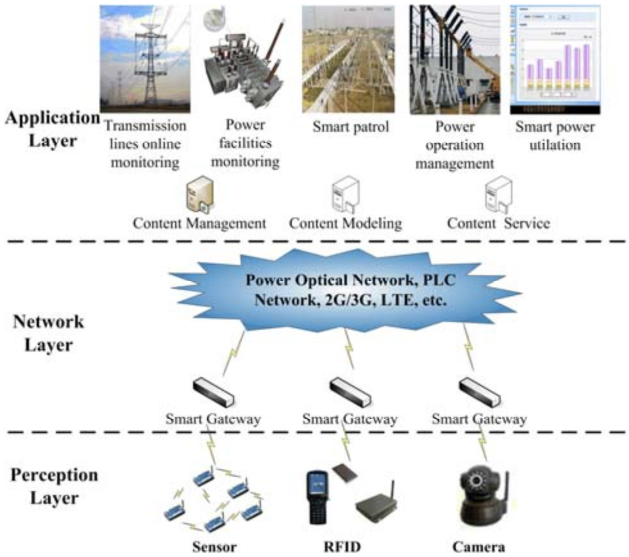

Figure 1. Architecture of IoT

A specific intelligent applications for a certain industry is usually provided by the application layer, thus IoT technologies can be combined with all kinds of industry enterprises. The application layer is usually composed of application infrastructure/middleware and terminal units. And the key issue of it is about information sharing and information security. Through the application layer, the deep integration of IoT technology with industry can be achieved, and then the development of economy and society would be influenced greatly.

IV. KEY TECHNOLOGIES OF IOT

The key technologies of applying IoT to smart grid include:

(1) Sensor technology[6]. Sensors can be considered as the "sense organs" of the material world, and provide the raw information for information processing, transmitting, analyzing and feedback, including heat, power, light, electricity, sound and signals. Sensors can be divided into various types in terms of materials, output signal types, and manufacturing technologies, etc. Recently, nanotechnology has been utilized to provide high performance sensitive material and new sensor production methods, such as Micro Electro Mechanical Systems (MEMS) technology which greatly extends the application field of sensors and promotes the development of sensor industry.

(2) Information and communication technology[7]. Based on information and communication technology, the transmission and collaboration of the perception information can be realized, thus the state of the power grid devices can be sensed. According to the range of transmission, information and communication technology can be divided into two categories: short range communication technology and wide area communication technology. In wide area communication network, IP based Internet, power line carrier, Optical Fiber Composite Low Voltage Cable (OPLC), power information wireless network, public 2G/3G mobile communication network, and satellite communication technology can achieve long-distance information transmission. For short range communications, IEEE 802.15.4 (ZigBee) represents the mainstream technology. Due to the characteristics of low-power, low-rate and short-distance, ZigBee is suitable for the IoT devices with constraint of computation and storage capacity.

(3) Data fusion technology[8]. The resources for IoT terminals are usually limited, including battery capacity, processing ability, storage capacity and bandwidth. In the process of gathering information, it is not appropriate to send all data to the cluster node because it would waste bandwidth and energy. In order to keep the efficiency of information gathering, data fusion technology can be utilized to collect data thus more effective and useful data can be combined.

(4) Reliable communication[9] for smart grid under the complex application environment. There are several requirements of IoT applications in different environments, such as reliability, self-organization, signal penetration, hybrid communication technology and self-healing. Since the performance of IoT highly relies on the actual environment, IoT technology needs to be carefully designed to overcome the adverse environmental factors. For example, when a small portion of devices fails to transmit data, the route and transmission strategy would be reselected by self-healing technology, thus the reliability of the whole network would not be affected.

(5) Power acquisition technology[10]. Due to the energy of IoT devices are usually supported by battery, power acquisition problem is very essential for the application of IoT, such as the power transmission line monitoring system, various sensors, sink nodes and video cameras set up in the transmission lines and the transmission towers. If the energy supply problem of IoT can be solved, the applications of IoT in smart grid would be greatly extended.

(6) Environment compatibility with high-voltage and strong-electromagnetic[11]. Since IoT terminals are often deployed in outdoor power transmission lines, substations, and even more severe electromagnetic environment in smart grid. In order to prolong the lifetime of the sensing terminal under the above severe environments, the sensor and its chip manufacturing process need to embed new technologies , such as waterproof, dustproof, anti-vibration, anti-electromagnetic, anti-high-temperature, anti-low-temperature and others.

(7) Information security technology[12]. Information security technology can be utilized in three layers to avoid information leakage and loss, and protect the safety operation of the applications. Security should be considered not only in the data transmission process, but also in the process of data storage and management.

