Research and Application of Visual Monitoring Technology of Protective Equipment Based on Virtual Model

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Abstract. Aiming at the problem of heavy workload and tight time for daily operation and maintenance of smart substations, a visual monitoring technology for smart substation protection equipment based on virtual models is proposed, and a visual monitoring system for protection equipment is established. The article establishes the virtual model of the protection equipment panel, configures the association relationship between the graphic elements in the virtual model and the data set entries of the protection device and the optical fiber link, and establishes the logical operation model of the graphic elements. The visual monitoring system for protection equipment collects the data set entries of the protection equipment and the status values of the optical fiber link data set entries, simultaneously display the status of the primitives in the virtual model of the protection device panel according to the status value of the data set entry of the protection device. The visual monitoring system of intelligent substation protection equipment is applied on-site to verify the effectiveness of the technology.

1. Introduction
A small number of optical cables are used in smart substations to replace a large number of cables, and the simplification of the hardware loop increases the dependence of the device on the digitization and networking of information. The workload of virtual loop configuration has increased sharply, physical network failure points are difficult to locate, daily operation and maintenance is difficult, and the problems and difficulties of the original substation management and control methods and the secondary equipment operation and maintenance management mode are gradually emerging[1]. Smart substations have gradually entered the peak of operation and maintenance. After a period of operation, the equipment defects and design defects in the substations have gradually been exposed. Therefore, equipment shortages and secondary circuit transformation work have gradually increased. With the increase in the number and operating of smart substations, equipment transformation and elimination will be normalized. Therefore, certain technical support methods are required to reduce the influence of human subjective factors. And with the unattended and remote operation of substations, unattended control methods need to be strengthened.

The secondary equipment is modeled based on IEC61850 communication protocol and unified information model. The information exchange between the equipment via GOOSE and SV network information flow. That provide a good technical condition and knowledge base for the intelligent operation and maintenance of the secondary equipment of the intelligent substation[2-3]. With the development of smart substations from large-scale construction to handover of operation and
maintenance, technologies such as IED visualization, intelligent state diagnosis, and intelligent evaluation can provide multi-dimensional information support for the daily operation and maintenance, abnormal handling, accident analysis, and maintenance of the secondary system of smart substations[4].

In view of the above problem, this paper proposes a visual monitoring method for intelligent substation protection equipment based on virtual models and establishes a visual monitoring system for protection equipment. And further establishes the virtual models of the intelligent substation protection equipment panels, configures the relationship between the graphic elements in the model and the operation status data of the protection equipment, and collects data from the substation station control layer and process layer perform logical operations. Based on the above work, the visual monitoring system for protection equipment simultaneously displays the status of the protection equipment and locates the protection equipment abnormality based on the logic operation results of the primitives in the virtual model of the protection equipment panel.

2. Visual monitoring method of protection equipment based on virtual model

With the large-scale construction of smart substations and the use of unattended and remote operation of the substations, research on the visualization of smart substation relay protection and equipment abnormal positioning technology, and strengthen the management and control of substations, have strong practical necessity, timeliness and technical foresight. The various states of the intelligent substation protection equipment itself are virtualized with graphical elements to obtain the device operating status display interface, and the operating parameters of the device are monitored in real time through the device operating status interface to realize the synchronous display of the protection equipment status and the abnormal location of the protection equipment.

This paper establishes a virtual model of the protection equipment panel, and configures the relationship between the virtual model and the substation signal to realize the visual monitoring of the protection equipment based on the virtual model. The method is shown in Figure 1 and includes the following steps:

1. Establish the virtual model of each protection equipment panel to form the virtual model library of the protection equipment panel of the intelligent substation;
2. Import the SCD file of the smart substation;
3. Establish the association relationship between the protection equipment in the SCD file and the protection equipment panel virtual model in the protection equipment panel virtual model library;

4. Configure the association relationship between the reference address of the signal indicator element in the virtual model of the protection device panel and the operation status data entry of the protection device, and establish a logical operation model corresponding to the reference address of the signal indicators;

5. Configure the association relationship between the reference address of the board card primitives in the virtual model of the protection device panel and the abnormal data set entries of the board and the board fault data set entries, and establish a logical operation model corresponding to the reference address of the optical fiber interface graphic element in the virtual model of the protection device panel and the optical fiber link interruption data set entry and the optical power over-limit data set entry of the optical fiber interface, and establish a logical operation model corresponding to the reference address of the optical fiber interface graphic element;

6. Configure the fiber link relationship of the virtual model of the whole station protection equipment panel;

7. Obtain the status value of the data set entry of the protection device, and display the status of the primitives in the virtual model of the protection device panel according to the status value of the data set entry of the protection device, so as to realize the virtual visual display of the protection device panel.

3. Virtual model of protection device panel

The virtual model modeling of the protection equipment panel refers to the visualization of the protection equipment panel lights, liquid crystals, buttons, boards, optical fiber interfaces, etc. on the software interface with graphical elements. The operating status of the equipment is monitored in real time through the equipment panel virtual model. The virtual model of the protection equipment panel includes a virtual model of the front panel of the protection device and a virtual model of the rear panel of the protection device.

