Application Analysis of 5G Communication in Power System

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Abstract. In 2019, State Grid Corporation of China (SGCC) proposed the strategic goal of building and developing a strong smart power grid and ubiquitous power Internet of things. Smart power grid and ubiquitous power Internet of things involve massive information interaction in power system, which cannot be separated from the support of advanced communication technology. 5G communication system integrates advanced network technology, and has the advantages of high resource utilization, fast transmission rate and high spectrum utilization. Compared with existing 4G communication systems, it has a great improvement in user experience, transmission delay and coverage. In this paper, we take the application of 5G communication system in power system as the main research content, discuss various wireless communication application scenarios in power system, and analyze the feasibility of 5G communication to support the ubiquitous power Internet of things construction in terms of key technologies and application costs of 5G communication. However, the energy consumption and security of 5G communication system are still major factors that limit its application in the ubiquitous power Internet of things, and these problems need to be fully paid attention to by researchers.

1. Introduction

At the beginning of 2019, SGCC proposed the goal of three types, two networks, world class, vigorously promoting the integrated development of strong smart power grid and ubiquitous power Internet of things, and building a world-class energy Internet enterprise with the characteristics of hub, platform and sharing.

Smart power grid combines various advanced technologies such as communication, computer, automation and so on, and embodies its intelligence incisively and vividly. In particular, sensing technology and information technology have made power grid self-healing a possible function. With the development of China's modernization drive, energy saving and environmental protection initiatives have become an inevitable trend. Through the establishment of green power grid, effectively resisting external interference, the grid flexibility can be enhanced. Although the development route of smart power grid varies from country to country in the world, it is the combination of advanced information and communication technology, sensing and measurement technology and other advanced technologies with power technology to form an intelligent and automatic power supply network.

Ubiquitous power Internet of things is essentially a kind of Internet of things, which is a specific manifestation and application of ubiquitous Internet of things in the power industry. Whereas the traditional Internet connects computers with advanced means of communication, the Internet of things connects ordinary objects that can perform independent functions. For the power system, the interconnection of all the physical objects or equipment related to electricity is to some extent an
important realization of the ubiquitous power Internet of things. The traditional Internet of things mainly emphasizes the interconnection of information, while the ubiquitous Internet of things has both the interconnection of electricity and the interconnection of information.

In recent years, with the development of optical fiber communication technology, optical fiber communication technology has been widely used in power communication system. The optical fiber backbone transmission network in Shandong province has been completely constructed, and the optical fiber communication network has covered all voltage grade substations, power supply stations, business offices and hundreds of directly affiliated units in Shandong province. Ubiquitous power Internet of things requires the realization of the interconnection of everything in all links of the power grid, while the cost of comprehensive coverage of optical fiber is relatively high. At present, the massive equipment on the power distribution side has not fully realized the interconnection of information, and the last kilometer access challenge of the power system still exists and needs to be solved urgently. Therefore, the realization of ubiquitous power Internet of things requires the support of wireless communication network.

5G mobile communication system is an extension and development of the current 4G mobile communication technology. At present, all telecom operators in China are actively studying 5G mobile communication network, and China is expected to realize large-scale commercial use in 2020. 5G mobile communication system integrates advanced network technology, and has been greatly improved in user experience, transmission delay and coverage, etc. In the future, 5G mobile communication system will continue to develop in the direction of automation, intelligence and comprehensiveness. Compared with 4G, 5G mobile communication system has a big leap in bandwidth, delay and other aspects [1], which is manifested in the following aspects.

- High data rate. The peak data rate of 5G mobile communication system is no less than 20Gbps, and it is required that the user's perception data rate of 100Mbps to 1Gbps can be realized in each location within the cell, so as to realize the high-speed data transmission.
- Wide connections. 5G mobile communication system can realize mass connection of devices, up to 1 million mobile terminals per square kilometer, including household appliances, various wearable devices, etc., providing the foundation for realizing the information interconnection of everything.
- High reliability. 5G mobile communication system sends a 32-byte data unit with a 99.999% probability of success and a packet loss rate of just 0.001%.
- Low latency. The air interface delay of 5G mobile communication system network reaches 1ms and the end-to-end delay is less than 10ms, which improves the flexibility of system services to respond to various changes.
- Low terminal energy consumption. 5G mobile communication system extends the battery replacement or charging cycle of sensors and communication devices by reducing the energy consumption of devices, so as to keep all kinds of devices in the network online for a long time.

