Study on the adaptability of 5G and wireless private network applied to the protection of medium voltage distribution network

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Abstract. With a large number of grid connected renewable energy power generation brings new challenges to the operation and management of power grid in the future, the deep penetration of distributed energy makes the distribution network from the passive network with unidirectional power flow to the active network with bidirectional power flow, and the protection business of distribution network presents the situational demand of large data volume, high performance and new energy access. This paper makes use of the characteristics of 5G communication network, such as large bandwidth, low time delay and high reliability, to avoid the difficulties of traditional communication network deployment, and makes in-depth research and comparison from two aspects of demand and technology to explore the adaptability of 5G communication and future medium voltage distribution network protection servicebearing.

Keywords: 5G, Wireless private network, Distribution network protection, Adaptability

1. Introduction
The communication level of traditional distribution network protection is very low. The existing distribution network protection is mainly single terminal protection. At present, it mainly adopts over-current protection, fault line selection and partial distance protection. With the increasing proportion of new energy access, the increasing complexity of network topology, the increasing requirements for power reliability and power quality, the existing distribution network protection can not take into account the requirements of rapidity and selectivity, and it is difficult to adapt to the requirements of new energy access distribution network and new energy power plant station protection function, the vertical differential protection and wide area protection can have Effectively improve the protection level of distribution network. Therefore, the future distribution network protection business requires more strict performance of communication network. It is necessary to select the communication network bearer that meets the business requirements, comprehensively solve the limited problems such as data bandwidth, data delay, data transmission distance, etc., and support the scope and reliability of distribution network protection [1].
2. Current situation and development trend of traditional distribution network protection communication network

Most of the traditional distribution network protection is single terminal protection, which uses the line operation reflected by single terminal electrical quantity; only a few lines are configured in the way of longitudinal protection. When there is short circuit current and other line fault information in the distribution network, the communication channel is used to realize synchronous information interaction between protection devices. In the past, due to the relatively small number of distribution network nodes, urban communication lines are easy to lay. Considering the reliability and stability of communication, optical fiber network communication mode is generally selected to support the realization of line fault location and identification function. The schematic diagram of longitudinal protection is as follows:

![Schematic diagram of distribution network longitudinal protection](image)

**Figure 1.** Schematic diagram of distribution network longitudinal protection

The main function of the distribution automation protection terminal is to realize the protection and control of the distribution network. Through the automatic relay protection device to detect the status information of the distribution network lines or equipment, it can quickly realize the fault judgment and accurate positioning of the distribution network lines and equipment. According to the survey, the medium and low voltage distribution network (35kV and below) mainly covers the urban center and residential areas. In the future, the urban coverage will gradually increase to the periphery, and the nodes will be scattered. In the construction of communication network, the difficulty of optical fiber deployment and pipeline excavation will be considered comprehensively, and the return on investment will not be too high, so a more flexible channel deployment mode should be selected.

With the gradual increase of the number of distributed new energy connected to 35kV Power supply, the number of terminal nodes of distribution network protection system is also increasing. At least one medium-sized city distribution network protection terminal needs to be configured with tens of thousands of quantity levels to meet the protection requirements. The power nodes of distributed new energy generally choose to be located in suburban areas, which makes the network topology of distribution network more complex and changeable. In the process of expansion of optical fiber network, new connecting joint equipment and road excavation will be involved, which
not only meets the basic node access, but also maintains the consistency of communication performance, increases the cost investment and the operation effect of distributed power access. It is not in direct proportion, and there is a phenomenon of putting the cart before the horse [2].

3. Analysis on the demand of communication network for automatic protection of distribution network in the future

At present, the distribution network protection system has not involved the monitoring of the protection operation process, but in the future, with the increase of the difficulty and pressure of distribution network protection, the system monitoring business is to be deployed. The monitoring business generally includes the standardized content of mobile terminal guiding inspection, inspection, repair, defect elimination, acceptance and other operations, multimedia small data such as recording operation results, and distribution protection business. The data bandwidth, node density, delay and data flow direction of will change dramatically. Next, analyze the business requirements one by one and focus on the parameter characteristics.