3.1. Virtual model of the front panel of the protection device

According to the protection equipment of different manufacturers, establish different types of protection equipment front panel SVG base maps. The protection equipment front panel SVG base maps include the LCD panel, the operation direction, the device model name, and the indicator area. In order to avoid inconsistency between the graphic reproduction and the design, the text in SVG is converted to an outline path; the length unit in SVG is conventionally pixel px; the root node of <svg> contains the attributes of x, y, width, height and viewBox; the aspect ratio of the SVG graphics is the same as the actual device panel, and the ratio of the SVG width to the actual height of the device is 1U:200px.

The dsDeviceState operating state data set of the protection device describes the state information of the panel indicator of the device. Establish indicator primitives based on the number contained in the dsDeviceState operating state data set. The indicator primitives are modeled using <circle>, <rect> or <path>; the id of the indicator light is consistent with the indicator name specified in the technical specification of the protection device, and the id of the indicator light is unique in the SVG.

Establish the virtual model of the front panel of the NARI relay protection PCS-931 line protection equipment according to the above method, as shown in Figure 2.

3.2. Virtual model of the rear panel of the protection device

Analyze the port information of the device in the ICD file of the protection device, establish the association between the board on the rear panel of the protection device and the fiber interface, and establish the graphic element of the board and the fiber interface. The board primitive is modeled by <rect>; the id format of the board primitive is "BOARD#board number", and the board number is the
same as the board number of the port in the device ICD file, for example, the board number of port "1-A" is "1". The optical fiber interface graphic element is modeled by <circle>, <rect> or <path>; the id format of the optical fiber interface graphic element is "PORT#port number#transceiver identification", and the port number is consistent with the port number in the device ICD file. The transceiver identification is "TX" or "RX"; and the board graphic element id and fiber interface graphic element id are unique in SVG. Create a model of the rear panel of the protection device according to the sequence of the board numbers.

Establish a virtual model of the rear panel of NARI's PCS-931 line protection equipment according to the above method, as shown in Figure 3.

4. Model configuration
Establish the association relationship between the virtual model of the protection equipment panel and the protection equipment operating state data set, and configure the fiber link relationship of the virtual model of the protection equipment panel of the whole site. Obtain the status value of the data set entry of the protection device through the data collection of the station control layer and the optical fiber link of the process layer. Display the state of the graphic elements in the virtual model of the protection equipment panel according to the status value of the data set entry of the protection equipment, so as to realize the virtual remote visual display of the protection equipment panel.

The model configuration includes:

a. Configure the association relationship between the reference address of the signal indicator element in the virtual model of the front panel of the protection device and the operation status data entry of the protection device, and establish a logical operation model corresponding to the reference address of the signal indicators;

b. Configure the association relationship between the reference address of the board card primitives in the virtual model of the rear panel of the protection device and the abnormal data set entries of the board and the board fault data set entries, and establish a logic operation model corresponding to the reference address of the board primitives;

c. Configure the relationship between the reference address of the optical fiber interface graphic element in the virtual model of the rear panel of the protection device and the optical fiber link interruption data set entry and the optical power over-limit data set entry of the optical fiber interface,
and establish a logical operation model corresponding to the reference address of the optical fiber interface graphic element:

d. Configure the fiber link relationship of the virtual model of the whole station protection equipment panel. The optical fiber link relationship includes the optical fiber connection relationship of SV signal and the optical fiber connection relationship of GOOSE signal.

Configure the signal indicator association relationship in the virtual model of the front panel of the protection device so that the status of the signal indicator in the virtual model of the front panel of the protection device is consistent with that of the actual protection device. Configure the signal indicator name, the shape of the signal indicator, the color of the signal indicator, and whether the signal indicator is self-holding; associate the signal indicator reference address of the signal indicator primitive in the virtual model of the front panel with the protection device operating state data entry in the protection device operating state dsDeviceState data set, and set the logic operation model corresponding to the signal indicator reference address according to the logic setting of the signal indicator of the protection device.

Taking a certain type of transmission line protection equipment as an example, the protection equipment operating status data entry associated with the “protection trip” signal indicator element in the virtual model of the front panel of the protection equipment is shown in Figure 4. The logic operation model of the signal indicator element is shown in formula (1).

\[
\text{“protection equipment trip”} = \text{“a” or “b” or “c” or “d”} \tag{1}
\]

In formula (1), a, b, c, and d respectively refer to the status values of the four operating status data items of the protection equipment in Figure 4. The status value of any one of the four protection equipment operating status data entries in Figure 4 meets the conditions, and the signal indicator element is illuminated according to the set signal indicator shape and signal indicator color.

For the board graphic element containing the fiber interface of the process layer, it is also necessary to configure the relationship between the reference address of the fiber interface graphic element and optical fiber link interruption data set entries and optical fiber interface optical power over-limit data set entry in the dsWarning data set and dsCommState data set, and set the logical operation model corresponding to the reference address of the optical fiber interface primitive according to the abnormal logic of the optical fiber interface of the protection device.

