Application of 5G Communication Technology in Power Communication and Research on Key Technologies

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Abstract: With the rapid development of power system and the deepening construction of smart grid, 5G communication technology is favored by all walks of life because of its ultra-low delay, ultra-high reliability, deep coverage, extreme capacity and ultra-low power consumption. It has become the key technology to lead scientific and technological innovation and promote the sustainable development of power system, providing a solid guarantee for the realization of human-computer interaction and Internet of Everything. This paper first introduces the network structure, basic principle and core features of 5G communication, and expounds the core slice of 5G communication and its three application scenarios; secondly, the potential demand scenarios of 5G communication in power system are analyzed in depth, that is, high capacity, high bandwidth and low delay business scenarios; finally, the key technologies of 5G communication, such as large-scale MIMO communication technology, ultra-dense heterogeneous network technology, green communication technology and millimeter wave communication technology, are discussed, and the linkage between current communication requirements and communication technologies is studied, which provides theoretical support for the application of 5G communication in power system.

1. Introduction
In recent years, the State Grid Corporation of China (SGCC) has been committed to building a world-class energy Internet enterprise to accelerate the construction of smart grid and upgrade information and communication network. With the continuous deepening of power communication network building, the number of IOT application terminals serving power grid production business is soaring. In face of the rapid development of distribution automation, distributed energy access, power consumption information collection and other businesses, coupled with the stepped growth of communication demand of various kinds of power grid terminal customers, problems such as difficulty to sense data return in the process of power IOT construction data and transmission delay. are gradually exposed, and these problems make it difficult to meet the diverse business and communication needs[1]. Therefore, the development of an efficient, real-time, reliable communication technology and power system is of great practical significance to enhance the level of information technology in the field of communication and promote economic and social development.
In March 2019, the SGCC proposed to take the power grid as the hub, fully apply advanced communication technology and modern information technology in all aspects of the power system to connect power grid enterprises, power users, suppliers, power generation enterprises and equipment so as to realize human-computer interaction, data sharing and interconnection of everything and provide value services for the whole industry, all market entities and the government. Among them, wireless communication technology will play a key role. With the rise of 5G mobile communication technology and its close integration with artificial intelligence, big data and other modern information technologies, the industry has ushered into a new era of “Internet of Everything”. 5G communication technology boasts the performance features of ultra-low delay, ultra-high network speed, super signal, ultra wide connectivity, etc. In addition, it is more diversified and comprehensive than 3G and 4G communication technology. Therefore, it will change the working and operational mode of the communication industry and provide technical support for the industry’s intelligent decision-making and the improvement of operation efficiency[2].

The application scenarios of 5G communication technology include low delay, high reliability, massive connectivity for Internet of Things, which demonstrate great potentials and commercial value in practical application such as driverless cars, high-speed downloading of information resources, remote surgery, Internet of vehicles, and are gradually leading human communication into an ultra-high speed era. Among them, 5G network slicing technology, as the core technology of 5G network, is an instance of network geared to specific business needs, and it can meet the construction of differentiated service level agreement (SLA), automatic on-demand construction and mutual isolation [3]. 5G network slicing technology has typical features of “end-to-end network guarantee SLA, service isolation, network function customization and automation”. It can not only dynamically allocate network resources and provide network as a service (NaAS), but also adopt information collection slicing and distribution automation slicing according to different business scenarios[4-6]. Under the premise of deep integration of 5G network slicing (virtual private network) technology and electric power communication network, different slicing can meet the technical index requirements of the corresponding scenarios. How to carry out in-depth research on the integrated development of 5G technology and power communication network under the background of smart grid and power Internet of things construction and solve the existing bottlenecks of power communication network is one of the priorities of current research on communication. Therefore, based on the basic structure, core features and principles of 5G communication network, this paper analyzes its application scenarios and key technologies in power communication network, which provides a reference for the research and application of mobile communication technology.

