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To cite this article: Jiye Wang *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **490** 062077

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Communication Network Simulation System for System Protection Service

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Abstract. With the continuous expansion of power grid, traditional protection strategies based on the local information can no longer meet the needs of the safe and stable operation of complex power systems, and it is necessary to establish a high-speed, real-time, safe and reliable power communication network to support AC/DC co-control, disconnect control, precise load shedding, and panoramic state awareness and other system protection functions. This paper designs a communication network simulation system for system protection services. It describes the system from both functional architecture and software architecture and analyzes the system protection business requirements, including the bandwidth requirements and the delay requirements based on existing communication technologies. The communication scheme based on MSTP and OTN is verified by simulation. and it provides a good basis for the planning and construction of system protection.

1. Introduction

With the rapid economic development, the structure and scale of power grid have become increasingly complex, and the operation and control of large power grid are facing greater challenges. Human factors, equipment failures, natural disasters and other internal and external factors may pose a greater threat to the safe and stable operation of the system. The traditional protection strategy based on the local information can no longer meet the needs of the safe and stable operation of complex power systems [1]. Therefore, the concept of system protection emerges. It uses modern communication technologies to obtain a real-time information on all points in the power system and dynamically monitors the operating status of the power system. Comprehensive analysis, identification of disturbances that may have serious consequences for the power system, and the adoption of appropriate control measures to eliminate or mitigate the consequences of disturbances [2].

System protection multi-band, high-precision panoramic state awareness and multi-scene, full-process real-time intelligent decision-making need to build a high-speed, real-time, secure and reliable communication network. The main functions of system protection include AC/DC co-control, disconnect control, split control, precise load shedding, and panoramic state perception. It is difficult for the current communication network to meet the requirements for high-speed and secure transmission of the above acquisition and control information[3]. Therefore, it is necessary to analyze the node distribution and service flow, transmission distance, channel bandwidth, and communication delay of the system protection communication network, and study and compare the current common



communication technologies, and propose future-oriented communications that can support the system protection vision. Technical solutions, and related theoretical analysis and laboratory test verification.

2. System architecture design

2.1. Functional Architecture of Simulation System

The communication network simulation system for system protection services consists of three parts: the simulation function demonstration layer, application management layer, and distributed data interaction layer. It supports the joint modeling and simulation of multi-function modules. Its functions include comprehensive demonstration and system protection communication network simulation, data interaction, and system management to realize the simulation of system protection communication network equipment and the connection mode between devices, communication protocol, business frame structure, traffic characteristics, and simulation of QoS control strategies for different service types, providing the system management for users Visual interface, and real-time display of statistical data. The schematic diagram 1 of the function of the comprehensive simulation and test platform of the system protection communication network is shown:

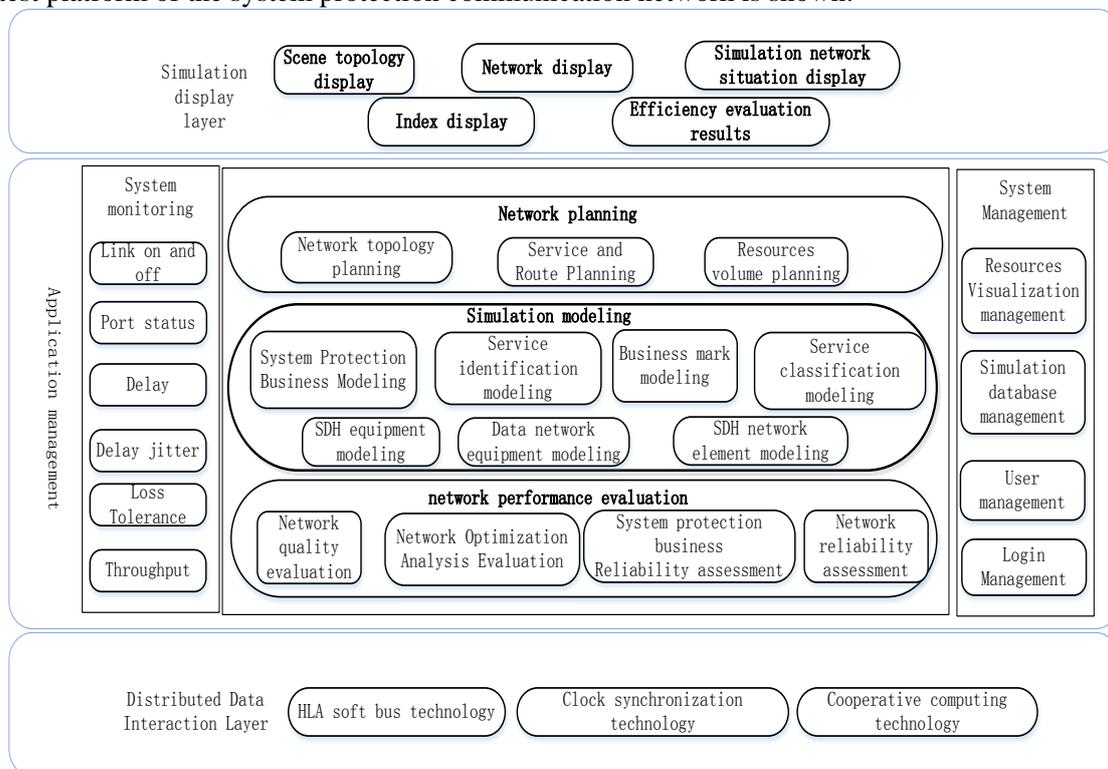


Figure 1. System function schematic diagram

Application management layer is a key module for implementing system protection communication network integrated simulation and system management. It is mainly divided into network programming, simulation modeling, network performance evaluation and other modules. Network planning includes network topology planning, service and route planning, and resource capacity planning. Simulation modeling mainly establishes channel and link models, equipment models, service models, signaling interaction process models, signaling message models, protocol specification models, scenario models, and visualization models[4]. Network performance assessment mainly includes network quality assessment and services. Quality assessment, network reliability assessment, and business reliability assessment. In addition, the system management function provides federal management, simulation database management, user login management, and resource visualization management. System Protection Communication Network Resource Data Structure and Visualization Management integrate power communication resources, implement unified management, enhance network coordination and improve resource utilization. The simulation display layer of the system

protection communication network comprehensive simulation and test platform mainly includes scene topology display, network demonstration, simulation network situation display, network performance indicator display, and effectiveness evaluation result display. The distributed data interaction layer serves as a simulation support system. It provides users with as many services as possible through a consistent user interface during the simulation process, and provides effective support for the management and integration of dynamic information during operation.

2.2. overall software architecture

The communication network simulation system software architecture for system protection services is mainly divided into five layers: the existing system, interface adaptation layer, data storage layer, application simulation layer, and interface presentation layer. The software structure is as shown in the figure 2 below. The system will connect the existing regional co-control master station, control master station, control substation and terminal through a semi - physical interface to the simulation module, and get the simulation module and display module as a distributed federation members, each function module through the HLA / RTI interface adaptation layer to complete real-time data interaction, The control module publishes the simulation scene and display scene configuration parameters through the interface for other modules to subscribe on demand; the actual equipment connects to the simulation module through the semi - physical interface, and the simulation module then stores the fault alarm data, statistical performance indicators, etc. into the data storage layer for the display module to take out some of the data as needed, and displays the evaluation results in a graph form; In addition, the resource management, user, and login management data are also stored in the data storage. Layers are used to display the front end of the interface. Finally, all modules pass data to the interface presentation layer. The user uses the functions provided by the system through a visual interface (GUI).

