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Research and application of assembly test platform for outdoor installation protection

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Abstract: Standardised and miniaturised outdoor installation protection is the development trend of relay protection in AC transmission power grid, which has the advantages of saving investment, promoting reliability, and reducing on-site workload. To realise fully functional and efficient automatic closed-loop detection of outdoor protection is of great significance. In this study, key technology of assembly line automatic detection and its platform construction method including hardware and software is firstly proposed. Furthermore, overall design idea, system structure, and core detection procedure of assembly test platform are discussed and then some key technology such as QR code intelligent scanning, automatic transmission and loading, design of general detection template, and information mapping correlation method are introduced in detail. Besides, this automatic detection system initially realises the function to simulate the actual operation data under prototype environment. The application of this new technology can meet the needs of popularisation and application of outdoor installation protection and establish foundation for the mode of ‘factory assembly test and on-site replacement maintenance’ for relay protection in future.

1 Introduction

As the first line of defense of the power system, protection device must be fully detection before entering the network to ensure the safe operation of the power system. With the increasing number of protection devices, a large number of detection works has led to the lack of carrying capacity of detection personnel. So the automatic detection of relay protection devices has become a hot research field in recent years, different research institutes and equipment manufacturers have carried out research on automatic detection platform of intelligent relay protection equipment [1–5], in the hope of solving the problems of low detection efficiency and susceptible to human factors in the traditional manual detection mode. However, protection devices of different manufacturers and models are quite different in the communication protocol, the external interface, etc. Existing types of detection systems are not compatible with automatic detection of different devices.

Localisation of protection devices is the focus of the National State Grid Corporation control centre, but also the future development trend of relay protection [6]. Localisation protection is based on the ‘nine unification’ of state grid corporation [7, 8], further unify device size and interface, enhance their own protection device. The purpose is to optimise the entire station construction program based on the standardisation of equipment [9–11], improve the speed and reliability of relay protection, and reduce the on-site detection, operation and maintenance workload of the device. Localised protection devices tend to be unified in terms of device size, communication protocols, application models, external interfaces, etc, this create a favorable condition for truly full-featured and highly efficient automatic closed-loop detection of the device [12]. On the other hand, the localisation protection device canceled the LCD panel, use standard connectors on the outside, existing detection methods and detection systems can no longer meet the needs of their promotion and application.

This paper presents an automatic assembly line closed-loop detection method for localised protection devices. With smart label scanning code, model-level mapping, automatic positioning, and loading technology, the paper carry out systematic research and development, achieve automatic assembly test of different types of localised protection device. This method ensure the efficiency and correctness of device detection, is adapted to the localisation of protection devices commissioning, operation and maintenance, and repair work, provide technical means to achieve the new mode of operation and maintenance: ‘factory detection, replacement maintenance’.

2 Overall design of assembly test system

Standardisation, miniaturisation and high protection are the salient features of localised protection devices. The promotion and application of localised protection can minimise the workload and requirements of on-site detection and operation and maintenance. A large number of verification complete in the factory or detection centre, to achieve the new model of ‘factory detection, replacement maintenance’. With the continuous expansion of power system, the workload of industrialised detection of localised protection will increase sharply. As a result, conventional localisation detection that relies on manual method cannot meet the requirements of technological development. Therefore, localised protection factory inspection should be based on assembly line automation, could improve the intellectualisation and standardisation of localisation protection detection, reduce the degree of reliance on the experimenter.

