Test Method and Data Application of Physical Model of Power Distribution Network

Weixiang Huang¹, Xiaoyong Yu¹, Lifang Wu¹
¹Electric Power Research Institute of Guangxi Power Grid Co., Ltd, Xining City, Guangxi Province, 350012, China
*Corresponding author’s e-mail: huang_wx.sy@gx.csg.cn

Abstract. This paper states the test method and data application of a kind of physical model of power distribution network. After the establishment of distribution automation physical simulation laboratory, the equipment in the platform is effectively controlled and reasonable test procedures are designed. The detailed solution is to record the test process during the physical simulation test. In the design of this test method, the main difficulty is that the data of each equipment at each stage in the system shall be recorded completely during the whole process for physical reduction of transient fault, and to design the interface with the power system simulation software; otherwise, the meaning of the test will be discounted heavily. The on-site operating environment of the distribution network can be restored furthest, all details in the test process can be presented to the testers clearly and intuitively, and the test data can be expanded and applied to provide strong support for technical research and analysis of distribution automation in this way.

1. Introduction
Along with the increasing demand of power consumption, the power system needs the stable power distribution network to distribute the power for the users of each level. Especially the crucial users, they have a extremely strict requirement to the reliability of power supply. Therefore, the power network research personnel have to perform the deep research to the various abnormal status and potential hazards that are possibly occurred under this pressure so as to ensure the reliable distribution network system. In order to realize the above target, the most appropriate method is to build the distribution network simulation system [1], as well as adopt the effective and flexible testing method to comprehensively analyze the influences from fault of various types under 10kV voltage level on the system, and study the properties of power system from multiple dimensions.

Currently there are three kinds of mainstream distribution network simulation testing systems domestically. The first kind is to utilize the digital simulation technology to build the model at computer. Take RTDS for example, each CPU simulates the components of one power system. The real-time communication can be realized among CPU without physical simulation equipment to cooperate with the test. This method is mainly used for the electro-magnetic transient simulation [2][3]; The second kind is to reduce the voltage level of 10kV distribution network simulation system to 400V system through the low-voltage equipment simulation 10kV distribution network equipment, and then connect each low-voltage circuit breakers to simulate the distribution network architecture to build the model. Through the resistor simulates the fault of grounding and short circuit, and using SCADA master station to control the equipment, this testing method is mainly used for the teaching of power system; The third kind is 10kV full-scale laboratory. The equipment and software used in this
laboratory are all built according to the actual distribution network environment. However, it is required to manually execute each testing step and record the results during the test with low flexibility and complex operation, which is applicable to the research of single fault.

Compared with the development and research of domestic distribution network automation, the construction and development period for the distribution network platform at abroad is earlier. Drexel University of America establishes the reconfigurable power distribution automatic and control laboratory at the beginning of 20th century, in which the isolation transformer simulates 4 complete same power distribution stations, and then use ZIP load to simulate the load. In terms of the data part, it uses the upper computer to connect with the equipment controller and realize the instant communication. This laboratory can realize the experiment of multi-phase radiation network tidal current and experiment of network reconstruction etc. with the comprehensive power distribution equipment and functions of system experiment; Japan Distribution Network Laboratory was founded in 2011, it is mainly used for the study on residential power distribution system. The laboratory simulates the user load, battery and photovoltaic system, and forms the micro-network through connecting the power amplifier and power system simulator. It is mainly used for researching the interaction between power network and residential equipment[4].

According to the research on the testing method for the distribution network test platform at home and abroad, this paper designs the testing method of combining with the advantages of above-mentioned several methods. It designs one testing method and data application method of physical model for power distribution network, and its focus relies on the functional design and testing plan configuration for testing modules, as well as automatically storing according to the categories after the system executes and completes the test so as to be used for the evaluation and inversion, and the calculation and analysis of power system simulation software to realize the data application.