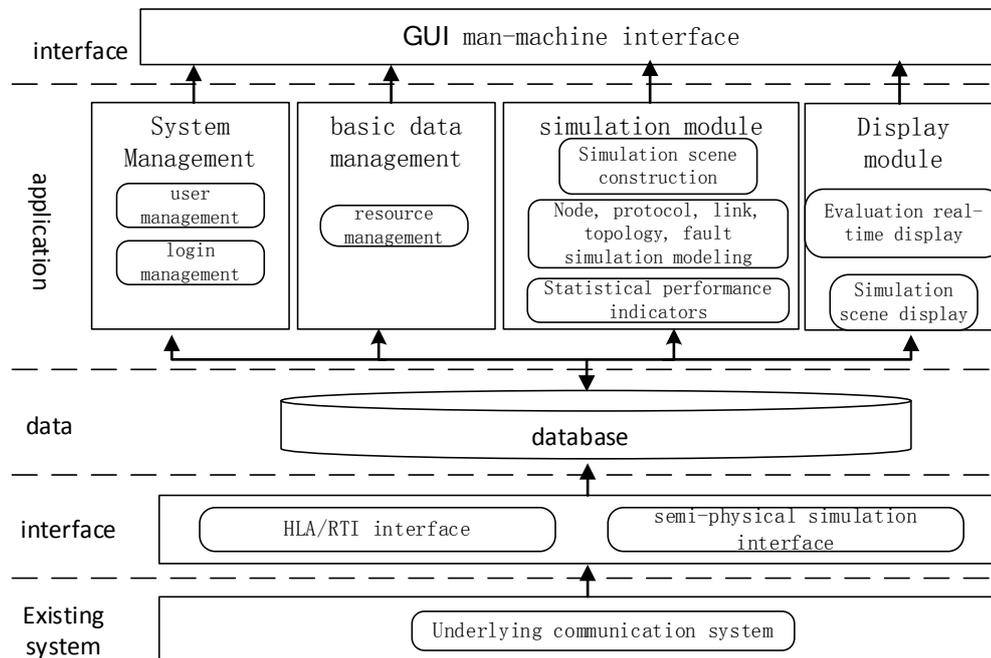


Figure 2. System software architecture

2.2.1. Distributed architecture based on HLA / RTI. High level Architecture (HLA) is the technology of dividing simulation members and constructing simulation federations based on object-oriented analysis and design[5]. In HLA-based simulation systems, federations are distributed simulation systems used to achieve a particular purpose of simulation, which consist of several interacting federations. All applications that participate in federations can be called federates. HLA mainly considers how to integrate federations on the basis of federations, that is, how to design federated members Interaction to achieve the purpose of simulation . In this simulation system, HLA / RTI

distributed system is adopted as the basic framework of simulation evaluation and demonstration system. In this framework, simulation module, hardware-in-the-loop simulation interface module and display module constitute HLA federation[6]. Each federate and running support environment RTI (run-time infrastructure) constitute an open, object-oriented distributed simulation system. RTI is a universal, relatively independent support service program, and each federate is a concrete simulation implementation. This architecture implements the simulation function. At present, simulation operation management and bottom communication are separated, so that each part can be developed independently, and the latest technology in their respective fields can be used to realize the standard functions and services to the maximum extent.

Each module develops and runs independently, develops RTI interface, forms federation, and publishes the information needed to interact in the federation through RTI interface. According to the functional requirements of each module, federate members select messages to subscribe to, and complete the interactive communication between the modules. The simulation platform develops three modules respectively, such as simulation module, semi-physica simulation interface module, display module and so on. Each module unit, as a federate member of HLA system, is interconnected through standard RTI interface under RTI running support environment[7]. Command interaction and data exchange between modules. The architecture of the system is shown in the Figure 3,