The assembly line inspection system should be able to automatically identify the type of device and loaded into the appropriate detection station, based on the highly standardised local protection device, automatically carry out the functional and performance detection [13, 14], complete the detection report generation work. It should provide efficient technical means for network access detection, infrastructure commissioning, overhaul detection, reconstruction and extension verification. The detection system should be able to achieve the following basic functions:

i. *Obtain device information*: Scan the smart tag of the localised protection device, automatically identify the device type, and obtain the device information and related configuration files;
ii. *Localise loading and unloading*: Automatically transfer the detected device to the corresponding test station, through precise location, automatically load and access detection system, can be automatically unload and exit the detection system after the detection;
iii. *Automatically detect the function and performance*: Call the detection template automatically [15], instantiate based on device information and configuration files, according to the

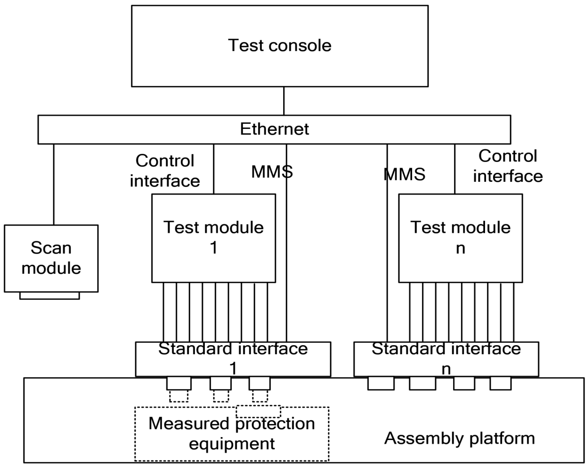

Fig. 1 *Assembly test platform system structure*

template complete the detection work automatically and form a report.

In order to achieve integrity detection of the expansion of localisation protection and monomer measurement of localised component protection sub-machine, in addition to the implementation of virtual terminal verification, verification of values, functional tests and other configuration and logic verification, the detection system should also have panoramic data simulation and device behaviour simulation capabilities of substation [16].

3 Architecture of assembly test system

3.1 Architecture of system hardware

In order to achieve the automatic assembly test of different localised protection, test system could use modular architecture design. In the hardware system, including the test console, scan module, assembly line platform, and test module, shown in Fig. 1.

Test console can be divided into data module and functional module, through mutual cooperation to complete the unified management of testing projects, testing processes, test results, and localised protection equipment data [17].

3.1.1 Data module: Data module of detection console mainly consists of the following components:

i. *Device information management library*: Including type, the specific model, version, factory number, substation, Intelligent Electronic Device (IED) number, specific scheduling naming, size, structure, physical interface, setting value, detection information;
ii. *Substation Configured Description (SCD) library*: Including SCD system configuration files for all substations to which the tested device under belongs;
iii. *Test report library*: Including test reports of the tested device after the test is completed.

3.1.2 Functional module: The function module of detection console consists of the following components:

i. *IED configuration tool*: Used to export the configuration of the tested device from the SCD file, and download it to the tested device;
ii. *Detection module*: Used to control the spreading, the test results analysis, test reports automatically generated of test module test items;
iii. *Scan control module*: Used to control the scan module to scan smart label of tested device, and receive the feedback data, obtain the information of the tested device from the data module;
iv. *Assembly platform control module*: Used to control the assembly platform to be tested device transmission, positioning, and docking;
v. *MMS client*: Used to interact with the tested device station control layer, obtain protection events, protect telemetry, protect remote signalling, alarm information, and control the soft plate of protection, call and modify the setting value, transfer fault recording of tested device and so on.

3.1.3 Scan module: Mainly used to scan the smart label of the tested device, and feed back the information to the detection console.

3.1.4 Assembly line platform: Mainly automatically transmit the tested device to the appropriate station, and through the precise positioning of the device interface in the station automatically docking, automatically load the tested device into the test system. In order to meet the simultaneous testing of multiple devices, assembly line platform set up a number of test stations. Each test station set a standard interface, one end interface with the aviation plug interface of localisation device; the other end is connected with the test module by cable or optical cable.

3.1.5 Test module: Responsible for one-to-one correspondence with the assembly line platform, receive detection tasks of test console, output voltage/power flow and switching volume, and receive the action signal of the tested device, feeds it back to the detection console. Test module input and output could be analog; it could be GOOSE and SV.

