**THE ANALYSIS OF TRACTION SUBSTATION PROTECTION BASED ON CENTRALIZED COMPUTER SYSTEM**

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**ABSTRACT**

With the development of the intelligent substation technology, the centralized protection attracts more and more attention of Chinese scholars. Due to the implementation of IEC61850, the development of the high-speed Ethernet, and the advanced performance of computer hardware, the centralized protection becomes a possible choice. Centralized protection simplifies the traction substation secondary wiring, and realizes real-time data sharing. It avoids the repeated configuration of hardware, and reduces the space required for the installation of protection devices. Under the consideration of these advantages, the centralized protection will be the main trend for micro-computer protections for traction substations. Compared with traditional protection, this paper discusses the schemes for the centralized protection for the hybrid dual redundant star network is discussed, and illustrates the design and reliability for these schemes.

**KEY WORDS**

IEC61850; Traction substation; Centralized protection; Protection scheme; System reliability

1. Introduction

Nowadays the secondary devices of conventional substation generally adopt a bay-oriented, functionally independent and hierarchical distributed structure. The functions of control, monitor, protection, fault recorder and measurements are completed by independent devices [1]. This distributed mode with one-to-one mapping has high reliability, and system extensibility. If one device is out of service, other devices will not be affected. However, some drawbacks exist as follows:

- The secondary connections are too much complicated.
- The hardware configuration is too much redundant.
- The cost for investment, operation and maintenance is high.
- The information is not easily shared by each device.
- The coordination and functional optimizations of all devices are lacked.
- The devices are based on the single point information with no global perspective, so due to the lack of effective information, this fact may cause some local optimal decisions, which are not global optimal. This may also lead to some wrong decisions and affect the safe and stable operation of the system.

Based on these disadvantages of traditional protections, the centralized protection was proposed to solve these problems. The centralized protection is not a device that simply integrates multiple traditional protection functions. In principle, it improves the selectivity, sensitivity and reliability of protection actions, and overcomes the influence of transition resistance. According to the fault information of the adjacent lines, it can realize the reliable locking or quick action of this line protection. Due to the information of adjacent devices such as transformers, it can diagnose the fault conditions of the line, prevent the protection mis-operation and realize the reliability of protection actions. Considering the protection information from the other end, the centralized protection can speed up the protection of the breaker at this end and trip the fault. Compared with the traditional distributed protection, the centralized protection has obvious advantages. The centralized protection integrates multiple kinds of protection functions and coordinates the protection uniformly from the substation level. With information and resources sharing, it reduces the number of protection devices, avoids duplicate configuration of hardware, improves the utilization rate of the hardware, etc. Therefore, the realization of centralized protection for substations has important significance.

2. The Analysis of Centralized Protection

2.1 The Influence of Intelligent Substation on the Centralized Protection

The basic requirements of intelligent substation are information digitization, communication platform and standardized information sharing. It realizes the information collection, measurement, control, protection, calculation, detection and other basic functions automatically. It supports the real-time automatic control, intelligent regulation, online analysis and decision, and synergistic interaction and other advanced functions of the electrical railway traction power supply system. It can realize the interactions with adjacent substations and the dispatching system. Based on the smart grid, the intelligent substation takes primary and secondary devices as the intelligent objects. Based on the high speed communication platform, it realizes the real-time sharing of the state information and sampling values of substation...
equipment’s. It provides technical supports for the integration of micro-computer protection configuration and realizes the centralized protection.

2.2 The Fundamental Principle of Centralized Protection

Centralized protection is a new substation microcomputer protection, which is based on a series of modern digital communications including intelligent substation, fiber optic Ethernet, and IEC61850 standard. This paper discusses the centralized protection for the whole station and considers the protection function as a unity. Most scales of traction substations are not large, and the main wiring structure is typically shown in Fig. 1:

![Diagram of Traction Substation](image)

