A Joint Verification System for the Secondary Equipment Safety Measures in Smart Substation

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Abstract. The secondary system of smart substation has high characteristics of network and integration. The secondary circuit and its safety measures are characterized by strong concealment and poor visualization. There is a great safety risk in the implementation of secondary equipment safety measures. In this paper, a joint verification system of secondary equipment safety measures for smart substation is proposed. The joint verification system uses the monitoring system and the third-party safety measure monitoring equipment to jointly arrange defence, carry out the whole process verification of the implementation process of the secondary equipment safety measure ticket, and carry out visual display, effectively ensuring the correctness of the implementation of the secondary equipment safety measure.

1. Introduction
With the comprehensive promotion of the construction of smart substation, the number and proportion of smart substation has increased significantly, which has become an important part of the power grid. With the rapid growth of the number, the pressure of safety, operation, maintenance and repair of smart substation is also increasing day by day. On the one hand, a large number of smart substations built in the previous stage will usher in the peak period of regular equipment maintenance; on the other hand, the renovation and expansion of smart substations are also increasing. When carrying out the secondary equipment maintenance and substation reconstruction and expansion project, it is very important to take the secondary equipment safety measures to prevent the maintenance, reconstruction and expansion from affecting the safety and reliability of the operating equipment. Different from the integrated automation substation, the secondary system of intelligent substation is highly networked and integrated, the secondary circuit and its safety measures are invisible and hard to touch, with strong concealment and poor visualization. In the actual implementation process, it is easy to have problems such as incomplete secondary equipment safety measures, incorrect implementation results, and difficult to visually check the implementation of secondary safety errors, which has great safety risks.
In the industry, the safety isolation measures for the secondary circuit of intelligent substation have been widely studied. Literature [1] summarizes and analyzes the safety measures implementation process and key technical links of secondary maintenance of intelligent substation. In terms of the generation of secondary equipment safety measures, the paper [2, 3, 4] puts forward the automatic generation technology of different principles. In the implementation of secondary equipment safety measures, literature [5] proposes a one key implementation scheme of secondary equipment safety measures. In the aspect of off-line verification of secondary equipment safety measures, literature [6, 7, 8] respectively proposed verification methods based on automatic correspondence rules of secondary virtual circuit and soft strap, connectivity state matrix and visual simulation. At present, the research has formed a relatively complete secondary equipment safety measures generation, offline verification and implementation technology, but in the process of implementation, how to ensure the correct implementation of secondary equipment safety measures in place online verification technology needs to be further studied.

In this paper, a joint smart substation monitoring system and the third-party monitoring equipment is proposed, which integrates the information of station control layer and bay layer equipment, checks item by item before and during the implementation of the secondary equipment safety measures, and shows the implementation of the secondary equipment safety measures in a visual form. The system can realize the functions of free editing and storage of the secondary equipment safety measure sheet. It can call the safety measure sheet to perform the "one key" sequence operation. It can check the operation steps in a single step, visualize the isolation area and the execution process, and check the whole execution process.

2. Structure, function and workflow of the system

2.1. Structure and function

The overall structure of joint deployment of monitoring system and third-party monitoring equipment is shown in Figure 1.

Among them, the monitoring system consists of the secondary safety measure ticket management module, the secondary equipment safety measure ticket execution module, the visual display module and the interactive interface module. The management module is responsible for the editing and storage of the secondary equipment safety measures of the whole station, and the historical storage of the executed secondary equipment safety measures for the convenience of subsequent query and retrieval. The execution module is responsible for fetching the secondary safety measure ticket stored in the secondary safety measure ticket library, performing the rehearsal according to the execution sequence defined in the secondary safety measure ticket, and supporting the one key sequential
execution function of the secondary safety measure ticket. The visual display module provides the human-machine interface for the secondary equipment safety measures ticket display, modification, preview and implementation process, and provides the visual display interface for the safety measures isolation area. The interactive interface module completes the information interaction between the monitoring system and the safety measures implementation online monitoring equipment.

