Research on the Application of Uninterrupted 5G Private Network in Smart Grid

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Abstract: Based on the demand for smart grid 5G network, this paper studies 5G mobile communication technology and the industry's 5G private network construction mode. Combined with power grid requirements, this paper focuses on analyzing the uninterrupted 5G private network solution, the principal of the solution is also explained. Taking a 5G test network deployed at a converter station as an example, the construction, isolation, operation, and maintenance plans of the uninterrupted 5G private network solution in the power communication network is proposed, the actual tests verify the feasibility of the continuous 5G private network. This paper will provide reference for the promotion and application of 5G private network technology in the power grid.

1. Introduction

A private network is a private network, which is a professional network that only achieves network signal coverage in specific areas and provides communication services for specific users in the organization, command, management, production, and dispatching links [1]. The private network is generally the internal private network of a certain industry system, and only serves the system. The network performance is reliable and the network function can be customized, so that the private network has irreplaceable advantages in industry applications. Because of its high isolation [2], 5G private networks have broad application scenarios in many vertical industries, especially in the field of energy and power.

At present, in the power industry, research on the application of 5G in smart grids is mainly focused on the slice-based deployment model. This deployment model consumes less resources and requires less investment, and the deployment speed is faster. It is suitable for scenarios where the electric power industry conducts wide-area coverage based on 5G networks. For scenarios with high requirements for data security, reliability, and delay jitter in power grid services, the slicing mode cannot well meet the needs of the business on the network. The industry generally adopts the method of user face sinking to solve such situations, this solution can basically meet the performance and security requirements of the service, but for the abnormal or active disconnection of the link between the user plane and the operator’s large network control network element, the continuity of the service cannot be guaranteed, and data transmission will be interrupted.
This paper proposes a continuous flow of 5G private network construction plan, by sinking part of the control network element, as a backup of the operator’s large network control network element when the control link is disconnected, to ensure that data does not leave the park and business transmission is not interrupted. This solution has been verified on the live network at a converter station, which can provide efficient and reliable 5G network coverage for smart grid services.

2. Smart grid 5G demand analysis
The concept of smart grid has long existed, and it is generally believed that it was first proposed by the Electric Power Research Institute (EPRI) in 2001. In 2015, the National Development and Reform Commission clearly defined smart grid "Smart grid is formed on the basis of traditional power system by integrating new energy, new materials, new equipment and advanced sensing technology, information technology, control technology, energy storage technology and other new technologies. The new generation of electric power system has the characteristics of high degree of informationization, automation, and interaction, which can better realize the safe, reliable, economical and efficient operation of the power grid."

1) Precise load control
Precise load control is an important part of UHV AC and DC grid system protection. It is mainly used to coordinate the comprehensive configuration of grid resources and loads, realize the mutual interaction of power supply, grid, and user load, and improve the emergency response capability of UHV grid faults.

2) Distribution automation
Distribution automation refers to the comprehensive utilization of computer, information and communication technologies based on the primary grid and equipment of the distribution network, and through information integration with related application systems, to realize the monitoring, control and rapid fault isolation of the distribution network, Provide real-time data support for the distribution management system.

3) Command and dispatch communication
It provides a strong communication guarantee for personnel commanding and dispatching in scenarios such as equipment maintenance and emergency rescue.

4) Video surveillance
Carry out real-time and controllable video surveillance on key places, so that no one or few people are on duty.

5) Mobile office
Provide mobile office services through wireless access through smart terminals.

3. 5G Private Network Advantages and Construction Mode
My country's IMT-2020 (5G) Promotion Group has defined the main deployment scenarios of 5G: continuous wide-area coverage, hotspots with high capacity, low power consumption and large connections, and low latency and high reliability. The 5G network is deeply integrated with the Internet and the Internet of Things, extending the connection between people to the Internet of Everything, and can provide users with personalized and intelligent services. It is a truly converged network.

3.1. 5G technical advantages
Compared with 4G, 5G's key technologies are innovative in many aspects such as air interface and architecture, and the development potential of wireless networks is huge.

For the key technologies of 5G, we can further refine and summarize large-scale antennas, ultra-dense networking, full-spectrum access, new multiple access, new multi-carrier, advanced modulation and coding, terminal pass-through technology, flexible duplex, full duplex. Key technologies such as spectrum sharing are briefly introduced as follows:

High-frequency transmission: The traditional working frequency band of mobile communication is
mainly concentrated below 3GHz, which makes the spectrum resources very crowded. 5G supports data transmission in high frequency bands (such as millimeter wave and centimeter wave frequency bands) to realize extremely high-speed and short-distance communication.

Large-scale antennas: Multi-antenna technology has undergone the development from passive to active, from two-dimensional (2D) to three-dimensional (3D), and from high-order MIMO to large-scale arrays. Compared with 4.5G, Massive MIMO has a larger scale of 5G, and the number of antennas is further increased, thereby improving the received signal strength, suppressing interference between users, and achieving higher system capacity and spectrum efficiency. The novel 3D-MIMO technology supports intelligent multi-user beam shaping and reduces interference between users. Combined with high-frequency millimeter wave technology, it will further improve wireless signal coverage.