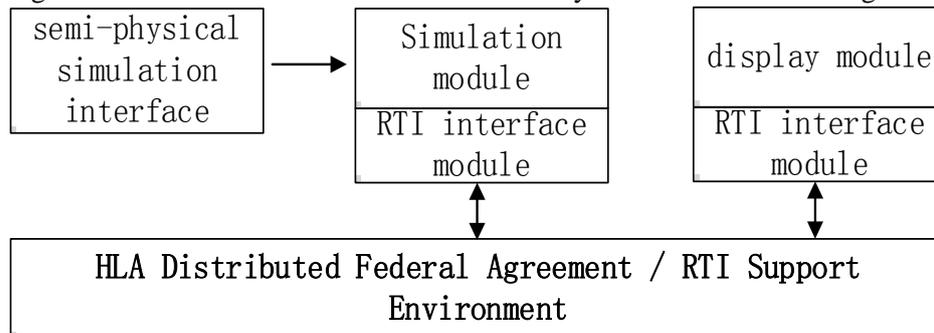


Figure 3. System architecture diagram based on HLA

2.2.2. Simulation module. The simulation module has network topology, traffic flow, node attributes and other scene configurable functions. At the same time, the simulation model base is complete, including node model, protocol model, link model, network topology model, fault simulation model and so on. Support typical network topology simulation, routing switching function, network management performance simulation, integrated network performance simulation and other scenarios, publish the network performance index values obtained by simulation, display the required index values for module subscription, and support network topology simulation, network management performance simulation, network performance simulation and so on. Simulation performance includes network performance, node performance, link performance, traffic performance and so on. Detailed models include:

(1) Defining all kinds of node models (wide area stability control equipment, network equipment and transmission equipment), protocol model, link model and network topology model which can quickly configure various layers and coverage;

(2) Fault simulation modeling, simulating single / multi-point fault of power system and network link fault;

(3) Receiving the script file from the control module and generating the corresponding simulation network scene file;

(4) Obtain the command from the control module to check the configuration scene and start the simulation;

(5) After the simulation is finished, the simulation performance parameters are published in real time.

2.2.3. Display module. The display module is used for the system design index value and performance index system published by the subscription control module after the simulation, and the network performance index value obtained by the simulation module. To evaluate whether the network topology can meet the real-time and reliability requirements of wide-area stability control, and display the simulation results in many ways, such as graphics, tables, text, etc., and support performance evaluation and analysis, at the same time meet the requirements of visualization and performance index view. Export data and other requirements. The detailed indicators are as follows:

- (1) Obtaining index system and designing index from control module;
- (2) Obtaining the network performance index value from the simulation module;
- (3) Taking the topological performance index value from the simulation module;
- (4) Graphical display of performance parameters of network simulation;
- (5) The function of index data derivation;
- (6) Result contrast display function.

2.2.4. Semi-physical interface module. Semi-physical simulation module connects the physical equipment to the simulation module through the semi-physical simulation module interface. The simulation module can carry out end-to-end transmission and performance statistics of the real business data injected by the physical device. The semi-physical simulation system meets the requirement of real-time simulation. The following takes the process of the virtual network connection between the real network and the simulation platform as an example to illustrate its basic design idea. As shown in figure 4, the real device data is first encapsulated, transmitted through the tunnel, the real device data is obtained by grabbing the net port packet, unencapsulated, and then re-encapsulated into the recognizable data packet form in the simulation software. Finally, the virtual network in the simulation platform is used to transmit service packets.