3.2 Architecture of system software

Assembly test not only need to automatically test the protection function, but also automatically carry out the test project of secondary circuit, voltage and current accuracy, switching point and so on. As a result, the software of assembly line testing system uses hierarchical, standardised, modular design ideas. In accordance with data transmission path in test process, the system is layered, divided into platform layer, service component layer, and platform layer, as shown in Fig. 2. By defining the standard format of interaction data between layers, it is possible to improve system scalability and portability.

The application layer is composed of a test module library, a test template editor, and a test case manager, complete the test item decomposition and process control, provide friendly man-machine interaction.

Service component layer provide public support platform for the development of application software, which complete the corresponding work by calling these components.

The platform layer consists of modules such as experimental configuration, state sequence machine, data playback machine, time synchronisation, and opening-into amount report. Its role is to receive the upper test tasks, drive the physical data interface to output voltage, current, switch signal, SV messages, GOOSE messages, and feedback the tested device response signal to the upper application software for data analysis. Platform layer and service components exchange information between layers through standardised communications services.

In order to improve the versatility of protection functions automatic testing, solve the problems of existing automatic tests poor portability and application development dependent on manufacturers, it is necessary to abstract various test functions and test flows, design a standardised test module. In the detection system, it redesign an enhanced state sequence module to complete most of the protection function test, system oscillation and other functional tests are performed by the data playback module. Enhanced state sequences could output amplitude and alternating signal of frequency linearly varying, and could superimpose decaying DC components. The detection console application layer decomposes the specific detection items into different enhanced state sequences or data playback sequences, and delivered to the platform of the test module through standard protocols. The platform layer calculates and outputs real-time data for each state

