Flow Control for 5G Smart Distribution Grid Protection

Jun Lin[1], Yunguo Yang[1], Shenhua Wang[1], Cheng Chen[1], Yangning Zhang[2(✉)], Yunpeng Zhang[2], Zhiwen Liu[2], and Xiaoli Liu[2]

[1] State Grid Zhejiang Wuyi Power Supply Company, Wuyi 321200, China
[2] School of Electrical Engineering and Automation, Wuhan University, Wuhan 430072, China
{zhangyangning,zhangyp2001,xlliu}@whu.edu.cn

Abstract. 5G communication technology has so many advantages with large bandwidth, high reliability and low latency that the 5G-based differential protection technology becomes a research hotspot in the field of intelligent distribution network protection. However, 5G-based differential protection still have some issues to be addressed, like delay jitter, data security and flow control. On the basis of the analysis of the difference protection technology based on 5G network slices, some methods of controlling flow are provided from multiple aspects like resource allocation, communication protocol, transmission mechanism optimization, algorithm optimization and transmission mode in this paper. (1) It is achievable for flow control to utilize weight-based bandwidth and resource allocation by customizing URLLC slices of 5G network. (2) Compared to TCP, MPTCP is more in line with the requirements of differential protection channel in many aspects, including delay, dislocation control, energy consumption management, security and data volume. (3) The monthly average data flow falls to 1 GB from 6.2208 TB by optimizing the transmission mechanism with the non-standard R-SV protocol of reducing transmission frequency. (4) By optimizing the data calculation algorithm, more than 20 GB of transmitted data will be reduced within one day in normal conditions. (5) Combining 5G with Fiber Channel, 90% traffic can be saved.

Keywords: 5G network slice · Smart distribution grid · Differential protection · Flow control

1 Introduction

Among the communication modes of differential protection of distribution network, the widely used fiber-optical exists some problems like long construction period, high cost, and fiber's fragility. The fiber coverage in 10 kV/35 kV distribution network is so low that results in the difficulty of application to the wire current differential protection. On the other hand, 5G wireless communication has the advantages of large capacity, low latency, wide coverage and so on, which is currently a promising communication mode for the IIoT (Industrial Internet of Things). Therefore, it is anticipated to exploit differential protection with 5G in distribution network.

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To exchange message of real-time electrical data (current & power), 5G-based differential protection needs to adopt UDP (User Datagram Protocol) message without any mechanism of flow control. However, facing a large amount of data, the UDP may cause network congestion [1]. Since the differential protection of the distribution network needs to transmit sampled value through the 5G wireless channel, the current mechanism with point-by-point transmission will obviously cause more traffic.

The flow control of 5G-based differential protection can not only lessen the one terminal occupancy for bandwidth resources, which reduces the requirement on air-interface resources, but also decrease the delay jitter, prevent network congestion and save traffic cost, which is significant for 5G application in smart grid. The main work of this paper is as follows. (1) Illustrating the feasibility of applying 5G slicing technology to differential protection of distribution networks. (2) Analyzing the data flow of 5G-based intelligent distribution network protection. (3) Providing the solutions for flow control with different aspects, involving in communication protocol, transmission mode, transmission mechanism and algorithm optimization.

2 Differential Protection Based on 5G Network Slicing

5G network slicing is a kind of technology that performs software definition of network functions, and separation of physical hardware facilities along with network functions, which is supported by Mobile-Edge Computing (MEC), Software Defined Network (SDN) and Network Function Virtualization (NFV) [2]. The overall architecture of network slices is shown in Fig. 1.

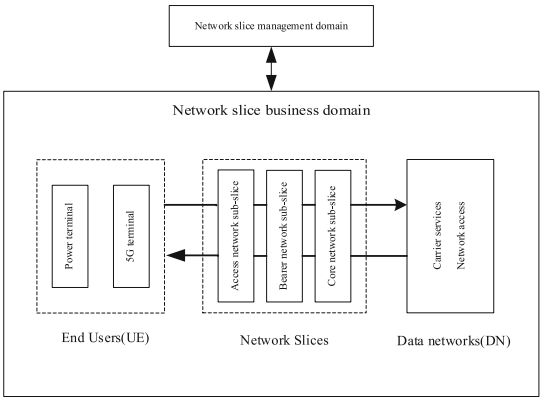

Fig. 1. Schematic diagram of overall architecture of network slices

The end users convert the collected electrical variables into communication data, which is received, transmitted and processed, then sent to the carrier by network slices. Also, the same information can be transmitted back to the end user via network slices. As shown above, network slices and data networks jointly realize network slicing services.