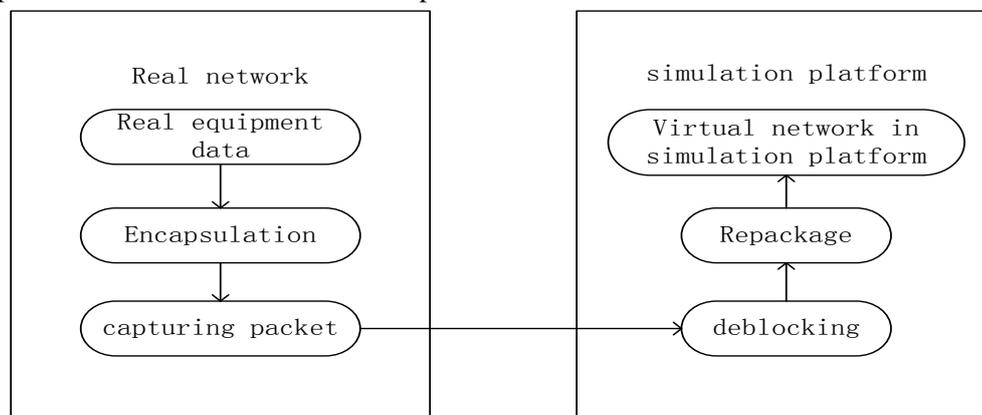


Figure 4. Real network and simulation platform interface

3. Simulation application

3.1. System protection business requirements analysis

System protection takes the regional grid as the main body and consists of a regional co-controlling station, a control master station, a control substation, and an execution station. The regional co-ordinating station is the central decision-making brain that implements centralized coordination control. Based on the real-time status monitoring information and fault information, it gives decision or control strategies, and sends the control information to the control master station. The control master station is divided into the DC control master station according to the function, disconnect control master station, Split control master station, Precision load shedding station, etc., generally located in 500kV AC substation, DC converter station or provincial power company; Execution

stations are generally placed on substations of 330kV and above or electromagnetic the 220kV substation, DC converter station, power plant (including pumping, new energy) and large-user power distribution room of the ring network are responsible for uploading the measurement information of the primary and secondary equipments to the relevant control master station and receiving the control master station's control command [8]. The system protection service architecture is shown in Figure 5. The data flow between nodes mainly includes between the execution station and the control master station, between the control master station and the co-control station, and between different control master stations, and the different regional co-control stations.

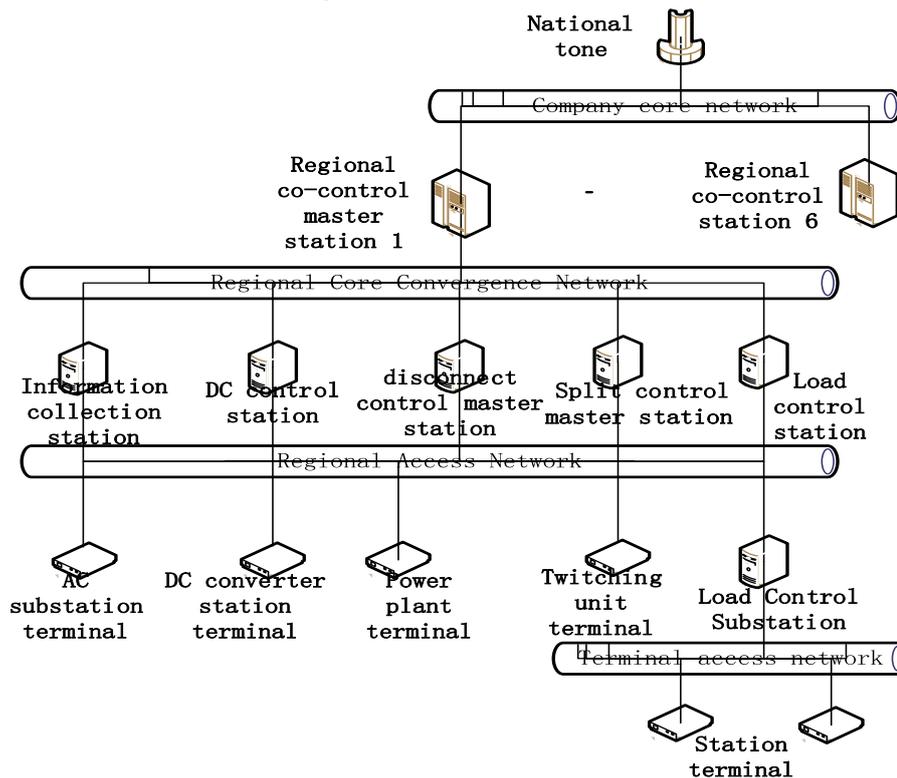


Figure 5. System protection system schematic diagram

3.1.1. Bandwidth requirements. The bandwidth of the channel is related to the service function, frame structure and the substation where the terminal is located. The formula for estimating channel bandwidth W is as follows[9]:

$$W = (L_1 + L_2) * 8nf \quad (1)$$

In the formula, L_1 is a data frame length, L_2 is the length of the time scale, n is the number of components in substations and power plants or the number of large user distribution house circuits, f is a acquisition frequency.