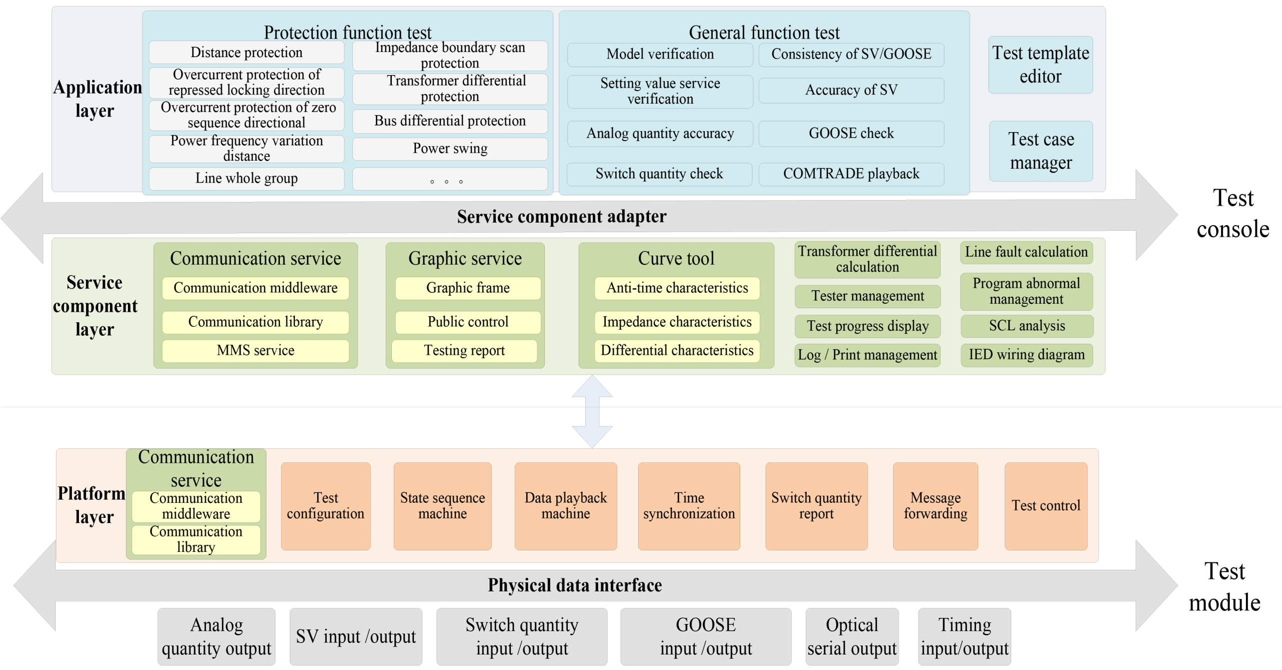

Fig. 2 *Assembly test platform software structure*

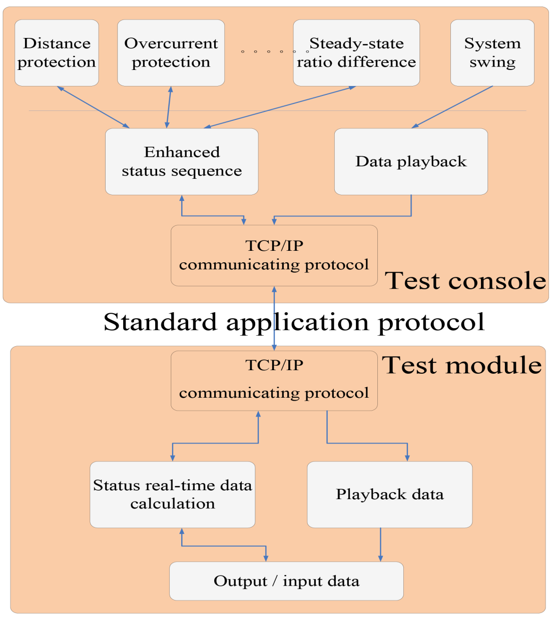

Fig. 3 *Automatic detection of protection function diagram*

based on the received status, as shown in Fig. 3. Enhanced state sequence and application protocol data of data playback sequence use XML format string to describe, make full use of the characteristics of XML language: scalability, structure, serialisation.

4 Overall process of assembly test system

As the core controller of assembly test system, detection console fully participate in the work as label scanning, automatic transmission, positioning loading, closed-loop testing, report generation and device unloading of localised protection device. The specific process includes the following aspects:

i. *Tested device information scanning*: After the assembly testing task is started, detection console control scanning module through the RF reader or camera to scan the tested device label, get the information entry of tested device, and feedback to the console. The console access the basic information from the information management repository through the information portal, including the device type, model, version, IED number, size, rating, profile, to determine testing location of the tested device;

ii. *Tested device automatic transmission*: According to the tested device information, the test console will automatically transfer the device to the appropriate test station through the assembly line platform;

iii. *Tested device positioning loading*: According to size information of the tested device, assembly line platform precisely align with the test station on the standard interface. Then platform push the tested device to the specified position, achieve a reliable connection with the standard interface, and feedback the 'accessed' signal to the console;

iv. *Test project formation*: According to the tested device information, test console obtain the relevant configuration files and common test templates, and conduct information mapping, instantiate the universal parameter letter in the test template, form test template of the tested device, determine the test items and processes;

v. *Full-featured automatic closed-loop test*: Test console send the test items to the test module one by one, output test data and receive response information, automatically closed-loop test the tested device, until all project tests are completed;

vi. *Test results automatically generated*: Based on the feedback of the tested device, test console automatically generate a standard format device test report, and archive to the report library;

vii. *The tested device is unloaded*: After the functional test is completed, the test console start the working of the assembly line platform, exit the tested device from the test station.

5 Test system implements key technologies

Assembly line automatic test of localisation protection, the key is in the absence of human intervention, can automatically transfer and load the tested device. Based on common test templates it automatically generate test sequences, then use the information-related mapping of the tested device to achieve full-featured function and closed-loop performance testing.