2. Test Module and Data Flow Design

Due to the test is designed on the basis of realistic simulation environment of 10kV distribution network, this environment is built by using the simulation equipment of distribution network, and performing the control to each simulation equipment of distribution network through the software platform so as to realize the purposes of test[5]. The implementation and logic control of test are responsible by the test management module of realistic environment simulation software platform, in which the execution of test at least needs the data support of three aspects: First of all, the test module needs the remote signals and telemetry data from various equipment. The data of equipment is the key of performing the test, thus it is required to guarantee the equipment data to be authentic and valid so as to provide the strongest conviction for the real-time service module. The equipment data flows to the front service module through the front service interface, the real-time service module acquires the data from the front service module, which is changed to the equipment real-time data after streamlining to provide to the test management module. Meanwhile, the matter service module acquires the data from the real-time service module, and it is able to obtain the matter information through the analysis to provide the support for the test management; Secondly, due to the power network model is the basis of test operation, it is required to manually draw the power distribution model data according to the actual lines; Finally, the test personnel develop the test plan according to the test purpose, in which they need to specify and configure each test step with the note description. The subsequent test operation can only be implemented after the test personnel confirm all above-mentioned test content.
The test process is shown as Figure 1. The test management module needs to perform the parameter setup or remote operation to the equipment during the execution, it is able to deliver the control order to the front service module through the middleware so as to deliver the control order from front service to the equipment. In addition, after the test is completed, the test module can output the data outwards, in which including the wave data provided for the wave management module, the test process data provided for the external interface, and the test result data provided for the report management module etc.

3. Test Preparation and Plan Configuration

It is required to ensure the distribution network system built by the test platform stays in a status of good operation before the fault injection. If the distribution network system stays in an abnormal operation status, the test will not have the representation, and there is the risk of damaging the test equipment. And then the design of test module needs to focus on considering two points: 1. How to carry out the self-inspection to the test system to ensure the current test system to be in a good preparation status; 2. How to design the test configuration steps to support the implementation of test plan. In terms of the above two difficult points, the test module designs the system self-inspection and test plan configuration, which will be illustrated in this chapter.

3.1. Self-Inspection of System

The system needs to carry out the inspection to the platform itself before each starting with the purpose of ensuring the equipment reliability and personnel safety during the test\(^6\). Thus the design for self-inspection shall be shown as Figure 2, which is composed of the system software self-inspection, communication inspection and environment acquisition confirmation. The self-inspection program performs the pop-up prompt after the users log in the test software. If the users don’t execute the program, it will prompt at the page that the users don’t perform the self-inspection before this test.
(1) System software self-inspection: Operate the self-inspection service through the test order and carry out the scanning inspection to all functional modules in the system so as to prevent the module crash, invalid control etc. appeared during the test due to the software reasons.

(2) Communication inspection: After the self-inspection of software, the system delivers the inspection report to all inferior equipment. First of all, confirm the equipment are all in a normal online status. Secondly check each equipment point automatically to ensure the equipment data is normal, switch is controllable and protection has been put into use.

(3) Environment acquisition confirmation: First of all, the platform monitors the temperature of equipment’s key contacts in real time through the accessory temperature sensor of equipment to prevent the equipment damage caused by the over-temperature of connectors. Secondly, the platforms inspects the switch to stay at the open position through the video signal, and it is required to gradually close switch during the test to avoid the sensitive equipment in the distribution network system to be electriferous directly caused after starting the test. Finally, the platform detects the gas concentration of SF6, as well as ensure the switch control part to be insulated from the outside and prevent the gas escape that will cause the personnel injury.

3.2. Test Plan Configuration
Due to the network configuration of platform is flexible and variable, regardless of the requirements to the network configuration used for the test, it is able to adjust the physical network model status of system according to the needs before the packaging of test. After completing the manual setup, the platform will form the test case. The switching status and load input for various network configurations during executing the test will be loaded according to the preset status. Meanwhile, it is able to confirm whether the configuration of physical network model reaches the testing requirements through the whole-network structural graph. The specific steps are shown as Figure 3.

Figure 2. Detecting Steps before Test

Figure 3. Packaging of Case Configuration

It can be known from the above figure that the researchers need to carry out the network selection, load configuration, fault point configuration before starting the test. It is required to design the above content before the test, and finally perform the confirmation of global graph.
(1) Network Selection

When designing the network, the system will design the code of global graph as ALL, the code of single radiation as SF, the code of single looped network as SH, the code of two supply and one back-up as 2S1R, the code of double looped network as TH. QF is the number of circuit breaker in the whole network. QF=1 indicates the switch on state, and QF=0 indicates the switch off status. Thus the whole-network graph is a general set, that is:

\[ \text{ALL} = \{QF1, QF2, QF3, QF4, \ldots , QF32\}; \]

When the system is switched to the double looped network status, the partial switches are closed, thus the close switches are listed as the set TH. The switches that are reflected in the set are open in default, and then the whole-network graph is shown as Figure 4:

![Figure 4 Whole-Network of Double Looped Network](image)

(2) Load Selection

When restoring the on-site load, the testers will confirm the load quantity and power required to input according to the purpose of test. For example, if the test is performed under the structure of double looped network and four load, the testers need to seek the four simulation load under the looped structure according to the demands, and set up the load as the input status. Secondly, due to the electrical load for the users of power system has the characteristics of being resistive, capacitive and sensitive, the test module has the three-phase parameter of setting up the simulation load so as to restore the electrical conditions of users. Such as:

\[ \text{Load} = \{\text{Resistive Power } a \text{ kW, Capacitive Power } b \text{ kVAR, Sensitive Power } c \text{ kVAR}\} \]

Where, a, b, c represent the fixed power values upon the research and design, which will be invoked by the load configuration module as the option so as to realize the purpose of fast setup.