The information of the integrated terminal includes 10 electrical quantities, including three-phase voltage, three-phase current, active power, reactive power, frequency and power angle, each cycle transmitting 8 points, each quantity is considered according to 4B floating-point and 8B time scale information, and one substation is divided into 50 components. Then the total data amount of $10 * (4B+8B) * 8 * 50 * 50 * 8 = 19.2\text{Mbps}$. 10 electrical quantities sharing time scale information $(10 * 4B + 8B) * 8 * 50 * 50 * 8 = 7.68\text{Mbps}$. At this time, the master station should be controlled to do the corresponding data processing.

24 points per cycle is collected, $10 * (4B+8B) * 24 * 50 * 50 * 8 = 57.6\text{Mbps}$, Total amount of data when 10 electrical quantities share time scale information $(10 * 4B + 8B) * 24 * 50 * 50 * 8 = 23.04\text{Mbps}$.

The non-electric quantity includes oil temperature, switch quantity, control device state information, etc. Each component is 1B, sharing one time scale information, each cycle uploading 8 points, Total data volume $(1B+8B) \times 8 \times 50 \times 8 = 28.8\text{kbps}$. Therefore, the collection bandwidth of each point is considered by 20Mbps[10]. Due to the small amount of control information data, the control bandwidth is temporarily considered by 2Mbps.

Consider 20 terminals per sink access control master. Area access layer bandwidth $20M \times 20 = 400\text{Mbps}$. Considering the demand of later access site expansion, it is suggested that the bandwidth of the regional access layer is not less than 1Gbps.

The information collected by intelligent load terminal includes electrical quantity information and non-electric quantity information. The electrical information includes four electrical quantities: voltage, active power, reactive power and frequency. Each cycle collects 8 points. Each quantity is considered as 2B integer and 8B time scale information, and one terminal has 8 loops, then the total amount of data is $4 \times (2B+8B) \times 8 \times 8 \times 50 \times 8 = 1.0\text{Mbps}$. Total data when 4 electrical quantities share time scale information $(4 \times 2B+8B) \times 8 \times 8 \times 50 \times 8 = 0.4\text{Mbps}$. At this point, the master station needs to be controlled to do data processing. Non-electrical quantities include relevant state information, and the amount of data is negligible. Therefore, the acquisition bandwidth of each point is considered at 2Mbps, and the control bandwidth is temporarily considered at 2Mbps because of the small amount of data of control information.

For centralized load shedding, 50 terminals per 500kV station are considered according to one control master station per province. Access network bandwidth is $2M \times 50 = 100\text{Mbps}$. For accurate load shedding. One control master station per province, 20 control sub-stations, 100 terminals per sub-station, access network bandwidth is $2M \times 100 = 200\text{Mbps}$. Therefore, the bandwidth of load control access layer should not be less than 1 Gbps.

In each province, 100 substations and 100 power plants (including pumped storage, new energy) are calculated, with a total of 200 integrated monitoring and control terminals. The calculation is based on the decoupling control and wide-area power generation control, which has the largest amount of information interactive data. Each province set 1 cleavage control station and 1 wide area power generation control station. Regional core convergence network bandwidth is $20M \times 100 \times 1 + 20M \times 100 \times 1 = 4\text{Gbps}$. For AC / DC coordination control stations, we should also consider the concurrency of each terminal to 10 control stations in our province. Regional core convergence network bandwidth is $4M \times 100 \times 10 = 4\text{Gbps}$. So the bandwidth of the regional core convergence network is more than 10Gbps.