2. Principle and Features of 5G Communication Technology

2.1. Structure of 5G communication network
5G communication refers to the fifth-generation communication technology, and its network structure is composed of core network, micro base station and macro base station[7], as shown in figure 1. Among them, macro base station is connected with the core network through microwave or light, and uses wireless communication to realize information transmission between different areas. It has the features of wide coverage area and high transmission power, and is called the “central nervous system” of communication system. The core network mainly controls the data transmission and system operation, and it is responsible for connecting data requests of different ports with the corresponding network, and it functions like the “brain” of the communication system; micro base station is a collection of all small base stations, featuring small coverage area and low transmission power, and it is equivalent to the “peripheral nerve” of communication system. The cooperative operation of large-scale micro base stations is conducive to improving the communication signal strength and increasing the wireless connection density[8].
2.2. Basic principles of 5G communication technology

Communication technology can be divided into wireless communication and wired communication. The wireless communication technology that transmits information in the air still faces bottlenecks such as limited transmission rate and scale. The 5G communication technology was developed to solve this problem. Mobile communication refers to the transmission of information in the air with the help of electromagnetic wave signal to achieve communication. In this process, scattering, reflection, diffraction and other phenomena will inevitably appear, and it will be transmitted to the destination through multiple paths[9]. The signal-to-noise ratio, channel bandwidth and other factors will affect the transmission rate of information in wireless communication. The famous Shannon formula provides the upper limit of signal transmission rate in a single link[10]:

$$C = W \log_2 (1 + \frac{S}{N})$$

Where, $W$ represents the spectrum width; $N$ and $S$ represent the noise power and signal power, respectively; $C$ indicates the maximum transmission rate; and $\frac{S}{N}$ represents the signal noise ratio.

It can be seen from the above equation that the information transmission rate is limited by the channel bandwidth, but the same frequency spectrum can be used repeatedly in different areas far away from each other to improve the spatial reuse degree of frequency resources so as to provide more communication services with effective resources. This serves as an important foundation for the mobile communication technology. By using 5G communication technology to achieve peak rate, the following work can be carried out[11]: ① Arrange highly dense micro base stations to improve the degree of spectrum resource reuse and combine other wireless technologies to form a high-density network connection; ② Select larger spectrum width to increase the frequency of electromagnetic wave signal; ③ Apply the Shannon theorem to parallel communication links or develop large-scale multi-antenna technology to improve the utilization rate of spectrum resources.

2.3. Core features of 5G communication technology

5G communication is the basis for realizing ubiquitous connectivity for the Internet of Things. It can build connection between people and between different things quickly, freely and safely. It is an open technical framework with low cost, high reliability and low delay[12]. The 5G communication performance indicators (delay, bandwidth, peak rate, mobility, network energy efficiency, connection density, user experience rate, unit area capacity) are superior to those of 4G[13], as shown in figure 2.
Specifically, the future 5G communication should include the following core features:

1. Low energy consumption. In 5G communication, the Internet of things equipment has the features of low power consumption; its network energy efficiency is 100 times that of 4G, and it can transmit more data under the same energy consumption, so it has a great application prospect in the field of low energy consumption WAN. Low energy consumption is mainly based on software defined network and network function virtualization. This technology can generate specific network slices in different communication scenarios through software definition combined with business requirements. For example, for large-scale data transmission scenarios, it can generate corresponding “high-performance” network slice, while for scenarios with high power consumption requirements, the corresponding “low power consumption” network slice can be generated.

2. Low latency. 5G communication relies on data cache, wireless transmission network and core network to achieve the features of low latency. The air interface latency is only 1ms, which enables the power communication system to flexibly respond to various data requests. This feature mainly benefits from the following aspects. First, the distributed data caching technology is adopted. When the system receives a data request, it first searches in the local cache, micro base station/macro base station cache and device cache to check whether there is corresponding data information, and then selects the fastest data channel to transmit data. Second, the NR frame structure is shorter than 4G, and the data frame control technology is optimized. Third, through the comprehensive combination of cloud computing and edge computing, the data processing latency is reduced [14].

3. High capacity. The 5G communication spectrum broadband can reach gigahertz and achieve high-capacity device connection and support millions of mobile devices per square kilometer. The 5G air interface technology improves the flexible reuse of data resources and expands 5G communication capacity. Under the background of rapid development of “distributed” communication technology, 5G communication will deploy more micro base stations to establish greater device connection density.