Figure 1. The diagram of traction substation

A typical traction substation is with two main transformers, four to six feeders and ten breakers. Generally, the protection system samples 10 voltages from the high voltage and low voltage side, and 14 circuits from both sides of the lines and transformers. It is reasonable to concentrate the information from all equipment into a central computer system, and then it forms a flexible, reliable, and diverse complementary protection system. The centralized protection obtains the real-time status information from traction substation devices. Therefore, new functions and algorithms could be produced based on the traditional micro-computer protection. These algorithms can compensate the deficiency of the conventional protection devices and improves the protection performance. After the centralized protection used in traction substations, it reduces the weaknesses and solves some problems of traditional protections. For example, the recovery inrush current will appear when the breaker trips after line fault occurs at the low-voltage side of the transformer which will lead to the mis-operation of traction transformer. Actually the mis-operation of microcomputer protection can be effectively prevented by appropriate atresia or adjustment using the line information in the centralized protection. Usually, the setting time of backup protection in the conventional traction transformer needs to match the configuration of the downstream circuit protection. The setting value of backup protection may increase after a multi-stage delay due to many devices on the line. Therefore, damage may easily occur on the traction transformer when the line protection is not under the correct action. In the centralized protection, the start information and the backup protection of the line protection can be associated and the action of backup protection on traction transformer can be judged by the action of downstream circuit protection. In this case, the speed of the back-up protection can be accelerated and it improves the system stability. In addition, due to the application of electronic voltage transformers (TV) and electronic current transformer (TA) in the intelligent substation, it causes damage in the system when the fault occurs in TVS or TAs in the conventional intelligent traction substation. According to the topology of the network, the centralized protection makes the decision based on all the information associated with TVS and TAs. It could also solve the problem caused by the abnormal operation of TA (TV). The measured voltage becomes abnormal regardless of the fault occurs on the first or the secondary side of TV. In the centralized protection system, multiple voltage information are obtained and sent back to the protection system. Using the voltage from the other TVS instead of the faulted TV, the status of the equipment could be diagnosed by the operator.

The principle of the centralized protection system of traction substation is listed as follows: In the process layer, the voltage (current) data of TAs and TVS are collected to send to the merged unit. Then from the unit, the data are sent to a centralized protection via fiber-optic communications network. At this point, the breaker status is also sent to the centralized protection from the intelligent execution unit. The centralized protection According to the received data and switch status, the centralized protection device will call the protection algorithm package in the software program respectively. After completing all calculations, the logical decision is given, and the export information is organized into packets. This information includes the alarm and the quick trip command. Then the task is initiated that the packets are sent to the smart execution unit through the optical fiber communication network. Finally, the microcomputer relay protection function is completed.

2.3 The Advantages of Centralized Protection

Centralized protection strengthens the coordination of different interval protection functions and analyzes the export action of the protection. It enhances the reliability and adaptability of the microcomputer relay protection. The cooperation between the primary protection and backup protection of traction substation, it requires different setting time and the centralized protection can monitor the real-time information of electric quantities. It also accelerates the backup protection with a shorter delay when the mis-operation of the primary protection occurs.

The centralized protection integrates all protection functions of traction substation, and realizes the
coordination and cooperation of the entire devices. Compared with the traditional protection, it provides an easier access to the message standardization of microcomputer protection and the centralized management of protection functions. Due to the real-time operation of substations, this reduces the rates for mis-operations and provides an access to modify the protection logic and adjusts the protection scheme online.

A central computer is used to realize the protection and control function. This design reduces the number of the existing IEDs, avoids the repetition of the hardware configuration and saves the investment. It also reduces the area for the installed IEDs, reduces the stress and simplifies the structure of communication network.

Due to different designs of various manufacturers of the conventional relay protection devices, it is hard to connect them in the substation. With the implementation of the IEC 61850, the protection units should follow the IEC61850 standard in traction substation. The centralized protection realizes the coordination of the protection module by algorithms unifies the interfaces of intelligent execution unit and merge unit.