The company's core network is set up by 2 co-control master stations and 1 control sub-center station in each region, 18 master stations in 6 regions, and 2 master stations in national dispatch, a total of 20 master stations, Taking into account the real-time information acquisition interaction between regional cooperative control stations such as AC / DC coordination control, and the non-real-time panoramic state monitoring information and control information transmission requirements between the regional co-control master stations and the national central control stations, The bandwidth of cross-domain core layer is not less than 10 Gbps.

3.1.2. Delay demand. Taking into account the communication requirements between regions, the maximum transmission distance is considered by 3000 km (within the region) and 5000 km (between regions). The system requires that the fault defense control of important disturbances within 300ms for power grid generation, transmission, distribution and DC system panoramic state monitoring in 60ms, and the acquisition and control of communication delay should be controlled in 50ms. As shown in the following figure:

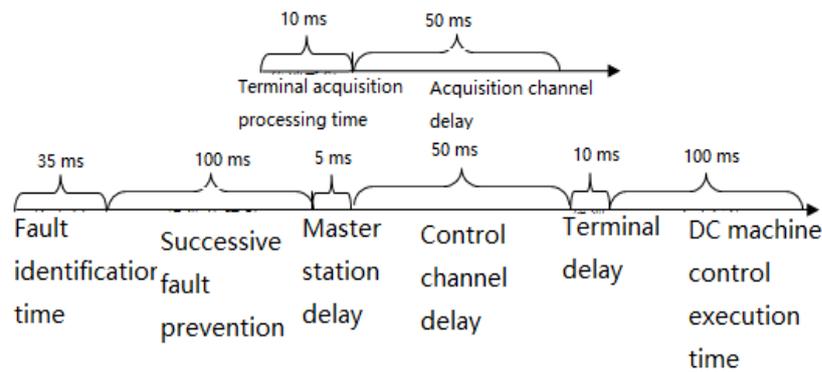


Figure 6. System protection delay allocation diagram

At the same time, the delay of communication nodes is also as small as possible, which is less than 100us.

3.2. Communication Scheme Simulation based on Ethernet over

Figure 7 shows the protected communication network in a certain area. The network consists of 2 provincial adjustments (node 19 and node 40), 2 ground adjustments (node 17 and node 22), 16 substations (Orange node) and 2 power plants (node 41 and node 42). The service process is mainly divided into information exchange between power plants and 220kV substations, and information exchange between each 500kV substation and ground adjustment. And their information needs to be transferred to provincial regulation, and at the same time, The provincial adjustment will issue corresponding protection orders to the ground adjustment and substation. In order to increase the reliability of the network, the nodes of each plant and station are connected to the backbone layer nodes on the dual 2m fiber link through the router. After the link is tied, the backbone layer nodes are connected to the local adjustment points in their respective regions.