Configure the fiber connection relationship of the SV signal and GOOSE signal of the fiber interface graphic element according to the actual fiber connection relationship of the protection device and the connection relationship of the virtual terminal of the protection device in the SCD file. The fiber connection relationship of the SV signal and GOOSE signal of the optical fiber interface element includes the board-fiber interface information of the optical fiber interface element at both ends of the signal, and the APPID of the signal transmitted on the optical fiber.

5. System construction and application

5.1. System construction

Build a visual monitoring system for protection equipment as shown in Figure 5. The system includes two parts: data management unit and data acquisition unit. The data management unit and data acquisition unit are deployed in the substation two zone network. The acquisition unit is connected to
the process layer network to collect SV, GOOSE and MMS data, and to the station control layer network to collect MMS data. The management unit is connected to the station control layer MMS network, and communicates with the protection through the intelligent management unit. The management unit is connected to the intelligent operation and maintenance master station through the dispatch data network[5], and transmits various business results to the intelligent operation and maintenance master station in the form of files. The management unit and the acquisition unit communicate through the internal switch.

![Figure 5. Architecture of the visual monitoring system for protection equipment](image)

The visual monitoring system of intelligent substation protection equipment obtains the status value of the operation status data entry of the entire station protection equipment and the state value of the board abnormal data set entry, the board failure data set entry, the optical fiber link interruption data set entry, and optical fiber interface optical power over-limit data set entry from the station control layer network.

Based on the signal indicator reference address logic operation model, perform logical operations on the status value of the protection equipment operating status data entry associated with the signal indicator reference address. When the logical operation result is "1", light up the virtual model signal indicator element on the front panel of the protection device according to the shape and the color of the signal indicator, and according to whether the signal indicator is self-maintaining determine whether it needs to be reset, so as to keep the status consistent with the actual protection equipment. When the logical operation result is "0", the signal indicator element of the virtual model on the front panel of the protection device is not lit.

Based on the logic operation model of the board primitive reference address, perform logical operations on the status value of the board abnormal data set entry and the board fault data set entry associated with the board primitive reference address. Based on the logical operation model of optical fiber interface reference address, perform logical operations on the state value of fiber link interrupt data set entry and optical fiber interface optical power out of limit data set entry. When the logical operation result is "1", it indicates that the board or fiber interface is abnormal, and the virtual model board or fiber interface graphic element on the rear panel of the protection device is marked with red.
If the result of the logical operation is "0", it indicates that the board or fiber interface is normal, and the board or fiber interface graphic element is not marked in red.

The visual monitoring system of intelligent substation protection equipment reads the process layer data of protection equipment, locates the relationship between logical link interruption and card and optical interface elements according to the optical connection relationship of SV signal and GOOSE signal.

The visual monitoring system of intelligent substation protection equipment displays the status of protection equipment synchronously and locates the abnormality of protection equipment based on the virtual model of protection device panel, and monitors the protection equipment remotely by uploading the monitoring results to the smart operation and maintenance master station.

5.2. Field applications
The visual monitoring system of intelligent substation protection equipment is connected to a 220kV intelligent substation process layer and station control layer network to collect data from the substation process layer and station control layer, perform logical operations, and visually display the results of the calculations on the system interface.

According to the signal indicator reference address logic operation model, the status value logic operation results of the protection equipment operating status data item associated with the 220kV line protection A equipment running light and abnormal light reference address is "1", light up the virtual front panel signal indicator primitives according to the shape and color of the signal indicator. The logical operation results of the status value of the protection device operating status data entry associated with the other signal indicator reference address is "0", and the virtual front panel signal indicator element of the protection device is not lit. The system interface is shown in Figure 6.

![Figure 6. Protection equipment operating status monitoring](image)

According to the optical fiber interface reference address logic operation model, the logical operation result of the status value of the optical fiber link interruption data set entry and the optical fiber interface optical power limit data set entry associated with the reference address of the optical fiber interface 5-A, 7-A, and 7-B of the line protection is "1", m-ark the optical fiber interface graphic element corresponding to the virtual model on the rear panel of the protection device in red, and the other optical fiber interfaces are not marked in red, as shown in Figure 7.
6. Conclusion
The characteristics of intelligent primary equipment and networked secondary equipment of intelligent substations provide a technical foundation for intelligent visual monitoring of protective equipment. The article establishes virtual models of the protection equipment panels, configures the relationship between the model primitives and the protection equipment operating data and optical fiber link data, visually displays the status of protection equipment through information collection at the process level and station control level of the intelligent substation. The status of the protection equipment can be understood intuitively without relying on the protection equipment itself, which is convenient for centralized monitoring and remote monitoring of the protection equipment. In addition, it can locate protection equipment abnormalities and faults to boards and optical fiber interfaces, so that operators and maintenance personnel can quickly understand the status of protection equipment, and effectively improve the level and ability of remote visual operation and maintenance of intelligent substation protection equipment.

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