4. High speed. The speed of 5G communication is extremely fast, its peak speed is as high as 20Gbps, the regional speed will be more than 1000 times higher than that of 4G. The edge speed is 100Mbps ~ 1Gbps, and the user experience speed is as high as 100Mbps. The high speed of 5G communication mainly depends on the improvement of transmission efficiency, spectrum range and spectrum utilization. The first is to improve the transmission efficiency. According to Shannon’s theorem, the maximum rate of signal transmission increases logarithmically with the increase of signal-to-noise ratio. Therefore, 5G communication can obtain lower transmission power and higher signal-to-noise ratio by using 3D beam-forming technology, so as to effectively improve the signal transmission rate. The second is to improve spectrum utilization. 5G communication adopts large-scale antenna array technology, which can effectively improve the spectrum efficiency and system capacity without increasing the bandwidth. In millimeter wave system, more antennas can be
deployed than 4G-LTE system to form a large-scale antenna array, thus greatly improving the communication rate [15]. The third is to improve the spectrum range. According to Shannon’s theorem, the maximum transmission rate increases with the increase of frequency band while the signal-to-noise ratio remains unchanged. 5G communication will upgrade 4G band to 6GHz. As a result, the channel bandwidth will increase and the maximum transmission rate will also be greatly improved.

(5) High reliability. The reliability of data connection in 5G communication network is very high, and the performance index is 0.001% packet loss rate, which is mainly due to the multi-join technology[16]. 5G communication network fully integrates the frequency band and wireless resources below 6GHz. With the high speed of high frequency band and the mobility of low frequency band, coupled with multi-join technology, high-reliability communication is realized. In this process, communication mainly depends on multiple frequency bands rather than single frequency band, so even if a communication mode is interfered, it can ensure the stable transmission of data.

The core features of 5G communication technology correspond to the basic requirements of power system[17], as shown in table 1.

| Features of 5G communication | Demands of the power system                  |
|------------------------------|---------------------------------------------|
| High speed rate              | Massive data transmission                   |
| High capacity                | Internet of Everything                      |
| High reliability             | Power system reliability                    |
| Low delay                    | Flexible response and cooperative control   |
| Low energy consumption       | Battery life and low energy consumption     |

2.4. 5G communication core slice and application scenario
5G communication technology has three application scenarios in power communication, which are massive machine communication slice (mMTC), enhanced mobile broadband slice (eMBB) and ultra reliable low delay slice (uRLLC) [18]. In the field of electric power, the mMTC focuses on the human-machine interaction in the large-scale Internet of things, mainly for the massive data transmission business, such as smart meter information collection, equipment running state parameter monitoring. The typical application scenarios are smart city, smart home, industrial automation, etc. The realization of these applications mainly depends on the features of 5G technology with low energy consumption and high capacity. eMBB focuses on the improvement of user experience performance, mainly for high traffic and high broadband services, such as natural disaster protection, high-definition video monitoring, power grid information management. Typical application scenarios include augmented reality, 3D video, virtual reality. The realization of these applications mainly depends on the high-speed features of 5G technology; uRLLC is mainly for meeting the requirements on ultra reliability and low delay, such as automatic demand response, distributed power distribution, precise load control. Typical application scenarios include smart grid control, driverless car, telemedicine. and the realization of these applications mainly depends on the low delay and high reliability features of 5G technology [19].

3. Typical application of 5G communication technology in power system
The core features of “three highs and two lows” render 5G communication technology great potentials in realizing interconnectivity for Internet of Everything, broadband communication, precise control, massive measurement and other aspects of power communication system. The integration of 5G communication technology with artificial intelligence, big data, cloud computing and other modern information technology will bring unprecedented changes and improvement in power system operation and maintenance, dispatching, control and other links to promote the power communication system to form a new intelligent ecology. According to the three network slices of 5G communication, the typical application of 5G communication in the future power communication system plays an important role in studying the current communication demand and communication technology, and
promoting the sustainable development of 5G communication.