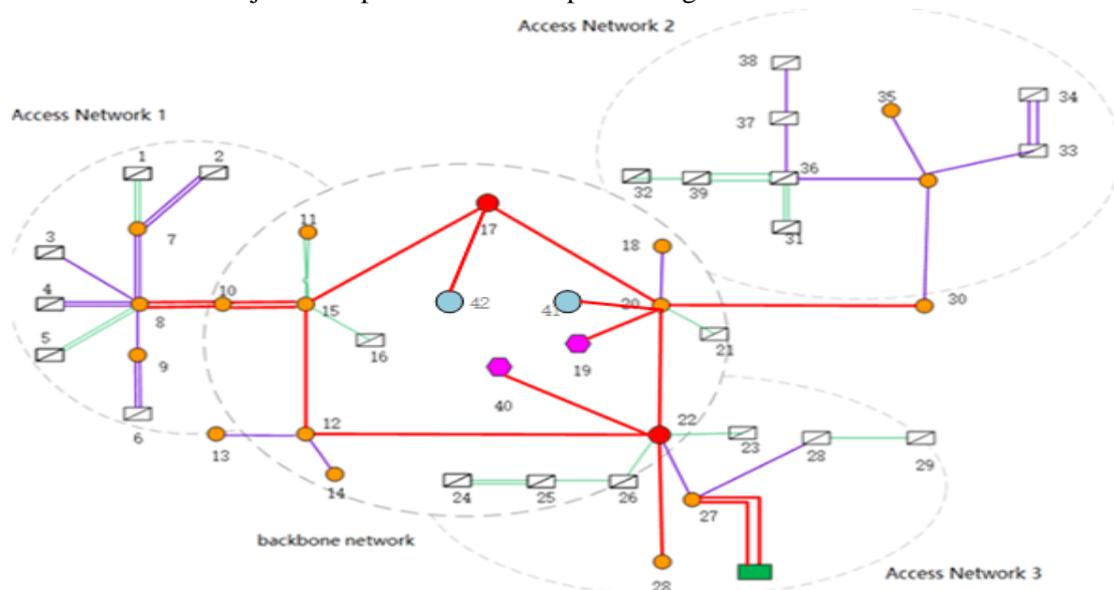


Figure 7. Topology of protected communication network in a certain area

The protected communication private network is divided into four regions, including 3 star access networks and 1 ring backbone layer network, in which station 19, station 40 are the provincial dispatching station, and they are also the core of the whole system protection communication network. Station 15, station 20 and station 22 are the core of access network 1, access network 2 and access network 3, respectively. Station 12, station 15, station 17, station 20 and station 22 are connected

through the optical fiber ring network to form the backbone network of this system to protect the communication private network. Each access network connects to each site in a star way.

The maximum speed of MSTP is 10G, the minimum scheduling particle is VC12, and the MSTP network has mature and stable structure with large network scale. In current power communication systems, it can fully meet the needs of the service. Therefore, the MSTP network is still the cost-effective choice for carrying TDM services and small-grained services in the power communication network. In the past 10 years[11], OTN technical standards have gradually matured and stabilized under the double drive of business and technology development. OTN inherits the advantages of SDH in networking, management and protection. In the meantime, it can provide large-particle transmission and flexible cross-grainity, support multiple protocols and have the ability to bear and adapt to multiple services[12]. In addition, it is also a bearer service network commonly used in power communication networks. In order to objectively evaluate the network performance of the system protection private network, the system protection service in the simulation scheme uses the MSTP network and the OTN network bearer respectively. Through the simulation system, the delay and bandwidth of the two networks are simulated and verified respectively. In the delay test, the transmission distances of the two nodes are set to 0km, 2500km, 5000km respectively and test the corresponding values under these three distances. The bandwidth test mainly tests the bandwidth of the cross-domain core layer. The corresponding simulation results are shown in Table 1 and Table 2.

Table 1. The result of Network delay test

Equipment type	Transmission distance /km and Delay/ms		
	0	2500	5000
MSTP+Router	1.3	13.6	26.1
OTN+Router	1.2	13.6	26.2

Table 2. The result of Network bandwidth test

Equipment type	Maximum network bandwidth	Remarks
MSTP+ Router	10G	
OTN+ Router	Network bandwidth up to 40G at 4 10G ports	Small bytes up to 21G

Comparing the above simulation results with the system protection service demand analysis, the delay of MSTP and OTN satisfies the delay requirement of information transmission between regions and regions in the power communication network. Since the bandwidth of the cross-domain core layer is not less than 10 Gbps, both MSTP and OTN satisfy the bandwidth requirement, but the OTN is superior.

4 Conclusion

In this paper, a communication network simulation system for system protection service is designed, which describes the system from two aspects: function architecture and software architecture, and analyzes the requirements of system protection services. The performance of the protected communication network in a certain area is simulated and verified by the simulation system, and the simulation results are compared with the demand analysis to draw conclusions, which provide a good

basis for the planning and construction of system protection.

Acknowledgments

This work is supported by Project of State Grid Corporation of China in 2017; Technical System and Key Technologies Research of System Protection Communication Networks(SGXT0000ASJS1700054)

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