5.1 Automatic transfer loading technology

Conventional relay protection test requires a lot of man-made wiring work, and the correctness of the wiring directly affects the test result. Localisation protection highly standardised in terms of

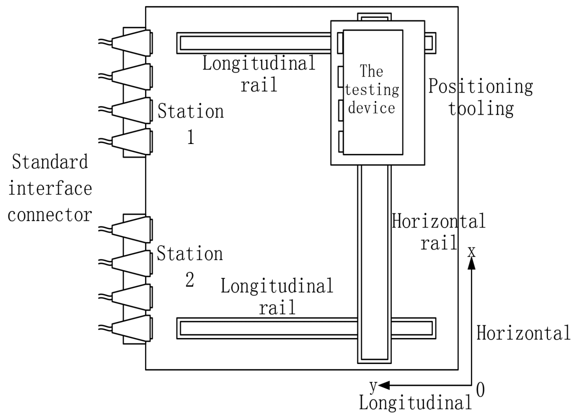

Fig. 4 *Motor-driven slipway diagram*

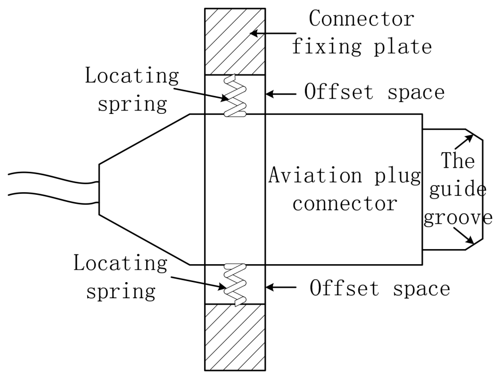

Fig. 5 *Flexible connector diagram*

Table 1 Diagram of virtual terminal and strap path

Signal name	Common path	Instantiation path
SV input virtual terminal	*PISV*/SVIN-GGIO*.MX.*	PL2201APISV/SVIN-GGIO2.MX.SvIn1
telemetry signal	*PROT*/*MMXU*.-PHV.phsA.cVal	PL2201APROT/MMXU1.-PHV.phsA.cVal
GOOSE input virtual terminal	*PIGO*/GOIN-GGIO*.ST.*	PL2201APIGO/GOIN-GGIO1.ST.DPCS01.stVal
remote signal	*PROT*/*GGIO*.ST.*	PL2201APROT/-GGIO17.ST.Ind5
soft plate	*PROT*/ *GGIO*.CO.-SPCS*	PM2201APROT/-GGIO10.CO.SPCS01

device size, communication protocols and application models, supplemented by prefabricated aviation plug interface applications, created the conditions for automatic positioning and docking during the test. Localised protection testing can use automatic transmission and loading methods of assembly line, access the tested device to the test system designated station, reducing human intervention.

Assembly test system use electric sliding table to achieve automatic transmission and loading, shown in Fig. 4. Slipway mainly is consisted of slide rail, positioning tooling, connectors, and other major interface components. Slide rail is divided into horizontal and vertical slide rail; the use of precision servo motor control could achieve horizontal and vertical two-freedom precise movement in the horizontal direction. Horizontal movement could achieve the precise positioning of station; the vertical movement allows the docking of the vertical connectors. Slide rail displacement straightness accuracy of better than 0.03 mm/300 mm, when the design moves in the range of 1000 mm, the accuracy is <0.1 mm error.

Positioning tooling is used to fix the tested device. Its size and position directly determine the vertical positioning accuracy of the tested device, and affect the level of the device under test together with the slide rail. The size and interface location of different type of tested device may be different, so it is needed to adjust the position of the slide to achieve precise positioning.

The standard interface connector matches with the aviation plug interface of local protection, and different connectors correspond to different station; meet different local protection testing needs.

Longitudinal slide rail torque of motor-driven slipway is controlled within a certain range. When the tested device is aligned with the standard interface connector, the tested device is reliably connected to the standard interface; when the tested device is not aligned with the standard interface connector, the slide rail should be able to automatically stop, to prevent the aviation plug interface and connector from being damaged.