(1) Protect business bandwidth requirements

| name                          | description                                                                 | Uplink (Mbps) | Downlink (Mbps) |
|-------------------------------|-----------------------------------------------------------------------------|---------------|-----------------|
| SV backup protection          | In case of failure of main protection, fault isolation and recovery can be carried out in time | 140           | 93              |
| SV longitudinal differential protection | The sampling data is packaged according to iec61850-9-2 frame structure         | 90            | 90              |
| Online monitoring             | ISO/IEC 9506 MMS application layer message is used to send online monitoring data, and TCP communication is used in the link process, with the maximum data of 64-1518 bytes per frame | 46            | 46              |
| Mobile operation and maintenance | The maximum MMS message of a protection device is about 300K bytes / s when sending the recording file | 200           | 93              |

(2) Delay requirements

The delay time of differential protection is required to be less than 10ms, the time synchronization accuracy is 10us, and the delay jitter of main and standby channels is ± 50uS when the distance of substation where the current differential protection device is located is less than 40km. At the same time, in order to achieve precise control, the adjacent intelligent distributed distribution automation terminals must carry high-precision time stamps when they interact with each other [3].

(3) Node density

The distribution lines shall be divided into no more than 4 sections. For a single 10kV distribution line, the number of distribution terminals in the core area shall be estimated as follows:

For the core area with medium growth rate, 6 circuits are estimated based on the 10kV circuit number N per square kilometer area. Considering the protection terminal demand of the most line segments and interconnection switches, 5 sets of protection terminals are required for each circuit. The required protection number N terminals are [4]:

\[
N \text{ terminal} = 6 \times 5 = 30 \text{ sets} \tag{1}
\]

If it is considered to install a boundary switch on the high voltage side of the distribution transformer of each line, the N terminal of the protection terminal at this time is:
Then the maximum number of distribution terminals $N$ per square kilometer estimated by this example is 80 sets.

(4) Data concurrency rate

According to the maximum upstream flow of a single terminal of 205.4 Mbps and 72 devices per km2, the concurrent flow per km2 is about $205.4 \text{ Mbps} \times 72 = 14788.8 \text{ mbps} \approx 14.5 \text{ Gbps}$.

(5) Isolation requirements

Distribution automation belongs to the I/II production area business of power grid, which requires complete isolation from other III/IV Management area businesses.

4. Discussion on the adaptability of 5G communication network performance and distribution network protection service

4.1. 5G communication network architecture design under distribution network protection

5G communication technology has improved significantly in terms of terminal access rate, base station connection capacity and service delay on the basis of 4G system. Its unique slicing ability can meet the load of multi scenario services. Typical scenarios include enhanced mobile broadband (eMBB), large-scale machine like communication (mMTC) and ultra-high reliability and low delay communication (URLLC). In urllc scenario, 5G communication The signal delay can be reduced to 0.5ms (one-way) at most, which can provide millisecond level end-to-end delay and nearly 100% service reliability guarantee, and the transmission rate is greatly increased, which can fully adapt to the realization of the distribution network protection function with large data volume, high performance and new energy access under complex topology. 5G wireless communication has the characteristics of large bandwidth, low delay and high reliability, which can meet the communication requirements of urban distribution network protection. In order to realize 5G communication in distribution network protection device, only 5G communication module needs to be installed in the existing device. The cost of reconstruction is low, the overall construction cost and workload are significantly reduced compared with laying optical fiber, and the economic analysis is the preferred scheme. Schematic diagram of distribution protection architecture under 5G communication network architecture [5] [6]:

\[ N \ \text{terminal} = 6 \times 12 = 72 \text{ sets.} \]
Figure 2. Schematic diagram of protection architecture after 5G communication application

Each protection device can directly exchange information through 5G base station, and can easily access and remove multiple new energy generating units, protection devices and their network nodes. Using 5G communication to carry distribution network protection can make full use of multi-point electric quantity and state quantity information in the power grid, and build a new type of relay protection system based on 5G communication, which can realize fast and reliable protection action and take into account the optimal cooperation between protections, so as to improve the overall level of distribution network protection [7].

