Research on automatic physical testing method of relay protection equipment through data fusion technology

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Abstract. Intelligent substations can accomplish deeper and more complex substation information exchange and processing by virtue of their equipment intelligence and data integration. In this paper, a relay protection equipment test system for intelligent substations is investigated for intelligent relay protection equipment. By applying data fusion technology in the testing process, functions such as automatically obtaining the action information of secondary devices and judging the response status of secondary devices can be accomplished. Applying the test system proposed in this paper to high-voltage line protection devices, the results show that the relay protection equipment test system can optimize the relay protection equipment test process, which further improves the accuracy and efficiency of relay protection equipment testing.

Keywords: Relay protection, Test System, Data fusion

1. Introduction

With the development of intelligent substations, the intelligent relay protection devices have been improved and updated [1-2]. Intelligent relay protection devices adapted to the application system of intelligent substations have been developed and launched at home and abroad. The State Grid Corporation has introduced a series of standards to promote the development of intelligent equipment detection and regulate the intelligent equipment in substations [3-6], especially relay protection equipment in substations. These standards enable various manufacturers to use the same dimensions, communication protocols, and functions in their production. In this way, the production of equipment according to a unified standard helps intelligent substations to be more standardized, standardized and unified, and reduces the requirements for intelligent substation testing equipment. At the same time, the IEC61850 standard was developed [7-8], and the data communication aspects of smart substations became more standardized.

The application of these measures still requires repeated communication configuration and modification of test items and parameters in the actual testing process [9]. This requires a large investment of human and material resources to complete, which cannot be automated and fails to reflect the advantages of highly informative intelligent substations [10-11]. At the same time, due to the limitation of the speed and proficiency of manual operation, the testing of protection devices takes a lot of time to complete, resulting in a generally long testing period and a decrease in test accuracy, which
cannot meet the requirements of efficient and reliable commissioning and daily operation and maintenance of intelligent substations [12].

This paper studies an automatic test system for relay protection equipment in intelligent substations. Based on the actual characteristics of relay protection device testing in intelligent substations, data fusion technology is introduced to automatically obtain the action information of secondary devices, judge the correctness of secondary device response and generate comprehensive test reports that meet the requirements of the power industry. The automatic test system not only improves the testing efficiency and accuracy, but also optimizes the testing process and provides a new non-manpowered testing method, which is of great importance for the promotion and application of intelligent substations.

2. Introduction of the system

2.1. System test principle
Before testing, the test software should first be connected to the test instrument. Connect and ensure normal communication, so that the test data can be recorded in real time data, while completing the data transmission and shortening the test time.

The test system installed on the PC can operate the calibration value of the relay protection device, throwing and releasing the pressure plate, etc. At the same time, the test data can be processed and analyzed by programming and the test report can be generated automatically.

2.2. Composition of the system
The system consists of five parts, namely, application layer, logic layer, data layer, communication layer and physical layer. As shown in Figure 1. The physical layer consists of testing instruments, PC and protection device; the communication layer consists of test instrument communication interface and protection device communication interface. The data layer includes original records, template data, report data, experimental parameters, protocol information, etc. The logic layer consists of five parts, including: tester control module, protection communication control module, data management module, protection test protocol processing module and test report generation module. The application layer is also composed of five parts: model selection and analysis operation module, test plan editing module, scheduling control module, test report processing module and secondary development interface module. The layers are interconnected and the modules in the logic layer are invoked by processes in the

![Automatic test system components](image)

**Fig 1.** Automatic test system components
application layer and their results are fed back to the application layer or stored in the data layer. The communication layer sets up communication interfaces according to the devices in the physical layer for data transfer and interoperability. The next section will provide a focused overview of the application layer.