According to this analysis, various performance advantages of 5G mobile communication system make it provide strong technical support for promoting the construction and development of ubiquitous power Internet of things.

2. Application Scenarios of 5G Communication in Power System
According to the typical data application scenarios, the communication services of smart grid and ubiquitous power Internet of things can be divided into two categories: control and collection. The control service mainly includes power grid protection and control, power distribution automation, accurate load control, distributed energy regulation, intelligent patrol and inspection, etc. The collection service mainly includes electricity consumption information collection, advanced metering, distribution transformer monitoring, environmental monitoring of distribution room, video monitoring, operation status monitoring of distribution equipment, energy storage station monitoring, etc. In this
section, several typical application scenarios of 5G mobile communication in power systems will be described in detail.

2.1. Power Distribution Automation
Power distribution automation refers to the integration and integration of real-time and off-line information of distribution network feeders, equipment and users by using modern communication technology and computer technology to realize the normal operation of distribution system and the monitoring, protection, control and distribution management in the case of accidents. Due to the large number of power distribution network nodes, the realization cost of comprehensive coverage of optical fiber communication system is too high. Wireless communication network enables the measurement, control, automatic isolation and recovery system of feeders in distribution network automation to be realized at a relatively low cost. With the application of 5G communication system, when abnormal conditions such as short circuit occur, the system will quickly perceive the fault location through the measurement of the data transmitted back through the wireless network, and then accurately control the switch, ring network cabinet and other equipment through the wireless network to achieve rapid fault isolation and power access recovery.

2.2. Accurate Load Shedding
Accurate load control system focus on power grid failure early falling fast frequency, and trends in the trunk channel of the limit, a provincial tie line power use, power grid problems such as insufficient for spinning reserve, according to the different control requirements, divided into rapid load control millisecond control system and a more friendly interaction levels seconds and minutes of the control system. The millisecond control system can cut off part of the interruptible load in the first time according to the urgent control requirement of frequency. The second and minute-level control system can cut off part of the interruptible load in the second time period to achieve power balance [2]. Wired power communication network can realize millisecond load control, but due to the large number of supports, the per-user configuration of optical fiber and PTN equipment costs more. The usage of 5G wireless communication system can not only meet the requirements of accurate load cutting business delay, but also effectively reduce the cost.

2.3. Power Transmission Line Inspection
In power system, the traditional power transmission line inspection work mainly adopts the manual way. Affected by the geographical environment, some areas can only be reached on foot or inaccessible. Manual inspections are usually done with telescopes, making it impossible to observe transmission lines in all directions. In recent years, unmanned aerial vehicle (UAV) patrol and transmission line surveillance devices have gradually replaced manual patrol. UAV patrol usually adopts the way of recording video, and then analyzes the video after returning [3], which lacks real-time performance. The transmission line monitoring device can be used to realize real-time monitoring. However, affected by the bandwidth, the video and image quality is poor, which makes the staff unable to find the problem in time. The characteristics of high rate and high bandwidth of 5G communication system enable high-definition videos and images to be quickly and conveniently transmitted by remote wireless transmission, which can be widely used in power system video image monitoring scenes to improve monitoring efficiency and reduce communication costs. By configuring 5G communication module in the UAV, high-definition video and images of the power transmission line can be transmitted to the monitoring center in real time. The staff can also focus on checking some problem lines and take corresponding measures in time.

2.4. VR Intelligent Patrol
Virtual reality (VR) intelligent patrol is a hot research topic of power grid intelligence and informatization in recent years. With the support of the existing communication network, some universities and research institutions have made phased progress. VR intelligent patrol is similar to
telemedicine technology in principle. Workers can realize remote observation of the running state of
electric equipment and remote maintenance of faulty equipment by remotely controlling the patrol
robot. VR intelligent patrol has a high requirement on the bandwidth and delay of communication
network. Therefore, the existing technology is mainly based on wired communication, which has a
high limitation on the mobile range of patrol robots and makes it impossible to realize outdoor VR
patrol. The application of 5G communication network can greatly improve the flexibility of VR patrol
under the premise of ensuring the system bandwidth and delay. At the same time, it can effectively
avoid the risk of personal injury and improve the operation safety under the special situations such as
live equipment maintenance and cable trench operation.