V. INFORMATION AND COMMUNICATION NETWORK OF IOT

The devices of IoT would generate massive data, which brings great pressure on the communication networks of IoT. The communication network is composed of optical fiber, wireless network, power line carrier or hybrid communication networks. According to the specific business demands and the characteristics of communication resources, we may choose the power optical fiber private network, power wireless private network, and public wireless broadband network as long-distance transmission network.

The power communication network is mainly based on optical fiber, such as Optical Fiber Composite Overhead Ground Wire (OPGW), Optical Fiber Composite Phase Conductor (OPPC), All-Dielectric Self-Supporting Aerial (ADSS), OPLC and so on. Currently, OPLC-OPPC-OPGW-based hierarchical power optical fiber communication network is under construction in China. Abundant services could be provided to the users by the three dimensional fiber network, including power fiber to home, "tri-networks integration", user interaction, information consultation and intelligent home security.

The Backbone communication network of State Grid Corporation of China (SGCC) is based on SDH broadband communications network with 2.5G bps. Since the power facilities trail behind the function of IoT, the 2.5G bps network cannot afford the intelligent video sensing and other IoT services. This fact means the 2.5G bps network need to be upgraded to the 10G bps network when IoT becomes popular in smart grid. Nowadays, power information wireless broadband private network is in planning in China, and it would provide a platform with comprehensive coverage, convenient access and integrated broadband service, which means it can support many IoT applications in smart grid. The available wireless technologies for power information wireless network are various, including IEEE802.16, LTE, McWill and 4G wireless broadband technologies.

Currently, public wireless communication network includes GPRS, CDMA, 3G, etc. At present, GPRS has the widest coverage but only provides the data rate with tens of Kbps. Therefore, it can only afford low data rate businesses. Public wireless communication network has the advantage of lower construction costs, but its shortcomings are also obvious. First of all, the network is mainly designed for voice services, when there are more users in some cellular area, the performance of real-time data transmission cannot be guaranteed at all times. Secondly, most of the power transmission lines are built in remote areas, where lacks signal or the signal coverage is poor. Thirdly, as the power information is private for power enterprises, the safety of public wireless communication network needs to be carefully considered.

In the communication network of power grid, the optical fiber and wireless network are often combined thus the advantages of low-loss optical fiber communication and ubiquitous wireless communication terminals can be integrated. For example, in the power transmission line monitoring system, optical fiber private network and wireless Mesh network are often used to transmit data together. Wireless Mesh system can connect multiple terminals or gateways through multi-hop method, and the coverage area can be dozens of square kilometers in the suburb. Moreover, dozens of Mbps of bandwidth can be provided to a single terminal, which is enough to meet the demand of high-definition surveillance video and other broadband services. Through the export of OPGW Fiber, remote data transmission can be realized by the Mesh base stations.

VI. TYPICAL APPLICATIONS OF IOT

A. Online monitoring for power transmission line

Power transmission line monitoring is one of the most important applications of IoT in smart grid, particularly, disaster prevention and mitigation of power transmission lines. In recent years, natural disasters bring about many challenges to high-voltage power transmission, including security, stability, and reliability. Moreover, current power transmission line monitoring system is mainly implemented by manual operation. In order to achieve real-time online monitoring of power transmission lines, the sensors about conductor galloping, micro-meteorology, wind vibration, icing, and conductor temperature are deployed on the 220kV, 500kV high voltage power transmission lines in the experimental area.

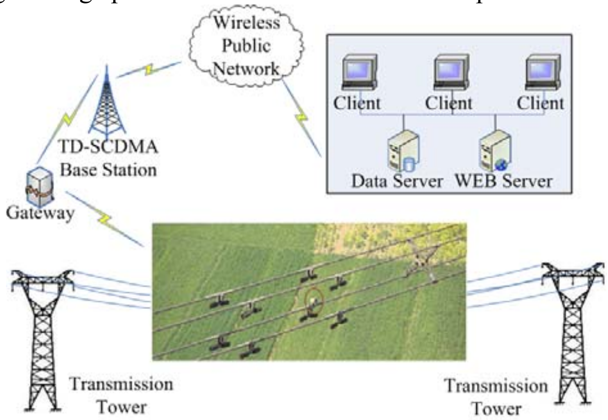

Figure 2. Online monitoring of power transmission lines

The power transmission line monitoring system is composed of two parts. One part is installed along with the power transmission lines to monitor their states; the other part is installed on the transmission towers to monitor the environment and their states. The communication between the IoT devices on the power transmission lines and the transmission towers is usually based on wireless networks. The master station system could transmit data through the wireless Mesh network together with power optic fiber network and/or wireless broadband network.