(3) Configuration of Fault Point and Fault Recording Point

In the physical network model, due to the fault recording device needs to collect the voltage and current waveform of 10kV through PT and CT, along with considering the size and immobility of acquisition device, usually preset the fault simulation device on some representative positions with a rare replacement. In terms of the fault recorder that is as the accessory research tool, it is required to set up the triggering conditions on the fault recorder, and then install the acquisition module in the switch before and after the fault point and the outlet switch of the substation bus. In terms of the parameter setup of fault simulation device, it is mainly required to set up the fault type, fault grounding resistance, fault triggering phase angle and quantity of trigger[7].

(4) Confirmation of Global Graph

After completing the above-mentioned fault parameter, the test configuration needs to be confirmed again manually. However, due to all configuration information that is set up before is all independent, it is required to perform the overall check to all setups at the global graph during the final step of configuration. The steps include: First of all, manually confirm the switch status configured at
the corresponding network structure at the global graph, the software will color the switches automatically according to the status before fault triggering; Secondly, the platform will demonstrate the preset status of all loads, and the testers need to confirm whether they comply with the setup values; Finally, the testers seek the lightening symbol represent the fault simulation point at the graph, and it is able to check the fault configuration injected here\cite{8}. It is able to formally enter the test only after completing the above confirmation steps.

(5) Fault Tolerance Setup

Due to the voltage and current of physical network model have a certain difference from the theoretical values, it is required to set up the allowable deviation scope, that is the fault tolerance setup. It is assumed that the allowable current deviation after inputting load is 1%, and the theoretical circuit current after inputting load is 30A, but the actual circuit current is 30.5A with the deviation value is 0.5A, that is 1.67%. The difference value is larger than the allowable deviation, and it is unable to enter the fault simulation. It will prompt the system is abnormal, and the working personnel need to seek the reasons; If the current deviation is within the scope of allowable deviation, it is able to continuously execute and input the corresponding fault.

In summary, this test method adopts the method of referring to menu for configuration, self-define the selection after classifying the test steps, and the test options can be configured flexibly, which enables the categories of test to become various. Package the test items after completing the configuration to use them for the function test of same equipment of the other manufacturers. Simplify the operation procedures, reduce the possibility of configuration error and enhance the testing efficiency.

4. Monitoring of Test Execution Process

Due to the distribution network system is an integrity, if the fault occurs, the power distribution automation terminal in the system will carry out the corresponding actions so as to enable the system architecture to have changes. Therefore, in order to capture all details of test process, the platform not only needs to directly demonstrate the whole-network status during the process monitoring, but also needs to particularly emphasize the changes of each detail for the test. According to the above demands, the module design of platform during the process monitoring is shown as Figure 5:

![Figure 5. Test Status UI Diagram](image)

The switch on-off and electrical conditions of circuit for the whole-network structure of entire physical network model can be seen from the left whole-network structure graph, this method can directly demonstrate the changes of entire system at most. The top of right side is the name of this test, and the bottom is the current stage of test. For example, “Case Configuration-Network Switch-Load Input-Fault Inversion”\cite{9}, and the current stages of test will be indicated with the special mark. The middle of right side demonstrates the changes of voltage and current for all switches and transformers
from the last stage to current stage by the means of sheet, the changed part at the current stage can be marked with the red font in the sheet of current stage. The bottom is the video images for several key position of this test platform, including the incoming transformer of current stage, incoming switch of 10kV bus, looped network cabinet of 10kV and user transformer etc. The users can check the on-site status through the images and review whether the remote signals uploaded by equipment are consistent with the on-site physical network model.

The properties of this design rely on adopting the master station SCADA function of test software to check the global conditions during the test, and carrying out the reaction to the impact of faults on all equipment through the topological connected relation graph so that the researchers can capture every detail of whole network, as well as identify the potential research subject more easily and perform the deep analysis.