In order to be compatible with localisation protection device aviation plug interface error of the same type and different manufacturer, standard interface connector should have a certain degree of flexibility. When the aviation plug interface on the connector fixed in the station, the vertical direction cannot be moved, the horizontal direction has a certain amount of lateral offset space. It is fixed with a spring, to be offset by a certain force. The front end of the connector has a larger diameter guide slot, so that aviation plug interface of tested device can enter the guide slot. Then the longitudinal driving force of longitudinal slide rail is transmitted to the guide slot through the device under test, converted into a lateral force, drive the connector on the aviation interface to occur offset, align the aircraft interface of the tested device (see Fig. 5).

5.2 Universal test template design

In the localisation protection assembly line testing process, it needs to test one by one according to the items included in the standard template. The current test templates generally individually build models based on the tested device type, there is a lot of repetitive work. When the configuration file of tested device is modified, and it need to re-adjust the template. Firstly, the developed assembly-line test system establishes a common test template for the type of protection. Then through the mapping with the configuration file, the universal test template is instantiated, and the dedicated test template which for pipeline testing of the specific device is obtained. Universal test template establish for each type of protection, such as line protection, main transformer protection, bus protection, is compatible with different manufacturers, different models of devices, optimise the test template. The process of instantiating universal test templates and profile mapping can be automated by the program, simplify the template creation process.

Common test templates include test items, test input and output and its common path, test items related to soft plate and its common path and so on. Test project is maximisation project for a class of protection equipment. According to modeling protective function of the tested device CID file, test project select and associate during instantiation. The common path is the reference path for the corresponding input, platen. The information such as logical device type, logical node prefix, logical node class, and function constraint is clearly defined in the standard, and can be directly specified in the path. For instance number, the suffix, the data name, and other ambiguous information, then the wildcard * is used in the path. During the process of template instantiation, by searching common path in the CID file of the tested device, information is confirmed, and matching the name, description, instantiation the '*' said.

In the test template, the common path and instantiation path of virtual terminal and platen information are shown in Table 1.

5.3 Station control layer/process layer information mapping association

At present, the automatic protection test mainly use the process layer information for function test [6, 7, 9], lack the comprehensive judgment of station-level information, and affect the test accuracy. With the development of the relay protection information standard, the classification and requirements of localised protection action information, alarm information, state change information, online monitoring information, intermediate node information, and log record have been clear. Station control layer information tends to

Table 2 Mapping relationship of break position and remote signal

Process layer signal name	Process layer signal name path	Station control layer signal name	Station control layer signal path
a position of side circuit breaker	PIGO/ GOINGGIO1.-DPCS01.stVal	Phase tripping position TWJA	PROT/ GGIO3 .Ind32
b position of middle circuit breaker	PIGO/ GOINGGIO1.-DPCS05.stVal	Phase tripping position TWJB	PROT/ GGIO3 .Ind33
remote 1-1	PIGO/ GOINGGIO2.-SPCS01.stVal	Remote 1	PROT/ GGIO16 .Ind6
locking reclosing-1	PIGO/ GOINGGIO4.-SPCS01.stVal	Locking reclosing	PROT/ GGIO17 .Ind5

Table 3 Mapping relationship of sampling signal

Process layer signal name	Process layer signal path	Station control layer signal name	Station control layer signal path
current Ia1 of protection A-phase	PISV/SVIN-GGIO5.AnIn1	Measurement of protection	PROT/ MMXU3-A.phsA
voltage Ua2 of protection A-phase	PISV/SVIN-GGIO4.AnIn2	Measurement of starting	PROT/ MMXU10-PhV.phsA
synchronisation voltage Ux1	PISV/SVIN-GGIO4.AnIn7	Protection synchronisation voltage	PROT/ MMXU3-OthV

be unified, take the process layer and station control layer of circuit breaker position, remote transmission and the process of locking reclosing signal an example, as shown in Table 2.