Compared with traditional networks, 5G network slicing can be customized according to the requirements of specific bandwidth, delay and so on, which ensures network

resources. In addition, the faults and network congestion of the slices do not affect each other due to their isolation. With the basic network equipment, the slices can be rapidly activated and services can be rapidly deployed [3]. Therefore, it is undoubtedly a good choice to apply 5G network slicing to smart distribution grid.

It is different for the demands of latency and resource with each function in the smart grid [4], among which the differential protection requests network transmission slices with high reliability, high accuracy and low latency. To realize the 5G-based differential protection of distribution network based on the current network resources environment, the business requirements for differential protection should be guaranteed first. We can manage and assign appropriate resources with specialized URLLC (Ultra-Reliable Low-Latency Communications) slices to properly manage and ensure the flow corresponding to each slice.

3 Flow Control of 5G-Based Distribution Grid Protection

Network flow control is the key to realize the real-time transmission of power information [5]. Differential protection of distribution network adopts the mechanism of transmitting the sampling value point-by-point, and replacing fiber channel with 5G will produce more data traffic, which causes certain augmentation of the average latency, delay jitter, packet loss rate and so on. As a result, the operating time and stability of differential protection will be affected, which further brings safety risks of operation. Therefore, in order to reduce the packet loss rate, delay and bandwidth resource occupation during transmitting power information, it is necessary to control the flow of 5G-based differential protection.

3.1 Communication Protocols of Transmission Layer in Power Systems

In power grids, Transmission Control Protocol (TCP) and UDP are usually used as protocols of transmission layer. TCP is based on the connected mode, while UDP is based on the disconnected mode [6]. It is known that one of the greatest differences between TCP and UDP is that TCP needs to establish connection in advance before communication, its mechanism of retransmission and congestion control ensures the accuracy of data, which results in the low real-time performance. By contrast, UDP is a real-time connection protocol, which can transmit data one-to-many and has high real-time performance.

Differential protection of distribution network has high requirements on data integrity and timeliness [7, 8], so the direct adoption of these two protocols is undesirable. TCP flow is at a week position in the case of high real-time requirements and bandwidth competition of large capacity, meanwhile UDP has no flow control mechanism, which may lead to network congestion or even crash. Therefore, it is necessary to improve the communication protocol of the power system to control the flow within the required delay range of differential protection.

There are two types of messages used in differential protection based on the fiber optical communication, which are private message based on the HDLC (High-level Data Link Control) and SV (Sampled Value) message based on IEC 61850–9 protocol [9]. The 5G communication system takes TCP/IP as the core, and has UDP layer.

The communication message of differential protection is similar to the UDP message, so it is available to use UDP to realize the DSP (Digital Signal Processing) package transmission of 5G communication. (1) Based on the IEC61850–90-5 protocol, it can modify the original SV and GOOSE protocol, use UDP multicast technology to achieve routing, namely R-SV, R-GOOSE. Afterwards, we can use the IP network to realize the free transmission through the router message. (2) The differential protection device is connected to the 5G network by the CPE (Customer Premise Equipment), and it can adopt the R-SV message to exchange the real-time sampling data to realize the differential protection.

3.2 Flow Control

Through the analysis of communication protocols of transmission layer in power systems, we know that using either TCP or UDP to transmit information, it is necessary to control the flow when applying 5G-based differential protection. The following will discuss flow control strategies from different aspects, including communication protocol, transmission mode, transmission mechanism and algorithm optimization.