Simultaneous same-frequency full-duplex: Using this technology, on the same frequency spectrum, both the sender and receiver of communication transmit and receive signals at the same time. Compared with the traditional TDD and FDD duplex mode, the air interface spectrum efficiency can theoretically be doubled.

Dense network: through more "dense" wireless network infrastructure deployment, to obtain higher frequency reuse efficiency;

New type of multiple access: through the superimposed transmission of multi-user information on the same resource, the receiving side uses advanced receiving algorithms to separate multi-user information, represented by SCMA, PDMA, MUSA, etc.;

New type of multi-carrier: reduce sub-band or sub-carrier spectrum leakage through filtering and relax the requirements for time-frequency synchronization, such as F-OFDM and UFMC;

Advanced modulation and coding: including link-level modulation and coding, link adaptation, network coding, etc., to reduce interference between nodes;

Terminal direct connection: realize the communication of the vehicle, vehicle, road, and vehicle-to-vehicle;

Unlike previous mobile communication systems that mainly emphasized user peak rates, 5G key performance indicators are more abundant. In addition to user peak rates, they also include user experience rate, connection density, end-to-end delay, traffic density, and mobility.

Among them, the user experience rate is the most important performance indicator of 5G. It truly reflects the real data rate that users can obtain, and is also the performance indicator that is most closely related to user experience. Compared with 4G, 5G has higher performance,

3.2. 5G private network construction model analysis
Vertical industry applications have become an important driving force for the rapid development of 5G. Compared with 4G, 5G mobile communication technology has such technical characteristics as large connections, high reliability, and low latency, which are highly compatible with private networks. It can realize the application of typical industries such as live video broadcasting, massive Internet of Things device access, unmanned driving, telemedicine, intelligent manufacturing, or government and enterprise private network applications [3].

According to the different needs of industry applications for the security, reliability, and performance of 5G networks, telecom operators currently generally provide three 5G private network networking modes, namely the slicing mode, the exclusive mode for some network elements, and the exclusive mode for the core network. The electric power communication network covers a wide range of application scenarios due to the particularity of the services it carries. Different electric power communication applications have large differences in network delay, jitter, security, and reliability requirements, and different power services should be adopted according to specific power service applications. 5G network coverage plan.

4. Continuously streaming 5G private network networking solution
As a station in the high-voltage direct current transmission system, the converter station realizes the
mutual conversion between alternating current and direct current. Whether its operation is safe and stable directly affects the safety and power quality of the power system. The application of 5G technology in the converter station not only provides important support for the improvement of the communication capacity of the converter station, but also provides technical support for the intelligent development of the converter station.

Using 5G technology to achieve full coverage of indoor and outdoor 5G wireless terminal access methods for the entire site, providing terminal wireless access channels for converter station online monitoring systems, intelligent management and control systems, and other intelligent monitoring and monitoring systems to solve high bandwidth and large connections The need for safe and reliable service access and last-mile communication for various intelligent sensing services.

4.1 Overview of 5G Core Network Elements
The 3GPP standard determines the construction of a 5G core network based on a service-based architecture (SBA). This service-based network architecture draws on the design concept of “microservices” in the IT field and defines network functions as multiple relatively independent Flexible call service modules. Based on this architecture design concept, operators can flexibly add or upgrade network element functions according to business requirements, and realize flexible customized networking.

In this architecture, the 5G core network can be divided into control plane network elements and forwarding plane network elements. The control plane network elements are mainly responsible for processing 5G signaling, and the forwarding plane network elements are mainly responsible for service traffic forwarding. The 5G system architecture (R15) is shown in Figure 1:

Fig.1 Schematic diagram of 5G system architecture

Control plane network elements mainly include Network Slice Selection Function (NSSF), Network Exposure Function (NEF), Authentication Server Function (AUSF), Network Storage Function (NF Repository Function, NRF), Access and Mobility Management Function (AMF), Policy Control Function (PCF), Session Management Function (SMF), Unified Data Management (UDM) And the application function (Application Function, AF); the forwarding plane network element mainly includes the user plane function (User plane Function, UPF).

The 5G core network is characterized by modularity and softwareization. The control network element and the forwarding network element in the core network coordinate control flow processing and data flow forwarding to complete 5G network data transmission.

4.2 Analysis of Continuous Flow 5G Private Network Networking
The electric power communication network is an important basic system to ensure the security of the power grid, support the construction of smart grids, and promote the rapid development of digital, networked, and intelligent power grid companies. The power communication network technology is also evolving with the changes in business requirements and the emergence of new technologies.

In order to ensure the overall stability of the power system, some specific power services (such as differential protection) have higher requirements for network delay; at the same time, there are more important corporate information in the power communication network, and power companies generally require data to be only allowed in their Circulation in the park; In addition, in accordance
with the communication requirements of the application of the converter station, the network elements that need to be sunk are selected as follows:

Business data does not meet the needs of the park – sinking UPF network elements;

After the control link is disconnected from the operator, the 5G network services in the park will not be interrupted. – Sink SMF, AMF, UDM, and AUSF network elements;

After disconnecting from the operator's control link, the 5G network in the park supports the new access requirements of registered terminals-sinking UDM and AUSF network elements.