B. Smart patrol for power transmission, transformation and distribution

The patrol of power transmission, transformation and distribution in China mainly depends on manual operation of staffs. Due to climatic conditions, environmental factors, and other factors, the quality and in-place-rate of patrol cannot be guaranteed rigorously. Moreover, the patrol of unattended substation equipment is usually not easy to examine for the power workers. In order to effectively solve the above problems, the patrol system of power transmission, transformation and distribution system needs to be upgraded by IoT technology. RFID tags could be used to locate the power equipments which could supervise and guide the patrol staff with standardization and regulation of the workflow execution. With the help of RFID, smart patrol can enhance the quality and the efficiency of power transmission line patrol, guarantee the stability of power grid system and improve the power supply reliability.

C. Smart home service

Smart power utilization service includes hybrid smart AMR system, smart sensor network system, smart home system, security system, and energy information collection system, etc. There are three functions for the smart power utilization service system: reliable electricity supply, smart home experience for users and smart management and efficient use of energy.

As shown in Figure 3, the communication of the hybrid smart AMR system is mostly based on Power Line Carrier (PLC), Fiber to the Home (FTTH), broadband wireless communication, and other broadband communication network. Through this system, real-time communication between the power grid and users can be realized. The capacity of integrated services of power grid can be enhanced. The interactive marketing demands can be met. The quality of service can be improved. The user's energy efficiency can be enhanced significantly by applying the smart interactive terminal in smart home services.

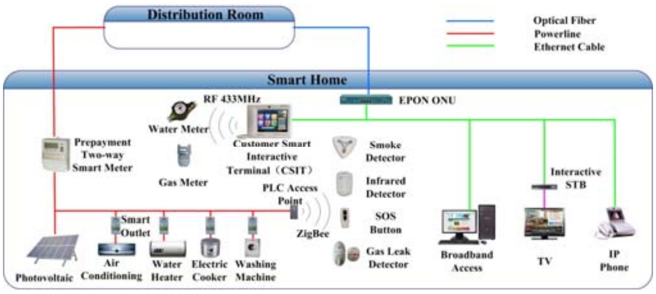

Figure 3. Smart home system

D. Information management system for electric vehicle

Electric vehicle (EV) offers an interesting smart grid opportunity beyond being eco-friendly transportation. It can be used to store energy. EV charging station is composed of four aspects: power supply system, charging equipment, monitoring system and related facilities, which is shown in Figure 4. Power supply system is mainly responsible for the safety output and measurement management of electricity, such as transformers and harmonic control equipment, etc. The charging and discharging of EVs are implemented in the charging equipment, including DC charger and AC charger. AC charger provides slow charging for the EVs, while DC charger provides fast charging mode and billing function. The monitoring system is responsible for real-time monitoring of charging environment and security.

Figure 4. Information management system for electric vehicle

EV can be considered as the mobile power storage device of smart grid, and it would help the power grid to mitigate the effect of peak-valley. This new capability results in better management of resources and is considerably more environmentally friendly. Consumers can also benefit independent of the utility by using cheaper electricity at non-peak time. In order to realize the interconnection of EV, charging station, and power grid, it is required to develop EV industry, communication supporting facility and management platform simultaneously.

Based on smart sensing and high capacity transmitting device, IoT technology could provide smart sensing and efficient interaction for EVs, batteries, charging stations. Smart sensing devices include wireless sensors, RFID tags, and GPS; high capacity transmitting devices include power optical fiber network, power line carrier communication, and wireless broadband. In addition, on-line monitoring, centralized control, optimal resource allocation and entire life-cycle management of the equipments could be achieved through comprehensive information analysis. By perceiving the available resources and the state of the resources in using, unified resources allocation and efficient service can be provided for charging station and the customers.

VII. Conclusions

IoT has been considered as the third revolution in the digital technology after the computer and the Internet. Currently, the power grid is transforming towards smart grid in China, the requirements of automation and intellectualization would lead to deep integrations of IoT with smart grid.

Up to one trillion RMB market would be brought by smart grid, which brings great challenges for IoT technology to become more practical for industrial applications in smart grid. The mature wireless communication theory and network optimization theory have been paved the way for theoretical basis of IoT. Moreover, several products of IoT have been produced. All these favorable factors make the development of IoT faster than other communication techniques. Mature, reproducible, and promotable IoT solutions are more promising, and these kinds of products can be widely deployed in power grid system.

SGCC has been actively promoting the research and application of IoT, a large number of smart grid pilot projects have been launched which effectively promote the application of IoT technology in power grid system. Initial achievements about IoT have been obtained by SGCC, including the development of modules and devices such as wireless image sensor, wireless temperature sensor, and smart outlet; the development of the equipments such as smart electric meters, PLC modems, broadband power line collection equipments, interactive terminals, smart patrol terminals and new energy access terminals; the development of the application systems such as AMR systems, intelligent electricity utilization service systems, GIS, smart patrol systems, and operation management systems. Smart grid will endeavor to provide attractive demonstration of industrial applications for the "Sensing China" project. SGCC will continue to strengthen the research and development of IoT in smart grid, promote industrial development of IoT, and make great contribution to the development of Chinese information technology industry.

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