3.1 High capacity business scenarios

3.1.1 User integrated load forecasting

5G communication network can carry a large amount of power data, and can collect, process and transmit the distributed data in real time, thus providing services for power system to obtain real-time power data and obtain the features of power consumption. 5G communication technology features high capacity and high connection density, which can accommodate a large number of intelligent devices and power equipment, and connect the information of user’s living, travel, social production, etc. in a more transparent and clear form. From the perspective of the integration of information, physics, society and environment, it can achieve precisely depict users’ portraits, perceive users’ electricity consumption behavior, and accurately predict their energy load[20].

3.1.2 Power grid operation state perception

At present, there are few measuring elements deployed in the distribution network, so it is difficult to realize the state estimation of the power grid, and the sampling period of the data acquisition and monitoring control system in the power grid is long; it can only measure the RMS of current and voltage but can not observe the change of phase angle. 5G communication network supports the deployment of a large number of measuring elements, which can realize the deployment of measuring elements on each node, observe the operation status of power system in real time, and comprehensively improve the system security. Some scholars assume that the voltage, phase angle and power of the grid nodes are measurable, and build a linear power flow model through data and model driven to realize the optimal control of the power system[21]. Some other scholars obtain the topology of the distribution system based on data driven, and accurately identify the distributed energy access points[22]. In addition, 5G communication supports PMU data lossless transmission, which provides technical support for the analysis of power system security and stability.

3.2 High bandwidth service scenarios

3.2.1 Photovoltaic short-term forecast

Currently, in the research on distributed energy and power system, how to realize the short-term prediction of photovoltaic power generation has become the focus of the industry. Due to different geographical locations and environmental conditions of the photovoltaic power station, the irradiation received by each group of photovoltaic units also varies. In the past, the accuracy of prediction results based on historical sequence and weather forecast was not high. To solve this problem, some scholars proposed a short-term high-precision photovoltaic prediction technology based on image intelligent perception, that is, by collecting the sky image of the photovoltaic base in real time and sending it to the analysis center. It uses neural network and machine learning to calculate the cloud operation path so as to achieve the purpose of accurate prediction of photovoltaic output[23-24]. 5G communication technology can quickly collect and transmit real-time information, realize the real-time interaction of distributed energy generation prediction data, and ensure the accurate prediction of photovoltaic output.

3.2.2 High definition image real-time monitoring

Based on the features of 5G high bandwidth and high rate, the fast transmission of structured and unstructured data can be realized. It can be used in the power system operation-monitoring scene to reduce communication cost and improve monitoring efficiency. The following technologies can be realized by using 5G communication. First, machine learning can replace the traditional manual monitoring and analysis, and automatic machine learning and judgment analysis can be realized by taking the videos or pictures transmitted by 5G wireless communication as training samples. The
second is to realize the fast transmission of large capacity data and improve the resolution of video or picture. The third is to realize real-time monitoring of power system based on low-delay features, so as to replace the traditional post-analysis and ensure “what you see is what you get”. Taking UAV power inspection as an example, the service mainly uses video recording to inspect the high-voltage and transmission lines, and judges the power operation status by analyzing the video or pictures. This method cannot ensure the timeliness of fault handling, or grasp the detailed power line status. The 5G communication technology applied in UAV inspection can sense the operation status of power system in multiple directions, transmit the operation status information of power grid to the analysis center in the form of high-definition image in real time, locate the fault area quickly and accurately, assist inspectors to focus on detecting the fault lines and take timely maintenance measures. In addition, the 5G communication technology can also reduce the cost of laying cable network in the distribution monitoring room, and provide strong support for HD monitoring business.

3.3 Low latency service scenario

3.3.1 Demand-side resource real time frequency modulation
With the large-scale access of new loads such as distributed new energy, charging piles and energy storage equipment, the power grid architecture is becoming increasingly complex, and it faces the challenge of imbalance between supply and demand of power system. The traditional power system frequency modulation method is unable to meet the current needs. The use of energy storage and user response to optimize the power grid frequency control has become the main solution, which puts forward higher requirements on the communication delay of demand-side resources participating in power grid frequency modulation. If the communication delay is too high, the demand side can not achieve fast and accurate response to the superior FM command[25]. With the low delay and high bandwidth features, 5G communication can effectively reduce the communication delay in the process of power system frequency modulation, and realize real-time scheduling of the massive distributed energy data. At the same time, its wide coverage and high capacity also enable the power system to include massive demand-side resources in the frequency modulation without laying optical fiber.