2.5. Electricity Consumption Information Collection
In recent years, smart electricity meters have replaced traditional electricity meters as a new user
electricity metering device. Smart electricity meters not only have high accuracy, but also have the
capability of communication expansion. That is, by installing smart electricity meters with
communication modules, users' electricity information can be transmitted to the charging platform of
the control center, so as to achieve remote meter reading. At present, electricity information is
collected mainly by leasing telecom operators' networks, and a large amount of service fees are
required to be paid to the operators every year. In this kind of power business, the innovation brought
by 5G communication is relatively small. But given the state grid's long-term vision of working with
telecom operators to build a 5G network, adopting 5G could save some costs. In addition, the current
electricity information collection frequency is relatively low. Supported by the large bandwidth
characteristics of 5G communication, the collection frequency can be greatly improved, so as to
strongly support the power system marketing business such as electricity fee inspection.

Table 1. QoS requirements of power system service.

| Service type                  | QoS requirements       |
|-------------------------------|------------------------|
| Power distribution automation | Delay: hundreds of milliseconds, Reliability: 99.999% |
| Accurate load shedding        | Delay: ≤100 ms, Reliability: 99.999% |
| Relaying protection           | Delay: ≤100 ms, Reliability: 99.999% |
| Electricity consumption       | Delay: seconds, Reliability: 99.9% |
| collection                   |                        |
| Image surveillance            | Delay: seconds, Reliability: 99.9% |

The delay and reliability requirements of various services of the power system are shown in table 1.
It can be seen from the table that 5G communication network can meet QoS requirements of various
services and effectively reduce the cost of laying optical fiber, thus promoting the development of
smart grid and ubiquitous power Internet of things.

3. Feasibility Analysis of 5G Communication Application in Power System

3.1. Key Technologies of 5G

3.1.1. Large-scale MIMO. Large-scale MIMO technology is one of the core technologies to realize 5G
communication. Its basic feature is to arrange dozens or even hundreds of transceiver antenna arrays at
the base station side. Multiple users distributed in a communication cellular can communicate with the
base station simultaneously on the same time-frequency resource by using the spatial degree of
freedom provided by the base station configured with the large-scale antenna array [4]. Using beamforming technology, the base station can effectively send signals to a very narrow range, so as to effectively improve the multiplexing ability of frequency spectrum resources and the anti-interference ability between multiple users. Therefore, the spectrum resource utilization of large-scale MIMO system has been greatly improved to effectively support the large bandwidth and low latency services in the smart power grid and the ubiquitous power Internet of things.

In addition, massive access technology in wireless communication networks needs to be further developed in order to realize the massive machine-type communication requirements in the ubiquitous power Internet of things. The 4G mobile communication system effectively improves the number of users in the cellular through OFDMA technology, but it still cannot meet the requirements of Internet of everything in the future. By developing more spatial degrees of freedom, the large-scale MIMO system increases the number of orthogonal pilot frequencies, reduces pilot interference between users in the cellular, further improves the system access capacity, and effectively supports large-scale machine-type communication services [3]. In addition to the orthogonal multiple access technology, 5G mobile communication system also significantly enhances the system access capacity by adopting the non-orthogonal multiple access technology [6].

3.1.2. Network Slice. 5G network slice is the first new concept introduced by the Next Generation Mobile Networks (NGMN) [7]. Using software-defined network (SDN) and network function virtualization (NFV) technology, network slicing technology divides a single physical network into several independent end-to-end logical networks for different network service functions, and isolates each other and makes it programmable [8-10]. Through the centralized control of SDN, the data plane is uncoupled from the control plane, which simplifies the network management, makes the routing configuration flexible, and realizes the decoupling of software and hardware, sharing of infrastructure resources and on-demand scheduling [11].

Smart power grid system has the characteristics of real-time, security and stability, and has a very strong demand in the aspects of wide network coverage, ultra-low delay and ultra-high reliability. Virtual power network slices are divided on the common hardware infrastructure, which can quickly and efficiently transmit power system services and realize the isolation of power services from other communication services. At the same time, according to the bandwidth and delay of different services of the power system, the power network slices need to be further subdivided to better meet the needs of diversified services of modern power grid.

3.1.3. Edge Computing. Edge computing is a new deployment solution, by deploying small data centers or nodes with caching and computing power on the edge of the network, which are closely connected to mobile devices, sensors and users, signals are processed by edge computing servers without having to be transmitted to the core network. The application of edge computing can effectively reduce the load of the core network and reduce the delay of data transmission. For example, in the Internet of vehicles, the real-time requirements of business control and data transmission are high. If the data analysis and control logic are all concentrated in the remote cloud, it is difficult to meet the real-time requirements of the business. Edge computing is an effective method to promote the flattening of communication network. In smart power grid, the deployment of edge computing server can effectively reduce the end-to-end delay, which makes it possible to realize other low delay services such as relay protection based on wireless communication.