As shown in Table 2, for the circuit breaker location, remote transmission, lock reclosing, and other signals, the station control layer description has been basically fixed. Its process layer model also has a clear name description. We can first determine the station control layer data set content. Then by means of keyword fuzzy matching, in the process of establishing the matching process of the association between station-level and process-level information, the content is decomposed into several keywords. Then compare the keywords to find the matching content, such as ‘circuit breaker position A-phase’ and ‘switch position A-phase’, break down into the words ‘circuit breaker’, ‘position’, ‘A-phase’ and ‘switch’, ‘position’, ‘A-phase’. Then compare the keywords one by one, set ‘circuit breaker’ and ‘switch’ to the same meaning. Multiple keywords in the two feeds have the same meaning, so the two match.

As for the sampling information of the device, since there is no definite regulation at present, the measurement information example and name description of station control layer in different manufacturers is different, and it is difficult to establish the association directly, as shown in Table 3.

As can be seen from Table 3, although the direct mapping relationship is difficult to establish, the name description of sampling information and the description of data object (DO) and data attribute (DA) are relatively clear. Firstly, the content of dataset is determined, by the name description, DO and DA fuzzy matching approach, associate the process layer sampling signal with station control layer measurement information.

5.4 Device functional level virtual data simulation

If localisation protection test is still stuck in the monomer performance and simple open, out of the verification level, it still needs to carry out systematic verification after the equipment is sent to the site. In order to minimise on-site workload, really achieve the goal of site plug and play, replacement maintenance, assembly line testing platform also need to consider the real operating data of simulated scene in the testing process, provide prototype environment of the tested device, and simulate the secondary equipment function logic.

5.4.1 Secondary equipment functional level simulation: In order to restore the real-time operating conditions of the equipment, the test system should be able to simulate the functional logic of the protection device, simulate the intelligent terminal feedback feature, and simulate merger unit sampling characteristics.

- The simulation of bay level protection device functions should simulate device such as differential protection, distance protection, and other functions, receive SV/analog, GOOSE/ switch and other quantity for logical discrimination and action. It send MMS and GOOSE message according to SCD file, to realise the information and logic interaction with the tested device;
- The simulation of intelligent terminal function should be able to set or return the primary device location status or alarm information, achieve locking reclosing and other internal logic simulation, could receive GOOSE control commands, change the primary device state and feedback, to determine and feedback the locking reclosing and other logic;
- The simulation of merger unit function should have the conditions for forming a seTable sample message based on IEC 61850-9-2, and can simulate the function of SV message sending discreteness, data quality, synchronisation status and voltage parallel/switch.

5.4.2 System level testing based on substation prototype simulation system: According to the type of tested device, SCD files and secondary equipment connection, it load and configure virtual protection, virtual merge unit, virtual intelligent terminal, jointly construct the secondary system simulation environment which is same with substation on-site operation environment, and carry out system logic function and interoperability verification. The former mainly include the simulation of typical fault, verify the behaviour of the device under test, and correlates with the correctness of relevant equipment, such as signal interaction and operation time coordination; the latter mainly verify the correctness of the configuration information of the tested device, the cooperation between the virtual terminal and other devices, and provide security for site protection lap.

6 Conclusion

This paper proposed the localisation protection assembly test method, and introduces the design idea, hardware and software architecture, test flow, and key technologies of the test system. On the basis of highly standardised localisation protection, the development of an assembly line test system can automatically locate the tested device, transmission, loading, and closed-loop testing process. At the same time, the system can provide the substation panoramic data operating environment which is based on device function level simulation. It helps to restore the actual operating conditions of device, greatly reduce the on-site debugging time, and realise the protection device of ‘factory assembly testing, on-site replacement maintenance’. Eventually it formed a rapid, automated, normalised, and standardised new model of localised protection device test.

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