Network Slicing Technology for Resource and Spectrum Allocation
5G slicing technology is applied to 5G channels in an end-to-end slicing mode based on SA (Standalone) networking, which provides bandwidth and resource allocation for transmission of different information data based on weight proportion, according to the different requirements of distribution network information and the characteristics of various scheduling policies [10]. The weighting factor is set by re-editing the message, and the flow is managed according to the different types of data and service priority. After the weighting factor is used for bandwidth allocation, the control information has the priority of occupying the bandwidth and frequency to ensure accuracy and efficiency when multiple types of services are transmitting simultaneously in the power grid. The remaining bandwidth is used to transmit multimedia and management flow.

Weight-based bandwidth and methods of allocating resource are used to customize URLLC slices of 5G network for the differential protection. In order to avoid congestion and realize service security isolation, the dedicated end-to-end channel is used in network. The customized network slices are applied to differential protection communication.

Table 1. Communication network performance comparison

Network performance	Customized slices	Original communication network
Frame loss rate%	0.005	0.05
Average latency/ms	10	25
Delay jitter >10 ms%	0.05	0.28

In this way, the data comparison of the communication network performance and 5G independent network conditions is shown in Table 1. We can conclude that the frame loss rate and average latency are greatly reduced, which achieves flow control.

In short, the weight-based bandwidth and resource allocation was used to accurately calculate and allocate the spectrum resources by 5G slicing technology. Then the number of base stations and intermediate nodes set up in the same coverage area decreased, which further reduce the end-to-end latency of differential protection channel, enhance the reliability, low both the bit error rate and the probability of net-work congestion. Correspondingly, the flow control and the real-time transmission of key information like differential protection message is achievable.

Utilizing MPTCP Communication Protocol

MPTCP (Multi Path TCP) is an evolutionary mechanism of traditional TCP, which enables the host to implement a single TCP connection in TCP through multiple different network interfaces, and realize effective utilization of data message and improve bandwidth availability [11]. Additionally, MPTCP which can use multiple links to transmit data at the same time is compatible with the traditional TCP. After the failure of one path, the other path can still continue to transmit data, which can not only shorten the period of transmitting data, but also increase the reliability. MPTCP maintains an independent congestion window, each sub-flow is one TCP connection, and changes in the congestion window are adjusted by receiving ACK (Acknowledge character) message or the loss of detected packets. MPTCP transfers some flow from the high-blocking path to the low-blocking path to maximize the utilization of network resources, so as to reduce the loss of links, improve the availability of multiple sub flows, and realize the effective allocation of network resources.

From the performance comparison of MPTCP and TCP, we conclude that MPTCP is more in line with the requirements of differential protection in many aspects, including delay, dislocation control, energy consumption management, security and data volume, which can effectively solve the problems of small amount of transmitted data and large latency in TCP and the flow control problems in UDP. Using MPTCP is expected to be an option for controlling the flow of 5G differential protection.

5G network already supports the transmission mode of copying data, which can realize high-level parallel transmission of multiple links, so as to ensure delay and reliability requirements when considering wireless resource usage [12]. The utilization of MPTCP, along with 5G data copy and transmission technology to the communication protocol of power system can meet the requirements of low latency and high reliability of URLLC service.

Optimizing the Transmission Mechanism

The realization of traditional differential protection requires the protection devices on both sides to obtain the synchronous electrical variables, whose amount is much large. Therefore, optimizing the transmission mechanism to reduce the data-transmission frequency can effectively reduce the amount of data transmission.

For example, the whole line in practice includes three substations of 35 kV and one substation of 110 kV, all of which adopt 5G differential protection devices and the SA independent networking mode. According to the statistics shared by CPE, when the data

exchange method of differential protection adopts standard R-SV protocol, assuming that the length of message per frame is 300 Byte, 4000 frames are transmitted per second, the output and reception are in progress simultaneously, then the transmission rate and unidirectional monthly flow is 9.6 Mbit/s and 24.8832 Tbit respectively. The bi-directional monthly traffic will be 6.2208 TByte with the standard protocol.

The non-standard R-SV protocol is used to reduce the packet transmission frequency. Under normal circumstances, there's unnecessary to exchange real-time sampling information between the protection devices on both sides, which just exchange information regularly at a specific frequency. As a result, the traffic is almost zero under this condition. When a fault occurs, the protection device will reactivate the function of transmitting sampling value when it detects a large fluctuation of voltage and current, and the devices on both sides begin to normally exchange data in real time.

