Research of Smart Substation Integrated Intelligent Test System

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***Abstract*—Nowadays for the devices of intelligent substations, testers only aim at testing single device instead of integrating whole substations. According to the "three-level and two-network" substation structure and based on the standard operation instructions, intelligent substation integrated intelligent test system targets at systematic and complete test and carries out the test work of project quickly and exactly through professional debugging tools supplied by integration system. This system can not only make the test work more perfect and effective, but also reduce the working strength of operators and improve the work efficiency and quality significantly.**

Keywords—intelligent substation， IEC61850， integration， relay protection， intelligent test system

I. INTRODUCTION

At present, intelligent substations are based on the IEC61850 protocol. The communication of station devices, like merging unit, intelligent terminal, protection device, measurement and control device, use a variety of digital transmission after specification. Compared with the traditional substation, especially for commissioning staff, it is more difficult to debug, test, maintain and manage intelligent substation due to the introduction of a large number of communication protocol and network communication concepts. The experience and methods accumulated in the past for various types of device testing, calibration, maintenance and fault diagnosis, such as many, are no longer applicable [1~3].

The rise of intelligent substation and the introduction of various smart devices have increased the demand of various testing equipment. At present, the tester still focuses on a single device, without considering multiple devices. Which means they didn't stand to the height of the whole station and cover the multi-level substation network and devices. For the merged unit, a merged unit tester is required. A digital relay protection tester is needed for the protection device conforming to IEC61850. For the SV and GOOSE networks that are unique to intelligent substations, testers need corresponding testing and intelligent systems. For the IEC61850 model (SCD, etc.), its normalization should be checked and corresponding connection information should be verified. At present, there are only independent test systems in the market. A set of comprehensive and complete test system enables testers to abandon all kinds of test device and single test system and consider the test scheme and test from the entire system. Foreign companies and institutions do not have similar products and research [4~6].

The system showed in this paper can convert the standardized operation instructions into device test plans (test templates and report templates), through the control of the relay protection tester, realizes the automatic verification of the digital protection device, automatically generates the test report function, and selects the test function module. And it can automatically test the parameters according to the fixed value, prompt the test junction box operation method, download the IEC61850 configuration of the tester, evaluate the test results and generate test reports. It opens the test report (data) file standard to facilitate interface with other systems.

II. DEVICE PRINCIPLE

According to IEC61850, the current intelligent substation classifies the devices in the station into "three-level and two-networks": process level, bay level, station control level, process level network and station control level network. Process level device mainly includes secondary device such as merging unit and intelligent terminal, as well as primary device such as transformer and isolator. The bay level is mainly for secondary device such as protection device, measurement and control device. The station control level is mainly composed of monitoring device, tele-control device, timing system and protection and fault information substation. The process level network is responsible for the communication between the process level device and the bay level device, and carries the messages such as SV, GOOSE, and 1588. The station control level network is responsible for the communication between the bay level device and the station control level device, and carries the MMS and SNTP message.

The integrated intelligent test system is based on the "three-level two-network" substation structure. It is mainly used to test the three-level device separately and the integrated system-level joint debugging testing. With the goal of systematic and complete testing, and based on standardized work instructions, the professional debugging tools provided by the system can quickly and accurately complete the testing projects.

III. FUNCTION DESIGN

Considering the future cross-platform portability of the system and the integration of the mastered technology, the system is mainly written in Qt5. The database is written in Sqlite, which can be compiled cross-platform. The application platform is Windows or Linux. If you need to use a third-party library, you can also choose an open source cross-platform

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library to ensure the cross-platform function of the entire software. The overall function of the system is shown in Figure 1.

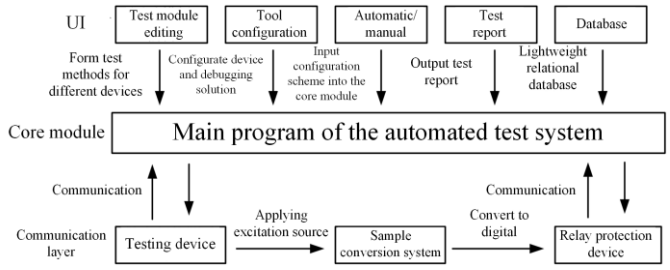

Fig. 1. System function diagram

A. Process Level Device Test

1) Transformer Inspection

The system is highly versatile. It can be used to inspect electronic transformers as well as traditional electromagnetic transformer. The system can perform the consistency check of IEC 61850 protocol for electronic transformers, output multi-channel optical synchronization signals, monitor the signal output under steady state, and accurately detect data indicators such as ratio difference, phase difference and frequency difference. The accuracy and stability of the system is good enough. The principle is shown in Figure 2 [7.8].