The on-line monitoring equipment for safety measures is arranged in the Bay layer, and connected to the station control layer network and process layer network at the same time. It can collect the function platen, SV, goose input and output platen, maintenance platen, remote / local platen information, optical port light intensity and chain breaking information of the Bay layer protection device in the station; collect the location information of the process layer switch knife switch, Mu and maintenance platen information of the intelligent terminal. Mu and intelligent terminal optical port light intensity, broken chain information, etc. The on-line monitoring equipment can check the initial conditions of the secondary equipment safety measures and the current status of the substation equipment, and check every step of the implementation process. The online monitoring equipment interacts with the monitoring system to double check the implementation process of the safety measures to ensure the correct implementation of the secondary equipment safety measures and eliminate the operation risk.

2.2. Workflow

The implementation and verification process of secondary equipment safety measures is shown in Figure 2.

![Figure 2 Work flow chart.](image-url)
Before the secondary safety measure operation, the operator selects or edits the safety measure ticket in the monitoring system, and after that, the monitoring system generates the corresponding safety measure library and sends it to the online monitoring device. After the safety measure monitoring equipment initializes and receives the safety measure library, the corresponding initial conditions of the safety measure library and the current status of the substation equipment are compared and checked. If the two are consistent, the current safety measure library is correct, otherwise, the current safety measure library is wrong, and the check results are returned to the monitoring system. If the monitoring system receives the check result as "error", select or edit the safety measure ticket again. If the received result is "correct", continue to execute downward. The operator starts to execute the secondary safety measure ticket. After each step of operation, the safety measure monitoring equipment will synchronously judge the change of the operation object and the real-time status of the relevant equipment, judge whether the step of operation is correct, and return the check result to the monitoring system. If the monitoring system receives the "correct" check result, it will continue to execute downward. Otherwise, it will pause the operation and prompt the operator to check. When all safety measures have been executed and the check results of safety measures monitoring equipment are all correct, the operation is completed successfully.

3. System communication technology

3.1. Communication mode
The monitoring system and safety measure monitoring equipment communicate with the secondary equipment through the station control layer network. The monitoring system collects secondary equipment data through the station control layer network and issues control commands. The safety measure monitoring equipment collects the operation status data of the secondary equipment through the station control layer network. TCP / IP protocol is adopted for communication between monitoring system and safety measure monitoring equipment.

3.2. Communication interface
If the Q & A type TCP / IP communication is adopted between the monitoring system and the safety measure monitoring equipment, both parties need to define the communication message and communication process, which is complex and unstable. In this paper, private TCP / IP communication protocol is adopted, one side initiates communication, the other side calls dynamic library through interface function. This scheme is not only simple, but also has a low probability of error. The interface functions set by the safety measure monitoring equipment are shown in Table 1.

| Serial number | Interface         | Explain                |
|---------------|-------------------|------------------------|
| 1             | long StartLink()  | Establish connection   |
| 2             | long SendPack()   | Send safety measures ticket |
| 3             | long GetInitCheck() | Get initial state correctness |
| 4             | long GetCurrState() | Get current state, cycle call |
| 5             | long StopLink()   | Stop connection        |

The specific communication process is as follows.
1) Establish connection: the external program calls the Startlink () function of the DLL object to start the connection process;
2) Send safety measure ticket: the external program calls the Sendpack () function of DLL object, and the prepared current safety measure ticket content shall be filled in;
3) Whether the initial state is correct: whether the external program calls Getinitcheck () function of DLL object and whether the initial state is correct;
4) get the current state: the external program circularly calls the Getcurrstate() function of the DLL object to get the latest state of safety measures in real time. Multiple item states can be obtained by one call.
5) terminate connection: the external program circularly calls the Stoplink() function of the DLL object, stops the connection, releases resources, and completes the process.

4. Verification technology of the secondary equipment safety measures

4.1. Joint verification technology
The verification process is divided into initial value verification and safety measure item verification. After receiving the complete safety measure sheet data, the secondary safety measure verification system starts the initial value verification process. During the initial value verification process, obtain the initial value of the safety measure check item, and judge whether it is consistent with the set initial value. If it is inconsistent, give the alarm information of the initial value of the safety measure, and feed back to the monitoring system.

The information needed for joint verification is mainly composed of pressing plate information, optical fiber on-off information and manual confirmation information. The pressing plate information consists of SV receiving pressing plate of secondary equipment, goose sending pressing plate, goose receiving pressing plate, function pressing plate and related hard pressing plate. The fiber on-off information is obtained from the configured fiber information. For information that cannot be obtained through communication transmission, it is listed as manual confirmation information.