On the other hand, edge computing can provide flow discharge. The mobile terminal can judge whether flow discharge is needed according to the application's tolerance of delay, its own processing capacity and energy consumption. Computationally intensive and time-delay sensitive applications can be processed on edge computing platforms by flow discharge. Computationally intensive applications can be further offloaded to the core network to obtain more abundant and powerful computing resources when time delays and backhaul link loads allow.
3.2. Cost Analysis

3.2.1. Expenditure on Existing Services. According to statistics, in 2019, the service fee of wireless communication service in Shandong power grid is 178 million yuan, among which the service fee of electricity information collection service is 156 million yuan. In other words, the state grid Shandong electric power company needs to pay nearly 200 million yuan to the telecom operators to realize the normal operation of the power wireless communication business. The adoption of wireless communication services from telecom operators will bring huge costs, which does not include the equipment cost of wireless communication modules applied to all kinds of services. With the construction and development of ubiquitous power Internet of things, the cost of wireless communication services will face a substantial increase. Power system wireless communication service charge in 2019 is shown in table 2.

| Service usage                               | Service charge (million yuan) |
|---------------------------------------------|-------------------------------|
| Electricity consumption information collection | 156.408                       |
| Power distribution automation               | 14.202                        |
| Mobile terminal for electric marketing       | 2.387                         |
| Safety control                              | 1.242                         |
| Charging piles for electric cars             | 1.089                         |
| Rural electricity service                    | 0.784                         |
| Marketing POS                               | 0.504                         |
| Smart distribution and substation            | 0.355                         |
| Image surveillance for electric transmission line | 0.352                      |
| Rush repair of distribution network          | 0.233                         |
| Integrated voltage management system         | 0.209                         |
| APP promotion                               | 0.138                         |
| Self-service payment terminal                | 0.023                         |
| Emergency communication vehicle (ECV)        | 0.022                         |
| Mobile office                               | 0.002                         |

3.2.2. Construction costs. According to the cost estimation of telecom operators, the construction cost of a single base station in 5G communication system is about 500,000 yuan, among which, land lease, tower construction and other costs related to site selection account for more than 50%. In power system, the location selection of transformer station and ring main unit is determined by the density of population and industrial production, which is consistent with the principle of site selection of base station in the communication system. Considering the way that the state grid company and telecom equipment operators jointly build and share the communication network, that is, the state grid company provides the base station address and part of the network construction costs, while the telecom operators are responsible for the communication network construction and provide free network services for the power wireless communication business. Based on this model, the application cost of wireless communication service in power system will be effectively reduced. At the same time, from a long-term perspective, the co-construction and sharing business model will bring other economic benefits to the state grid company, which will provide important technical and economic
support for further promoting the construction and development of the ubiquitous power Internet of things.

4. Bottleneck of 5G Communication Application in Power System

4.1. Energy Consumption of Communication System

In the 5G era, the functions of the core network will be largely dispersed to the base station, which undertakes most of the network tasks. In fact, according to statistics, the base station consumes the most power in the existing communication system, accounting for about 70%~80% of the total power consumption of the whole network [12]. In 2012, about 1.1 million base stations were deployed in the world's wireless communication network, consuming 14 billion KWH [13]. In the 5G era, it is expected that the base station deployment density will be more than ten times of the current deployment density, reaching 13.1 million in 2025, and the energy consumption of mobile base stations will reach 200 billion KWH.

The application of large-scale antenna array requires a large amount of additional hardware to send radio waves, which increases the energy consumption. Data shows that the power of traditional 4G base station is about 900W, while that of 5G base station is about 2700W. With the construction of a large number of base stations, the power consumption of 5G system will bring new challenges and problems to the power system energy management. In addition, the power load of communication base station is directly related to the amount of communication data. During the daytime, electricity consumption is high and low at night. The capacity and geographical location of the base station on the side of the communication system should be reasonably planned based on the power load, communication load and new energy generation, so as to realize the coordinated planning of 5G communication system infrastructure and distribution network.