2.3. Overview of the application layer

The application layer of the system is the interface for direct communication with users. The key to its design is to provide users with the services that they require and to achieve the characteristics of simplicity, beauty, practicality and convenience. The division of functions and interface display should be reasonably laid out and pay attention to humanized design. The system designed in this paper consists of five parts, namely, model selection and analysis module, test plan editing module, scheduling control module, test report processing module and secondary development interface module.

The model selection and analysis module is mainly used for model selection and analysis in the test system. The test plan editing module is mainly used to edit the test principle, test plan and test results that may be used in the test process. The XML data description language is used to facilitate the user to save the test plan. In addition, the data from the test process can be copied and exported in this module.

The scheduling control module mainly schedules and controls the test process, and completes the selection of test mode, the establishment of test task, the construction of test project and so on. At the same time, the scheduling control module should adopt appropriate tree structure diagram in the selection of test items to provide users with test contents in all aspects. A variety of test modes are also designed in this module for test users to choose, such as one click test (no matter what happens in the test process, the test process will not be interrupted), interruptible test (users can customize the interrupt conditions in this module), only test the selected items. When the test process is interrupted, the system will display alarm screen, sound prompt and other functions. The whole test process has a test status monitoring interface, which can display the measured value, input and output, time and other relevant data in real time.

The test report processing module is mainly used to operate the test report. Specifically, after completing all test tasks, the module modifies, exports and saves the test reports obtained by running the previous modules. The module also has the function of permission setting, so that different test reports are only open to some people, and then the test contents are kept confidential.

In addition, the system also has a secondary development interface module, the purpose of setting this module is: for special users, they can use the Luna language for secondary development of the system to realize the automatic test system. This also reflects the system's strong scalability and flexibility.

3. Application of data fusion technology in automatic test systems

3.1. Data fusion principles

Data fusion [13-15] is the integration of multiple descriptions of the same thing, and the integrated information has high accuracy in estimation and judgment compared to a single piece of information. A full range of information from multiple sources is analyzed to obtain the subset with the most characteristics of that thing.

Data fusion has three levels: data layer, feature layer, and decision layer, and the levels and algorithms can be fused accordingly according to different application contexts. In this paper, when the system is interrupted during testing, alarms and alerts will appear. After introducing data fusion technology, testers can distinguish the causes of test interruptions and alerts according to the warning sounds.

3.2. Data fusion decision process

In this paper, we design the following D-S fusion process based on the principle of data fusion [16].
Step 1. Construct a recognition framework $\theta$. For a certain target, the constructed recognition framework should be the set of all possible outcomes which describing the target. In this paper, the recognition framework can be the set of sampling value anomaly ($A_1$), switching value anomaly ($A_2$), action anomaly ($A_3$) and the set of uncertainties $\delta$, i.e., $\theta = \{A_1, A_2, A_3, \delta\}$.

Step 2. Set the Base Probability Assignment (BPA). For the recognition framework, the base probability assignment $m$ is a mapping from $\{0, 1\}$ to the interval $[0, 1]$, i.e., $m: \mathbb{B} \rightarrow [0, 1]$. The base probability assignment $m$ satisfies two conditions:

$$
m(\emptyset) = 0;$$  \hspace{1cm} (1)

$$
\sum m(A) = 1, A \subseteq \theta$$  \hspace{1cm} (2)

where $m(\cdot)$ is the basic confidence number which reflects the credibility of framework $\theta$. The relationship between the confidence function $\text{Bel}(\cdot)$ and $m(\cdot)$ is:

$$
\text{Bel}(B) = \sum m(B), B \subseteq A
$$  \hspace{1cm} (3)

where $\text{Bel}(A)$ is denoted as the sum of BPA of all subsets of $A$, which reflects the strength of support of $B$ for $A$. The BPA on the recognition framework is calculated as:

$$
m_i(A_j) = \alpha_i \times u_{ij} \hspace{0.5cm} i = 1, 2; \hspace{0.5cm} j = 1, 2, \cdots, n
$$  \hspace{1cm} (4)

$$
m_i(\delta) = 1 - \alpha_i
$$  \hspace{1cm} (5)

where $m_i(A)$ is the BPA of the $i$-th evidence for the $j$-th object; $m_i(\delta)$ is the BPA value of the $i$-th uncertain evidence; $u_{ij}$ denotes the affiliation of the $i$-th evidence for the output as $j$-th class of faults; and $\alpha_i$ is the reliability coefficient of the $i$-th evidence source.