3.3.2 Ubiquitous resources participation in precise control
Flexible response is one of the main requirements of power system, and to achieve timely response to power changes, it is necessary to carry out accurate load control, which needs to focus on solving the problems of insufficient rotating reserve, blocking of cascading faults, and power flow overrun of main channels. Combined with different control requirements, the purpose of accurate load control can be achieved by realizing friendly interactive control system and millisecond level control system [26], as shown in figure 3. The overall time delay requirement of millisecond level control system is less than 650ms, and the low time delay characteristic of 5G communication technology just meets the control requirements and at the same time it can realize the accurate control of power system load. In addition, 5G communication can ensure that the system starts accurately to the equipment level, realize the emergency load shedding control of the power system without cutting off the feeder, and enable distributed resources to participate in the accurate load shedding control of the power system.
4. Key technologies of 5G communication applied in power communication system

4.1 Ultra dense heterogeneous network technology

5G communication system is no longer a simple voice or SMS communication system under the coverage of macro base station, but rather a communication network system under the coverage of heterogeneous dense distribution network, which is oriented to diversified needs and integrates multiple technologies and services. 5G communication intensive heterogeneous network deployment can effectively solve the problems of small coverage and low spectrum utilization. Heterogeneous network technology includes two key technologies, namely D2D communication and small cell deployment[27]. D2D communication is to give adjacent mobile terminals the ability to transmit signals through the fastest transmission link to meet the need of bursty communication. Small cell deployment is to deploy low-cost and low-energy micro base stations in macro cellular network to expand network data capacity and meet more service requirements. For example, the combination of macro with relay, Picocell and other low-power base stations can effectively solve the problems of Macrocell network such as high delay, low reliability and coverage blind spot[28].

Although the 5G heterogeneous network framework has realized transformation from cellular to distributed communication mode, which has brought great benefits to network performance, its deployment mode still faces challenges. Dense heterogeneous network deployment adopts differentiated transmission power, closed access form, and the macro base station and micro base station use the same frequency band, which is prone to serious communication interference. In dense heterogeneous networks, increasing the number of users or increasing the transmission rate can make some macro cellular users carry out D2D communication, but the increase of network density will complicate the anti-interference methods, thus affecting the overall performance of the network. At present, the domestic interference of dense heterogeneous network is mainly solved by multi-point...
cooperation mechanism, but the application of 5G communication network will inevitably make the intra layer and inter layer interference more complex. In addition, the random deployment of low-power base stations will also bring greater challenges to the interference management, user access and system capacity of power communication network. Therefore, improving the utilization of communication resources will be the main research direction for eliminating communication interference.

4.2 Large-scale MIMO communication technology
MIMO communication network is a new architecture that can reduce the complexity of hardware implementation, improve the spectrum utilization, and increase the system coverage performance[29]. It has great application value and prospect in the field of wireless communication. Large scale MIMO technology is to configure a large-scale antenna array at the base station to provide information communication for multiple users. These antennas can be arranged in a large-scale centralized layout or distributed in the cell, and have greater communication data capacity and wireless communication freedom. Specifically, the performance advantages of large-scale MIMO technology are as follows: first, by using a large number of antennas, the array gain can be improved, the power consumption of the transmitter reduced, and the system network energy efficiency improved. Second, with the increase of the number of base station antennas, the interference between users can be effectively suppressed or eliminated, so as to enhance the system capacity. Thirdly, it has a large number of power amplifiers that can be used for transmitting signal spatial filtering to reduce the signal peak-to-average ratio, so that the signal RF front-end uses low-energy and low-cost, thus reducing the deployment cost. Fourth, the use of a large number of antennas can make the communication system present the channel hardening features, improve the radio frequency efficiency of the communication system, and avoid users falling into deep fading[30]. In addition, large-scale MIMO technology can improve the system performance through maximum ratio transmission, thus simplifying the complexity of system implementation. Because of these features, this technology is considered as the key technology of 5G communication system.