2.4 Drawbacks of Centralized Protection

Compared with the existing microcomputer protection, the centralized protection has great advantages, but also has some disadvantages. For example, we must ensure the real-time data acquisition and synchronization, which is the basis for realizing the centralized protection function; we must ensure communication network's reliability between the protection device and the intelligent execution unit and the merged unit. Once there is communication failure, such as a switch breakdown, or information network congestion and so on. The centralized protection function will be influenced. Therefore, the centralized protection device needs fiber-optical communication network with high reliability and strong anti-interference ability; in the traction substation, all protection functions are concentrated in a central computer system. If the central computer has malfunctions, and backup protection unit cannot be initiated in time. The substation equipment will lose protection. At this situation if there are some faults, it may bring disastrous consequences. Of course, the risk can be solving through some technical measures. For example, we can design of self-checking function in communication network, communication networks in the transmission of sampled value information and transmitting information of check code and channel check information, in order to avoid sampling value information error, but also in the communication system fault alarming in time to ensure the reliability of the communication system [1]; for the centralized protection device adopts double redundant system configuration, if a failure of the protection unit and a protective device can be put to use immediately, both of two are standby mutually and mutually check and can cast back, to ensure safe and reliable operation of the whole.

3. The Schemes of Centralized Protection System for Traction Substation

3.1 Comparison between the Conventional Protection and Centralized Protection Configuration of Traction Substations

At present, China has some digital traction substations under experiment, and their protection configurations are shown in Figure 2. Although the electronic instrument transformer is adopted, which can measure the voltage and current, and realize the substation digitization, the same thing is that the protection configuration is similar to the conventional transformer. And the conventional transformer is configured according to the object, not involving the protection theory, and it mainly includes transformer primary protection and backup protection, feeder protection, etc.

The centralized protection scheme is shown in figure 3. Hardware configuration consists of 3 parts: the primary device, network devices and control system layer devices. The primary device includes electronic voltage (current) transformer, merging unit, circuit breakers and intelligent execution unit; the network device is mainly composed of Ethernet-switch and centralized protection device; control layer includes remote workstation, GPS and monitoring system. Electronic transformer collects equipment information, and sends data information to the merging unit via fiber-optical. MU receives information package and then turns them into SMV message, sends the message to centralized protection. At the same time, IU sends the switch state information to the centralized protection devices. The centralized protection device combines with the switch state information, in turn calling protection algorithm to calculate sampling value information, and then gives the logical judgment result. After organizing the exit instruction (e.g. tripping, alarming, reclosing, etc.) into GOOSE message and starting message sending task, the GOOSE message will be sent to the IU, in order to achieve protection function. Because of the centralized protection needs high reliability, it should be equipped with dual redundant network.
3.2 The Requirements of Centralized Protection Communication Network

Both SMV and GOOSE packets of centralized protection system are transported through the fiber-optical communication network. Therefore, real-time, high-speed, reliable network communication system is the important guarantee of centralized protection's rapid-reliable action. There are some requirements of communication network, such as: real-time reliability, openness, supporting message priority transmission.

3.3 Centralized Protection Schemes

The topology structure for the intelligent substation network is not defined in IEC61850. In the configuration of traction substation communication network, the structures are selected by the time delay requirements, reliability, network node number, location and construction cost. In this paper, the hybrid dual redundant star network scheme is analyzed. A computer is used to collect all real-time sampling information for the centralized substation. It integrates all protection functions, and realizes the multi-functions including fault recorders, monitor and control devices. To realize the centralized protection and management of traction substation, three kinds of schemes are discussed and analyzed.

- **Scheme I (Shown in Figure 4)**

- **Scheme II (Shown in Figure 5)**

- **Scheme III (Shown in Figure 6)**

In this scheme, GOOSE forms a network respectively. The SMV packets is transmitted from the merged unit to the switch and then to a central protection device via the optical fiber. IEC61850-9-2 is chosen as the communication standard. There are two sets of centralized protection devices A and B. Each set of protection devices is equipped with two switches, one for receiving SMV packets and sending it to the protection device, the other receiving the GOOSE message from protection devices, and sending the instruction to the intelligent terminal by the multicast mode to control the breaker status. However, in case of a serious failure, the merged unit sends the SMV packets to the centralized protection devices through the switch and this situation inevitably causes the too much time delay for packets queued for transmission in a switch.