4.2. 5G communication transmission characteristics

(1) System performance index

5G needs to have higher performance than 4G, support 0.1-1gbps user experience rate, one million connections per square kilometer, tens of TBPs per square kilometer, mobility over 500km per hour and peak rate of tens of Gbps. Among them, user experience rate, connection density and delay are the three basic performance indicators of 5G. At the same time, 5G also needs to significantly improve the efficiency of network deployment and operation. Compared with 4G, the spectrum efficiency is increased by 5-15 times, and the energy efficiency and cost efficiency are increased by more than 100 times.

(2) System delay

In order to meet the requirements of automatic control and other services with high delay in the future industrial Internet, the delay of 5G system must be improved. The delay of DL and UL is required to be 0.5ms for urllc service. Based on 4G LTE network, further flattening design, simplifying air port transmission protocol, designing ultra short subframe structure, with interval length less than 1ms, which can easily reduce the periodic transmission time of subframe.

(3) Peak rate

5G network shows more enhanced functions in the process of practical application. Theoretically, its transmission speed can reach tens of GB per second, which is hundreds of times of 4G mobile
network. For 5G network, it shows more obvious advantages and more powerful functions in the practical application process. For example, a 1g movie can be downloaded in 8 seconds. With the birth of 5G technology, it can support more multimedia monitoring data such as video in distribution network. In order to obtain the actual downlink rate, it is estimated to take 2.5ms as the single frame transmission cycle:

It can be seen from the 2.5ms dual period frame structure that when the special subframe slot ratio is 10:2:2, there are \((3+2*2/14)\) uplink slots in 5ms, so the number of uplink slots per millisecond is about 0.657/ms.

\[
\text{273rb} \times 12 \text{subcarrier} \times 11 \text{symbol} \times 0.657/\text{ms} \times 6\text{bit (64QAM)} \times 2 \text{Stream} = 284\text{mbps} \tag{3}
\]

Downlink basic configuration, 4-stream, 256qam (one symbol 8bit)

It can be seen from the 2.5ms dual period frame structure that when the special subframe time slot ratio is 10:2:2, there are \((5+2*10/14)\) downlink slots in 5ms, and the number of downlink slots per millisecond is about 1.28/ms.

Rough calculation of downlink theoretical peak rate:

\[
\text{273rb} \times 12 \text{subcarrier} \times 11 \text{symbol} \times 1.28/\text{ms} \times 8\text{bit (256qam)} \times 4 \text{stream} = 1.48\text{gbps} \tag{8}
\]

4.3. 5G communication and distribution protection business matching

According to the transmission requirements of protection services studied in Section 2 and 3.2 and the description of 5G network bearing performance parameters, the two are put into the same table for comparison to determine whether each index can meet.

| Table 2. Adaptability analysis |
|--------------------------------|
| Communication performance index | Business requirements | 5G communication index | Matching degree |
| delay(ms) | 5 | 1 | 100% |
| rate(Mbps) | 205.4 | 10Gbps | 100% |
| Total data(Gbps) | 14.5 | 10 Tb | 100% |
| connections(num/sqkm) | 72 | 1× 107 | 100% |
| Isolation | Business isolation of each area | Network slice | 100% |

The final conclusion is that the 5G network design scheme and transmission specification parameters are fully matched with the future medium voltage distribution network protection business demand, and there is still some room for expansion and redundancy.

5. Conclusion

This paper deeply studies the typical application mode of distribution automation protection business in the power industry, analyzes the business characteristics and communication network requirements in detail, defines the 5G technical requirements and business requirements under the distribution automation protection scenario, studies the 5G network architecture and performance indicators, analyzes its adaptability with the power distribution automation business and whether it can meet the power distribution automation load-bearing needs. Please. It provides a reliable feasibility analysis process for 5G network to carry distribution network protection services.

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