If optimizing the transmission mechanism by reducing the packet transmission frequency according to the non-standard R-SV protocol, the 24 h traffic of the whole line will be only about 30 MB, which means the monthly average traffic decreases to just 1 GB. Thus, this method solves the problem of user's traffic charge to a great extent.

Optimizing the Data Calculation Algorithm

In different algorithms, the traffic generation during data transmission will vary a lot due to the different data frame sizes. Currently, there are two kinds of computing methods of differential protection data still used: vector differential and sampling value differential [13].

Because the criterion of the vector differential protection algorithm is simpler than that of the sampling value, and the sampling value differential algorithm discriminates repeatedly, the data amount generated by the vector differential protection algorithm is less than that of the sampling value. Table 2 lists the byte size and transmitted data amount of two methods [14], the amounts of bytes per frame and transmitted frames per cycle of the sampling value differential algorithm are larger, which generates more transmitted data. If adding time stamp, the number of bytes per frame of both algorithms will increase accordingly.

Table 2. Amount of data transmitted by a certain type of optical fiber differential channel

	Bytes per frame	Transmitted frames per cycle	Amount of transmitted data per second / (kbit·s^{-1})
Vector differential	63	4	100
Sampling value differential	79	12	379.2
Add time stamp	5	4	8

It is shown in Table 2 that the data calculation method of protection should be chosen as vector differential algorithm as far as possible during the construction of new substation. Through this improvement, more than 20 GB of transmitted data will be

reduced within one day in normal conditions, which can effectively reduce the traffic data of the protection device during data calculation.

Combining 5G with Fiber Channel

On the basis of the original fiber differential protection, this method is adding 5G channel and adopting the data transmission mode of 5G and fiber integrated channel [15]. The line differential protection diagram of the integrated channel is shown in Fig. 2. When the fiber channel works normally, the 5G channel only transmits the sampling time tag and the deviation from the external synchronization clock, and does not transmit the electrical data. When the fiber channel is abnormal but no fault occurs, the 5G channel sends electrical data at a certain frequency to monitor the status of sampling synchronization. When a fault occurs, the 5G channel sends differential protection data in real time. In this mode, 90% traffic can be saved when the fiber channel is normal and the line is working normally.

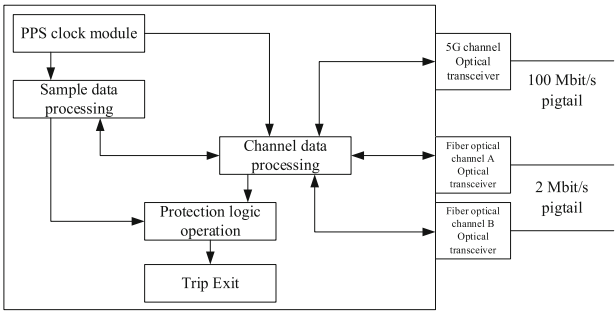

Fig. 2. Integrated channel line differential protection

The method of combing 5G with fiber channel can realize the transmission of R-SV, R-GOOSE and so on, which further reduce the requirement of the differential protection channel. In addition, the sampling synchronization status is monitored in real time, so as to improve the reliability of differential protection. The data transmission mode of 5G and fiber optical integrated channel is not only conducive to the promotion and application of two-channel and three-route, but also successfully controlling the data flow, which further improves the economy of data transmission.

4 Conclusion

Since the data flow is much larger when using standard protocols with 5G distribution network differential protection, which may cause delay jitter, information conflict and high traffic cost. The flow control is one of the keys to the application of 5G-based differential protection technology in distribution networks. In the paper, the protection principle of 5G intelligent distribution network was declared firstly. Secondly, we analyzed the feasibility of 5G network slicing in smart distribution protection. Finally, the solution of flow control from different aspects, including communication protocol, transmission

mode, transmission mechanism and algorithm optimization, was investigated. Through the paper, we expect not only to implement 5G based smart distribution grid protection effectively, but also improve the QoE (Quality of Experience) of smart distribution grid.

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