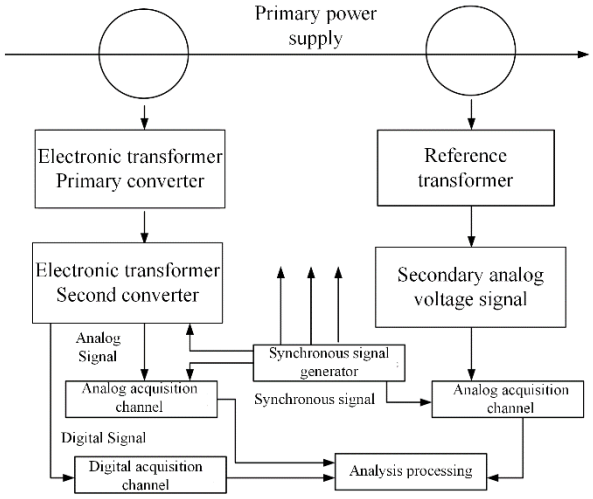

Fig. 2 Principle diagram of transformer inspection.

2) Merging Unit Testing

The merging unit (MU) is an important device in the intelligent substation as the interface device of the process level. It is a component of the transformer. It mainly completes the data acquisition of the acquisition unit and the analog input signal acquisition as well as the multi-channel data synchronization of the collected data. At last, the data is transmitted by a specific protocol (mainly 61850-9 and FT3) to the rest of the substation protection and control devices. The performance of the merging unit is directly related to the normal operation of the secondary equipment such as protection, metering, measurement and control, and fault recorder. Therefore, the testing of merging unit is particularly important. At present, there are some merging unit testers on the market, but most of them only test the data processing performance, the test of the 61850 model of merging unit has not been involved [9~11].

The system proposes a new type of merging unit test system, as shown in Fig. 3. The system collects the reference source analog signal through the high-speed synchronous analog signal collection board, and collects the output digital signal of the merging unit through the digital signal collection module. The collected reference source signal and digital signals are transmitted to the background analysis system via USB or Ethernet port. The background analysis system performs statistical analysis on the sampled data through advanced algorithms to obtain data indicators such as difference, phase difference and frequency difference, then gets test reports. At the same time, the consistency of the merging unit model is verified by the MMS service of 61850.

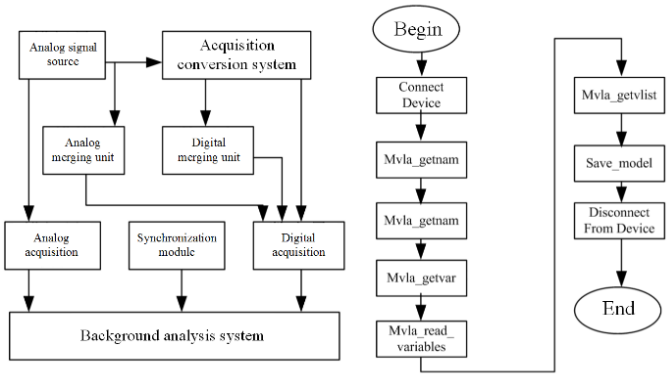

Fig.3 System function diagram

3) Intelligent Terminal Test

As the intelligent front-end device of the breaker and isolator, the intelligent terminal is the key node for the protection and control device to control the primary device. Through the SCD file, the system will comprehensively detect and evaluate the GOOSE message specification, regular functions, time performance, network performance and other functions of the intelligent terminal, as shown in Figure 4.