Step 3. Evidence combination. The combination rule is the core of the D-S evidence theory, which is calculated as:

$$
m_{1,2}(A_j) = m_1(A_j) \oplus m_2(A_j)
$$  \hspace{1cm} (6)

where $A_i = B \cap C$; $B$, $C$ is a subset of $\theta$; $\oplus$ denotes a heterogeneous or operation. The final discrimination result can be obtained according to equation (6), which achieves the combination of two types of data.

Step 4. Decision-making. The resulting BPA is to meet the following three rules:

Rule 1: $m(A_{\text{max}1}) = \max \{m(A_i), A_i \subseteq \theta\}$, $m(A_{\text{max}1})$ is the maximum value of the output BPA. According to Rule 1, the BPA after using the fusion of the two types of information should have the maximum BPA.

Rule 2: $m(A_{\text{max}1}) > m(\emptyset)$. Rule 2 specifies that the BPA after fusing the two types of information is greater than the uncertainty $\emptyset$.

Rule 3: $m(A_{\text{max}1}) - m(A_{\text{max}2}) > \varepsilon$. Rule 3 stipulates that the BPA after fusing the two types of information must have a relatively large value. The value of $m(A_{\text{max}2})$ is the second largest value of BPA, and the value of $\varepsilon$ should be chosen according to the actual situation.
3.3. Application of data fusion

Traditional relay protection equipment testing is usually performed item-by-item, and the testing process is shown below:

Step 1: The first step is to determine whether the analog zero drift and linearity performance are good, and then to determine whether the sampling value is normal or not. If the sampling value is normal, the next operation will be performed, otherwise, the test will be ended immediately.

Step 2: Judge whether the switching value. If the switching value is normal, proceed to the next step. Otherwise, the test shall be ended immediately.

Step 3: After each value is detected as normal, the test is performed. Firstly, send the GOOSE signal to put in the protection project soft panel and load the protection value by MMS protocol. Secondly, set the fault voltage value for each test. Thirdly, obtain the action information of the protection device. If the protection device operates correctly, proceed to the next operation according to the test list, and if it operates incorrectly, alarm and record immediately and proceed to the next operation.

In the process of item-by-item testing, each variable needs to be checked repeatedly. So, there exists many problems such as long testing time and complicated operation. In this paper, the system introduces data fusion technology in the testing process, which can automatically complete the test and diagnose test abnormalities during the test based on the data fusion technology. Based on the characteristics of the test sampling value, switching value and action information. The system can determine the test fault as abnormal sampling value, abnormal switching value or abnormal action. Meanwhile, the system generates an interrupt, with alarm screen and sound indication. In addition, the system can automatically generate fault and abnormality reports and provide them to the testers for targeted handling. The flow chart of test anomaly diagnosis based on data fusion technology is shown in Figure 2.

![Flow chart of test anomaly diagnosis based on data fusion](image)

**Fig 2.** Flow chart of test anomaly diagnosis based on data fusion

4. Application of automatic test systems

4.1. System testing process

Step 1. The staff shall prepare the standard test protocol template in the system.

Step 2. Ensure that the system software, test instruments and protection devices are interoperable during the test.

Step 3. The system software controls the test instrument output, while the test instrument returns the values of output.

Step 4. The system software controls the functions of the protection device such as signal reversion and modification of the fixed value. The protection device transmits fault reports, disturbances and other data to the system software.

Step 5. The test system will output voltage and current to the protection device, and the protection device provides the tester with the output value.