In this scheme, the SMV packet data utilizes peer-to-peer connection, without the switch, the combined unit will send the SMV message to the optical fiber communication network, it can avoid the uncertainty of the delay of switch. GOOSE forms a network separately and data acquisition utilizes direct transmission. However, the direct way also brings a series of problems for centralized protection since seven merging units are sending packets to the centralized protection at the same time. It raises the requirements of the CPU. Compared with Scheme I, this scenario decreases the transmission time of the SMV packets. It greatly reduces the reliance of the centralized protection on the complex communication technology.
Because of the advanced technology and information sharing characteristics, the combination of three nets, this scheme attracts the widespread concern. Three net includes SMV net, GOOSE net and the IEEE 1588 clock system. These three kinds of information are collected into the process layer switches and then the protection, measurements and control devices assess the system by one net export. Although the scheme has the obvious superiority on the advanced technology and information sharing, the combination of three nets is relatively complicated, especially considering the restrictions of the IEEE 1588 double network switch technology. Therefore, this scheme is hard to be implemented at present and its reliability is required to be evaluated.

In conclusion, hybrid dual redundancy star network scheme can reduce the message transmission delay in theory, which can effectively improve the reliability of communication network transmission message. Practical applications are chosen based on the size of the traction substation, the voltage level and the delay of the request, the hardware cost.

4. Centralized Protection Software Function Description

Centralized protection software is mainly divided into three modules: Sample processing module, protection function module, Communication processing module. The function structure of software is shown as figure 7.

- Sample processing module receives voltage, current sampling value information from process layer merge cells, and circuit breaker and isolating switch position information from intelligent terminal. And it can analyze SMV message and GOOSE message, extract the sampling voltage value and current value from all message channel, then deal with the sampling voltage value and current value. With the job done above, the processed sampling value information and the switch state information from the GOOSE message will be stored in sampling value buffer.

- Communication processing module mainly completes information interaction of the device LCD panel and communication with other devices. Besides, it is also responsible for transporting the fault report, the event report, the analog value and setting value, etc.

5. The Strategies for Reliability Promotion of Centralized Protection

Reliability is an index of measuring the safety and stability of traction substation, and evaluating the security of protection and control systems. The evaluation of centralized protection system for the intelligent traction substation attracts the attention from more and more scholars. Therefore, in the centralized protection system design, all kinds of advanced technology and innovation methods are applied to improve the system reliability. This paper uses the following method to improve the reliability of the centralized protection system:

- Dual redundancy of the protection configuration. The proposed hybrid dual redundant star network provides double redundancy configuration. According to the calculation of the front section, double redundancy configuration can obviously improve the mean time to failure (MTTF) of centralized protection.

- Using IEEE-1588 clock system. At present, the time synchronization is mainly achieved by the pulse time, serial communication or coding. IEEE 1588 is a precision Time Protocol (PTP) that is defined based on multicast technology and real-time Ethernet network. It relates to the network communication, the local calculation, and the distributed objects of measurement and control system. With the characteristics of high accuracy, it is suitable for local area network to support the sending information. It assures the precision of synchronization within micro-seconds, so it effectively the real time of the centralized protection system.

- To improve the performance of the system hardware device. For example, it increases the bandwidth of the fiber optic Ethernet and switch on the premise that the hardware cost can meet the requirements. CPU of Protection device uses high performance hardware based on the industrial PC motherboard.

- Using the real-time multi-tasking operating system. In the practical application of the centralized protection, strong real-time embedded operating systems should be selected to ensure the real-time system, such as VxWorks.

- Using new centralized IED devices. Compared with the traditional IED, the new centralized IED improves the system performance and reliability. Combining the priority of distribution and centralization, it reduces the number of the
existing IED configuration and save the hardware investment. It also improves the reliability of the protection system and the ability of network interface.

6. Conclusion

Centralized protection is a new microcomputer protection technology. Different from the traditional traction substation protection with independent one-to-one distributions, a central computer is used to realize the centralized protection function. The implementation of IEC61850, the development of the high-speed Ethernet, the information sharing for intelligent traction substations, the advanced performance of computer hardware provide the requirements for realizing the centralized protection function. This centralized protection scheme will bring a series of new technical problems, and change the mode of commissioning, operation and maintenance for traction substations. These problems should be researched in the future.

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