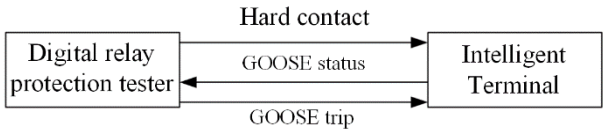

Fig.4 Schematic diagram of intelligent terminal

B. Bay Level Device Test

The protection and control device is the core component of the device in the substation. Its functions are complex and there are also large differences among the manufacturers. In the past, the functional tests were basically manual and process one-by-one, which not only puts higher requirements on testers, but also take a lot of time. In response to such a

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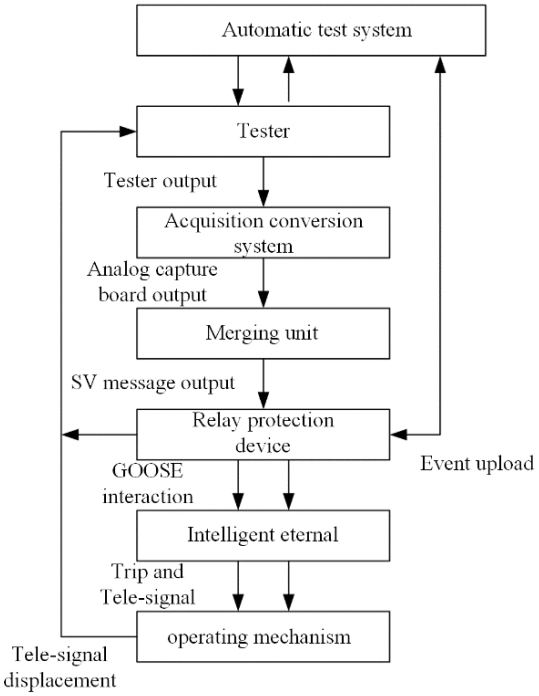

Fig. 5. Test flow chart

situation, an automatic test system for the protection and control device is adopted which will fundamentally change the situation. The standardized operation instruction book is converted into the device test plan, and the function of automatically checking the digital relay protection device and automatically generating the test report are realized by controlling the relay protection tester, and the device test solution can be obtained by using online or offline. According to the test template, the system prompts the staff to complete the preparation of dangerous point analysis and control and device handover. It also selects the test function module, tests parameters according to the fixed value, prompts the test junction box operation method, downloads the IEC61850 configuration of the tester and evaluates test results and produce test reports automatically. It opens the test report (data) file standard to facilitate interface with other systems. The process is shown in Figure 5.

After the test plan is loaded by the automatic test system, the system can configure the tested object including set value and platen, and control the output of the tester according to the value of the tested object.

The report corresponding to the test plan can be generated after the test, including the following:

a. Test environment: test set value, test platen, etc.

b. Test results: including various action behavior records during the test, such as trip time, event message, and remote signal displacement record.

It can be seen that the test process of the system is a closed-loop. And the generated report covers various behavior logics of the whole system during the test process, which not only improves the efficiency, but also leave a complete record for the analysis of the working condition of the system after the test.

C. Station Control Level Device Test

1) Online Monitoring Substation Test

In order to achieve the standardization of substation automation device and monitoring system functions, and the maximization of maintenance efficiency, State Grid proposed the “four unified and four specifications” which requires online monitoring and abnormal phenomenon analysis of substation automation device [12.13].

The specification requires that the online monitoring substation system of the automation device collects, processes, controls and stores information, and sends information to the online monitoring master station system as required to realize online monitoring, abnormal phenomenon analysis, status evaluation and centralized management of substation automation device.

The DL/T 860 is used as the communication standard between the master station and the substation, and the abstract service communication interface (ACSI) model defined by DL/T 860 is adopted. The communication function is implemented by using the MMS communication protocol set. The communication mode is as Fig6 and Fig7.

This test system can communicate with online monitoring substation by simulating as a master station to test and verify the communication function and related services of the substation.

The online monitoring substation manufacturer needs to provide: SCD file, monitoring substation IP address, and configuring the channel for communication with the test system.