4.2. Information Security of Communication System

Although 5G communication system has obvious technological advantages, the Internet of everything also brings challenges to communication security and privacy. The construction and implementation of 5G communications will also fully consider the future information security challenges. For the ubiquitous power Internet of things, information security and privacy are particularly important. For example, some data in the power system is related to the security and stability of the power grid, which requires a high level of confidentiality. For another example, the user's electricity data is related to the user's privacy. In the process of data transmission and exchange, it is necessary to set different data access rights for different objects, so as to realize data sharing while protecting the privacy of different participants. In the future, the ubiquitous power Internet of things will collect and transmit massive data. It is necessary to define the data confidentiality level, data ownership, and data authority, so as to realize the security and privacy of 5G communication network and power network.

4.3. Construction of Communication System

Although it is an ideal decision for state grid company to build and share the network with telecom operators, there is no clear information to confirm this idea. In fact, 5G communication systems are not yet commercially available on a large scale in China, and state grid company is not a traditional telecom operator and does not have the advantages to plan and build communication networks. The cost of building the wireless communication network of the power system alone may exceed the cost of leasing the telecom operator's network at present, and the future economic benefits are not clear. In addition, the high voltage level of power system transmission and substation network will cause electromagnetic interference to wireless communication. Therefore, it remains to be further discussed whether the communication base station should be set up in the existing substation.
5. Conclusion

2019 is the first year of the ubiquitous power Internet of things, which has put forward a more clear goal for the future energy Internet construction. 2019 is also the year that 5G communications, which will reshape the way of life and power and energy systems of the future, will begin commercial scale. In this paper, the characteristics and technical indicators of 5G mobile communication is analyzed, while the application scenarios of 5G in power system and the important technologies to promote the construction and development of ubiquitous power Internet of things is discussed. Meanwhile, there are still bottlenecks in the application of 5G communication in power system. How to use the advantages of 5G communication system to promote the construction and development of smart grid and ubiquitous power Internet of things is the main research direction in the future.

References

[1] Shafi M, Molisch A F, Smith P J, et al. 5G: a tutorial overview of standards, trials, challenges, deployment, and practice[J]. IEEE Journal on Selected Areas in Communications, 2017, 35(6):1201-1221.

[2] Zhou J, Yu Q S, Liu L, et al. Communication Technology Selection and Construction Scheme for Accurate Load Shedding System in Shandong Power Grid[J]. Shandong Electric Power, 2018, v.45: No.245(04):57-61(in Chinese).

[3] Mai J J, Guo S, Xu Z L, et al. Automatic Driving Intelligent Inspection System of Transmission Line Multi-Rotor UAV[J]. Computer Systems Applications, 2019, 28(4):105-110(in Chinese).

[4] You L, Gao X Q. Key Technologies in Massive MIMO Wireless Communication[J]. ZTE Technology Journal, 2014(02):30-32+44(in Chinese).

[5] Biral A, Centenaro M, Zanella A, et al. The challenges of M2M massive access in wireless cellular networks[J]. Digital Communications & Networks, 2015, 1(1):1-19.

[6] Bockelmann C, Pratas N, Nikopour H, et al. Massive machine-type communications in 5g: physical and MAC-layer solutions[J]. IEEE Communications Magazine, 2016, 54(9):59-65.

[7] NGMN. 5G white paper[R]. 2015.

[8] ORDONEZ-LUCENA J, AMEIGEIRAS P, LOPEZ D, et al. Network slicing for 5G with SDN/NFV: concepts, architectures and challenges[J]. IEEE Communications Magazine, 2017, 55(5): 80-87.

[9] CHOI Y I, PARK N. Slice architecture for 5G core network[C]. Ninth International Conference on Ubiquitous and Future Networks, IEEE, Milan, Italy, 2017: 571-575.

[10] CHARTSIAS P K, AMIRAS A, PLEVRAKI I, et al. SDN/NFV-based end to end network slicing for 5G multi-tenant networks[C]. European Conference on Networks and Communications, IEEE, Oulu, Finland, 2017: 1-5.

[11] ZHOU H, CHANG Z X, YANG W J, et al. An orchestration algorithm of 5G network slicing QoS[J]. Telecommunications Science, 2017, 33(8): 130-137(in Chinese).

[12] Ghazzai H, Yaacoub E, Alouini M S, et al. Optimized smart grid energy procurement for LTE networks using evolutionary algorithms[J]. IEEE Transactions on Vehicular Technology, 2014, 63(9):4508-4519.

[13] Chih-Lin, Rowell C, Han S, et al. Toward green and soft: a 5G perspective[J]. IEEE Communications Magazine, 2014, 52(2):66-73.