For NSSF, NEF, NRF, PCF and AF network elements, the main functions are slicing function selection, network opening, automatic network element discovery, policy customization and interaction with third-party application functions, taking into account the difficulty of operation and maintenance and the maturity of network elements, cannot sink for the time being, and adopt the mode of sharing with the big network[4].

In summary, the architecture of the continuous flow 5G private network is shown in Figure 2:

![Fig. 2 Schematic diagram of uninterrupted 5G system architecture](image)

As can be seen from the above figure, the campus network is deployed with AMF-Local, SMF-Local, AUSF-Local, UDM-Local and other control plane network elements and UPF-Local forwarding plane network elements, and the backup control network element (AMF-Local, SMF-Local, AUSF-Local, etc.) and the corresponding network elements of the operator's 5GC (AMF, SMF, AUSF, etc.) form a hot backup. When the campus network is disconnected from the operator's 5GC network, the control network elements in the park are seamless Takeover can ensure uninterrupted business.

5. Continuously streaming 5G private network application practice

As a station in the high-voltage direct current transmission system, the converter station realizes the mutual conversion between alternating current and direct current. Whether its operation is safe and stable directly affects the safety and power quality of the power system. The application of 5G technology in the converter station not only provides important support for the improvement of the communication capacity of the converter station, but also provides technical support for the intelligent development of the converter station[5].

5.1. Private Network Construction Plan

This paper selects the 5G experimental network of a converter station to analyze the networking scheme. The overall networking is divided into the large network 5GC, the headquarters node and the converter station park. Among them:

Bignet 5GC includes operator 5GC, Business Support System (BSS) and Operation Support System (OSS);

Deploy converge switches, egress firewalls, and manage cloud resource pools at the headquarters node;
The converter station park deploys macro stations, BBUs, 5G sinking network elements (including AMF-Local, SMF-Local, AUSF-Local, UDM-Local and other network elements), edge computing platform (Multi-access Edge Computing, MEC), Power grid applications, aggregation switches, firewalls and other equipment.

The power grid bearer network of the converter station park is connected to the second floor of the headquarters node, and the headquarters node is connected to the operator's network through the exit firewall and the operator's bearer network access equipment.

The purpose of this networking is to realize that when the 5GC headquarters nodes of the big network are normally connected, the operator can assist the 5G equipment in the converter station park; after the connection is disconnected, the 5G applications in the converter station park continue to flow and can carry the connections of registered terminals.

5.2. Private network isolation scheme

In the electric power communication network, the isolation and security of different district services in the private network are also important factors that need to be considered. The security isolation scheme is mainly divided into north-south security isolation and east-west partition isolation. The north-south security isolation is mainly guaranteed by the authentication mechanism and firewall of the 5G core network itself, and the east-west partition isolation is mainly guaranteed by virtual routing forwarding (Virtual Routing Forwarding, VRF) guarantee.

1) South-north terminal authentication and isolation security mechanism based on 5G network

The 5G terminal communicates with the data network and is controlled by two levels, namely the control plane and the data plane; the terminal needs to complete the interaction with the network elements in the control plane before the data plane network elements begin to transmit data. The interaction process between the terminal and the control plane network element can be divided into several steps: terminal registration authentication-session establishment-data plane resource allocation. If the terminal fails the control plane network element authentication, it generally cannot communicate with the application.

In the terminal registration and authentication stage, the terminal authenticates and interacts with AUSF through AMF. AUSF compares the information recorded in the UDM with the terminal information. Only when the information such as Equipment Identifier (PEI) is consistent with the user information pre-written in UDM can the comparison be passed. Based on the 5G authentication mechanism, the authentication protection of the legality authentication of the SIM card and the authentication of the APN account password can be realized.

2) Security mechanism of north-south isolation based on firewall

The terminal IP pool is located in the sinking network element of the 5G campus, that is, after the terminal data flow undergoes signaling interaction, the starting point of the data communication part is in the sinking network element of the 5G campus. The firewall can enable NAPT, ASPF and security protection measures for incoming traffic.

3) Firewall-based east-west partition isolation security mechanism

After transmission on the wireless side, the data communication side is initiated by the sinking network element of the 5G campus, and terminated in the power grid application access switch; the data flow of different partitions is isolated on the switch using VRF for Layer 3 routing.

6. Conclusion

This article sorts out the network requirements of smart grids, and explains that 5G mobile communication technology has great advantages in grid applications. At the same time, it analyzes the application limitations of the current 5G network in the slicing mode and the forwarding plane sinking mode mainly used in the power communication system, and proposes a continuous flow 5G private network networking scheme based on the sinking of some 5GC control network elements. A converter
station is a reference for actual deployment and describes the landing plan. In summary, the continuous flow 5G private network networking solution proposed in this article can be used as a practical reference solution when power services have special requirements.

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