4.2. Test report visualization

The relay protection automatic test system can achieve automation of testing process and intelligence of fault abnormality judgment. Meanwhile, in terms of information exchange with testers, it can automatically generate test reports, set usage rights and other functions.
The system is also designed with several versions of visual test reports, which can be accessed by different target groups according to their needs. For example, a simple version of the test report can be selected for the field staff. The report shows the failure points and possible causes of failure, and is provided either in paper version or directly transferred to cell phone or PC terminal. This facilitates testers to accurately and quickly analyze the test results and deal with abnormal situations.

For test problems that cannot be solved on site, the test report should be uploaded to the master system, and this test report will analyze the test results in more detail. At the same time, data from the test process should be provided to facilitate incident analysts to further analyze and handle the problem.

Therefore, providing visualized test reports helps to reduce the staff's time for analyzing accidents and improve the efficiency of relay protection equipment testers under the premise of guaranteeing a low accident rate, which has certain application value.

4.3. System Applications

Taking the PCS-943 high-voltage line protection device as an example, the automatic test system designed in this paper is used to complete all relevant tests such as longitudinal differential protection, distance protection and zero sequence over-current protection in turn, and the results are shown in Table 1.

| Test Items                                    | Expected results                                      | Test results            | Confirmation of the results |
|----------------------------------------------|------------------------------------------------------|-------------------------|-----------------------------|
| **Differential protection section I**        | The protection does not act                           | Reliable no-action      | no anomaly                  |
| The fault current is:                        | when \( m \) is 0.9                                    |                         |                             |
| \( I = m \times 0.5 \times I_{\text{max}1} \) | The protection can act when \( m \) is 0.90           | 29.795ms action         |                             |
|                                              | Check the action time when \( m \) is 1.15            | 29.238ms action         |                             |
| **Differential protection section II**       | The protection does not act                           | Reliable no-action      | no anomaly                  |
| The fault current is:                        | when \( m \) is 0.90                                  |                         |                             |
| \( I = m \times 0.5 \times I_{\text{max}2} \) | The protection can act when \( m \) is 1.00           | 79.875ms action         |                             |
|                                              | Check the action time when \( m \) is 1.15            | 79.245ms action         |                             |
| **Distance protection section I**            | The protection does not act                           | Reliable no-action      | no anomaly                  |
| The fault voltage is:                       | when \( m \) is 1.00                                  |                         |                             |
| \( U = m \times I \times Z_{D1} \)          | The protection can act when \( m \) is 0.90           | 19.748ms action         |                             |
|                                              | Check the action time when \( m \) is 0.75            | 19.284ms action         |                             |
| **Zero sequence over-current protection section II** | The forward protection does not act when \( m \) is 0.90 | Reliable no-action      | no anomaly                  |
| The fault current is:                       | Verification of forward protection action time when \( m \) is 1.00 |                         |                             |
| \( I = m \times I_{\text{OIZD}} \)          | The reverse protection does not act when \( m \) is 1.15 | 275.695ms action        |                             |

Table 1. The test reports of the automatic test system.
5. Conclusion
Aiming at the problems of existing relay protection device detection, such as large amount of manpower, long test time, poor accuracy and so on. In this paper, an automatic test system for relay protection devices in intelligent substations is researched. The system is designed in three aspects: module composition, test diagnosis, and visualization interface. The system can ensure the orderly testing of relay protection devices while achieving the automation and intelligence of testing. By introducing data fusion technology into the test system, it is not only possible to automatically change test parameters, cast soft platens and write control words, but also to automatically obtain the action information of secondary devices and judge the correctness of the response of secondary devices. At the same time, it can generate a comprehensive test report that meets the requirements of the power industry and constitutes a complete closed-loop test. The automatic test system not only improves test efficiency and test accuracy, but also optimizes the test process and provides a new non-manpowered test method, which is of great importance for the application of intelligent substations.

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