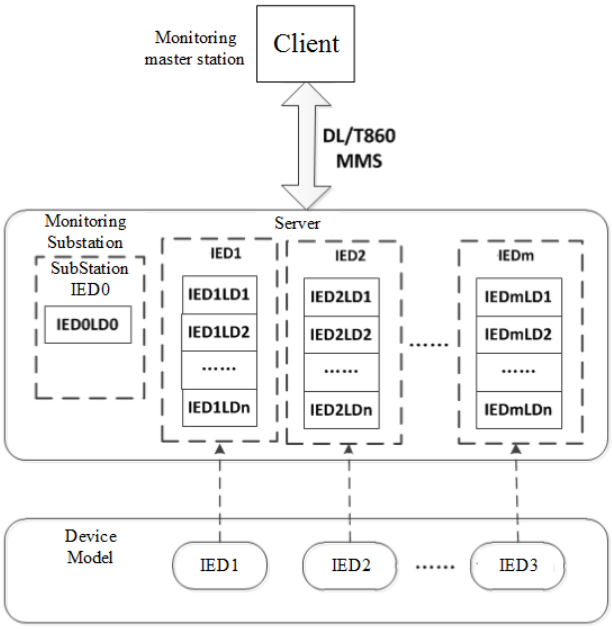

Fig.6 Communication mode

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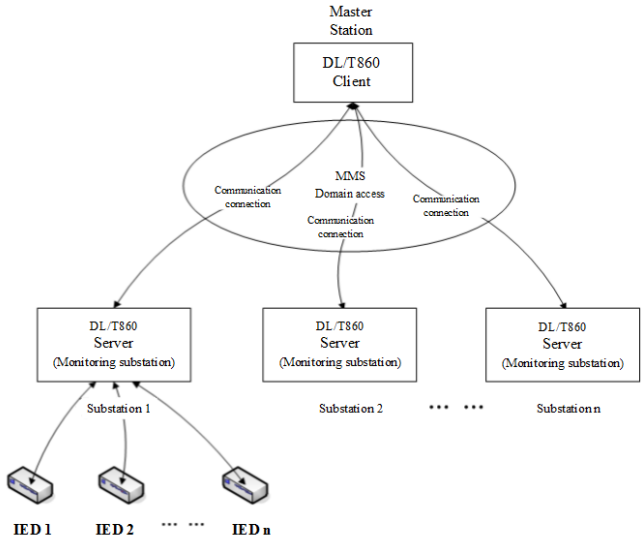

Fig.7 The network structure

2) Customized Advanced Function Test

The server can obtain various types of device information from the station control level device. According to the differentiated requirements, the system supports customized testing refer to the acquired information. Through the continuous deepening and improvement of customized testing, the integrated intelligent testing system is constantly improving. For example, according to the timing mode and the required parameter indicators of the substation, the corresponding test plan will be formulated and the system-level time characteristic test will be performed on the whole station time-aligned equipment.

D. System-Level Comprehensive Test

The communication test conducted by the automatic test system can completely cover the complete communication link of the digital station's background monitoring system, protection and monitoring device, switch, intelligent terminal and operating mechanism, so as to complete the complete communication link and system action behavior test, as shown in Figure 8.

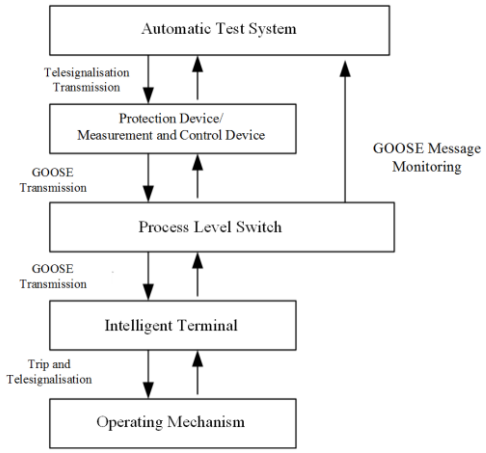

Fig.8 Monitoring schematic diagram

Through the above subsystem tests and using the graphical interface, we can complete the SCL correctness check of the whole station.

IV. CONCLUSION

First of all, the debugging of intelligent substation has added more equipment, and some functions are also the same among various equipment. This also brings waste of test equipment, and an automated intelligent test system will replace several of them, thereby reducing equipment costs. Secondly, if the intelligent substation still adopts the traditional substation method and mainly conducts single device testing, it will be very time consuming and does not completely test the related content between the intelligent devices. Therefore, the integrated intelligent test system developed in this paper can not only make the test work more complete and effective, but also greatly reduce the working strength of the related operation and maintenance workers and improve work efficiency and quality

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