Although large-scale MIMO technology has many performance advantages and has been widely recognized by the academic and industrial circles, it still faces some problems, such as the resource allocation limitation caused by the significant increase in the number of antennas, the difficulty of coherent beam design in frequency division duplex communication system, the channel estimation of TDD communication system. In addition, the pilot pollution caused by the reduction of orthogonal pilot sequence because of user movement is also a difficulty faced by related research. How to solve these key technical problems has become the focus of breaking through the bottleneck of large-scale MIMO system development.

4.3 Green communication technology
With the popularity of wireless communication network and the significant increase in the number of base stations, the energy consumption caused by information and communication technology is intensifying. According to relevant statistics, the energy consumption generated by the information and communication industry in 2019 accounted for about 10% of the global energy consumption, and about 80% of the energy consumption was generated by the base station. Therefore, improving the energy efficiency of communication system has become one of the core goals of 5G communication system development. The energy saving of communication system can be considered from three aspects: one is to adjust resources and transmission power and the number of users. Second is to reduce the energy consumption of base station. Third is to optimize topology and network deployment. At present, the communication industry and academic research are committed to green communication technology, and have proposed high-efficiency space-time resource allocation, spectrum efficient base station cooperative sleep, WDM optical network energy saving and other solutions. However, these methods aimed at improving the energy efficiency of communication system also reduce the spectrum efficiency to a certain extent, and in the actual operation process, the components and nodes need to be
updated in time. How to improve energy efficiency and spectrum efficiency at the same time has become the main research direction of green communication technology. In addition, the dynamic resource allocation for business needs and the data transmission mode with high efficiency and low energy consumption also need to be realized.

4.4 Millimeter wave communication technology
Millimeter wave is characterized by wide spectrum, short wavelength, high reliability and sound directivity. It can establish a super wide bandwidth communication system with communication rate up to 10Gbit/s. The millimeter wave communication technology can solve the problem of scarce spectrum resources. When designing millimeter wave communication system, we need to consider the propagation features of electromagnetic wave in the air, and analyze the spectrum of atmosphere and electromagnetic wave propagation path. In addition, compared with low-frequency wireless wave, millimeter wave has more serious frequency selective absorption in the process of propagation in the atmosphere, so it is suitable for short-range communication[31]. Due to the scattering, fading, multipath number and typical sparse features of millimeter wave communication transmission, channel estimation, pre-coding design and other MIMO communication system theory can not be directly applied to millimeter wave communication. Aiming at the problem of short transmission distance, the advantages of MIMO communication technology coupled with hybrid beam-forming scheme will become the key technology for the development of millimeter wave communication system[32]. Different from the traditional MIMO communication system architecture, 5G millimeter wave MIMO communication system adopts digital analog hybrid beamforming, as shown in figure 4. To solve the problem of channel data acquisition in MIMO communication system is an important precondition to realize hybrid beamforming. At the same time, channel modeling in digital analog hybrid beamforming architecture is also a big problem. How to solve the existing bottleneck and give full play to the advantages of millimeter wave communication has become the core content of 5G wireless communication technology development.

![Figure 4. Schematic diagram of traditional beamforming](a) and a schematic diagram of digital-analog hybrid beamforming(b) and (c)](a)

5. Conclusion
In recent years, China’s power communication network construction is deepening, and the demand for communication business scenarios is changing dynamically, which puts forward higher requirements on power communication technology. As an emerging communication technology, 5G will reshape the future lifestyle, become a key technology leading scientific and technological innovation, and play a key supporting role in the future power system construction. This paper systematically describes network structure, basic principles, core features, core slicing and application scenarios of 5G communication. Based on the frontier research on power system, typical application scenarios of 5G communication in power system are conceived, and the key technologies and research directions of 5G communication are discussed, so as to provide theoretical reference for the future application of 5G communication technology in power system.
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