The change of the secondary equipment pressing plate status will trigger the corresponding goose transposition sending, and trigger the MMS report service at the same time. The monitoring system can obtain the MMS report through the station control layer network. The safety measure monitoring equipment can not only obtain the MMS report through the station control layer network, but also obtain the goose relocation message through the Bay layer network.

The safety measure monitoring equipment starts the safety measure check function after receiving the status change information. Safety measure check function divides safety measure errors into initial state error, check state error and check sequence error. The initial state error refers to the inconsistency between the actual initial state of the protection device and the initial value of the safety measures information; the check state error refers to the inconsistency between the received information of the state change of the protection device and the safety measures information; the check sequence error refers to the inconsistency between the received data change and the expected sequence in the safety measures list.

After receiving the change data, the safety measure verification module judges whether the action behavior is correct. If it is judged as "error", it will give an alarm message. If it is judged as "correct", it will prompt that the operation is correct.

4.2. Visual display technology
The joint verification system uses the change of switch, switch position and pressing plate state to trigger each step of safety measure verification, and gives real-time warning for the missing and wrong safety measures (such as a set of protection pressing plate is put into b set of pressing plate), etc. In the human-computer interaction of joint verification system, if each step of operation data is presented in the form of text record, the description is tedious and not intuitive. This paper presents the data, operation results and check results in the form of tables and graphs, which is very intuitive and greatly improves the visualization of the implementation of secondary equipment safety measures. During the implementation of safety measures, the joint verification system can dynamically display the status of relevant pressing plates and the implementation status according to the wrong entry, as shown in Figure 3.
In order to further check the implementation of secondary equipment safety measures, the joint verification system can also graphically display the secondary virtual loop connection relationship and optical fiber information configured in the SCD file. The joint verification system not only monitors the information in the safety measure ticket, but also monitors the data outside the safety measure ticket and some other dynamic information. The monitored data is divided into different levels according to the importance, which are divided into regular messages, alarm information, error information, etc. and recorded in the form of tables. After the implementation of safety measures, the monitoring report will be generated automatically based on the comprehensive test data.

5. Conclusion
This paper presents a secondary safety measure joint verification system of intelligent substation, introduces the structure, function and execution process of the joint verification system, and describes the communication technology and joint verification technology of the joint verification system in detail. The joint verification system proposed in this paper fully adapts to the characteristics of intelligent substation equipment, and can effectively verify the whole process of the implementation of secondary equipment safety measures. At the same time, through good visual display technology, it provides operators with a very intuitive means of state confirmation. The secondary equipment safety measures joint verification system proposed in this paper can ensure the correct implementation of the secondary equipment safety measures, and has important practical significance for improving the safety and reliability of the intelligent substation.

References
[1] Zhijun Tang. Technology research on security measures of secondary maintained in intelligent substation, J. Technological Development of Enterprise. 06 (2017) 23-24.
[2] Yanfu Guo, Wenyeng Huang, Fuhai Song, etc. Expert system based automatic generation technology for secondary safety measures of smart substation, J. Electrical technology. 04 (2019) 95-100.
[3] Keyong Zhang, Xiaohang Li, Yichao Wang, etc. Automatic generation technology of safety measures for secondary overhaul of intelligent substation, J. Telecom Power Technology. 03 (2019) 243-244.
[4] Shaoqian Hu, Li Li, Xiaotong Zhu, etc. Auxiliary safety measures of protection relay in smart substation based on switching of maintenance states, J. Automation of Electric Power Systems. 01 (2019) 242-249.
[5] QiQi Zhang, Chao Zheng, Yangyang Meng, etc. Research and investigation of one-button secondary safety measures in smart substation, J. Power System Protection and Control. 18 (2019) 176-181.
[6] Zhipeng Zhang, Guixi Peng, Haibo Bian, etc. Hybrid visualization generation and offline checking technology for secondary safety measures, J. Electrical technology. 02 (2019) 116-119.
[7] Xu Gao, Yingxin Ma, Ke Wang, etc. Verification for security measures of smart substation based on communication state matrix, J. Electric Power Automation Equipment. 07 (2019) 195-202

[8] Wei Bao, Ke Wang, Xiang Gao, etc. Verification of security measures for smart substations based on visualized simulation, J. Power System Protection and Control. 24 (2018) 150-157.