5. Analysis Method of Test Data
In order to reflect the values of test, this method carries out the design from the analysis method of test data, in which it includes the accessory waveform tool and digital inversion tool of test system. It also designs the interface with the simulation software of power system so as to realize the distribution network analysis through the data invocation and avoid the limitation of test.

5.1. Research of Electric Information
The platform software records the information of each stage during the test, thus it is able to perform the load flow calculation and steady-state analysis of power system through these information. In terms of the transient changes generated from the fault, the platform software records the corresponding waveform files, and analyzes through the waveform tool of test module. The waveform tool designed by this test method can make a comparison to the waveform of several equipment at the same moment, and demonstrate the main values (e.g. primary value, valid value, phase angle)\[10\]. Meanwhile, the waveform tool has the functions of sequence component analysis (As shown in Figure 6) and harmonic analysis (As shown in Figure 7), which are used to check the negative sequence component and zero sequence component including the fault information, and understand the harmonic conditions of system so as to enable the researchers to perform the distribution network status analysis more comprehensively\[11][12].

| Parameter | Voltage | Current |
|-----------|---------|---------|
| A         | 004uA   | 001As   |
| B         | 005uA   | 005b    |
| C         | 006uC   | 003c    |

![Figure 6. Sequence Component Analysis of Waveform Analysis Tool](image)
5.2. Research of Digital Inversion

The simulation equipment under the test platform of distribution network in the realistic environment has a higher action frequency than the equipment that is put into operation on site. Although several methods have been considered during the design to ensure the stability of equipment, some repeated tests don’t have necessity of excessive physical inversion due to the same conditions and same faults of inversion. In terms of this test, it is designed to carry out the evaluation on the inversion module by the means of “stepped inversion” after storing the data acquired from adopting the initial physical simulation test.

The so-called “stepped inversion” records every equipment status and parameter change of physical test through the values with time scale to develop the case inversion set, and perform the permutation according to the time. In the digital inversion module, the system can restore the changes among every status, and design all changes as the sequence of steps. This method performs the “low-speed broadcasting” under the situation that the time status switch is short during the test and the action switch quantity is high within short time so as to accurately invert all details of test.

5.3. Data Storage and Application

5.3.1. Storage of Test Data.

When storing the test data, it adopts the parallel method of key flag collection and change set in order to simultaneously consider the accuracy and data volume. As shown in Figure 8, these two methods can be performed when the test system is operating.

1) Key flag collection: The testers can set up the fixed time interval according to the test demands, and the system will carry out one collection to all points during the test at a certain interval.

2) Change set: The system will automatically identify whether the information of collection point at each moment has the valid value changes (relating to the data sensitivity). If the data has changes, the system will record the information of this point in the memory buffer, and it will not collect on the contrary. This method represents that the system can only collect the information data value of collection point for the changes of this time point.
The advantages of key flag collection rely on the complete information of collection point without generating the data loss. The advantages of change set rely on optimizing to store the data volume of collection point. These two methods are complementary in advantages so as to enhance the efficiency of data storage.

5.3.2. Application of Test Data.
The test data can be taken as the data source for simulation software of power system after being stored and analyzed at PSASP platform. In terms of the interface design of test platform and PSASP software, it is required to invoke by making the formats of these two compatible with the focus on how to import the stored data in the basis database of simulation software PSASP.

The simulation software PSASP of power system applies Microsoft Visual FoxPro database, as well as indicates the open-close state with TRUE and FALSE. The test data text applies 0 and 1 to indicate the open-close state of switch. In addition, the data of PSASP database adopts the per-unit value, and the file data of test data text adopts the actual value\[13\]. There two have certain differences. Meanwhile, although the information volume has been minimized during the test storage design and keep the valid data, but the data scale is still not small, thus it is required to take the equipment number subordinated by each information as the only mark to distinguish. There are three steps for the entire data importing method: First of all, adopt the screening method to streamline the data stored in the test platform according to the only mark of data; Secondly, perform the front processing to the screened data before importing; Finally, store the useful data after being processed in the corresponding fields of corresponding data sheet in database. Their relation is shown as Table 1:

| Test Data                  | Position in Test Text | PSASP Numerical Table | Corresponding Field     |
|---------------------------|-----------------------|-----------------------|-------------------------|
| AC Switch                 | Breaker               | Acline.dbf            | i_break or j_break      |
| Capacitive reactor Switch | Breaker               | Acline.dbf            | i_break or j_break      |
| Three-Phase Transformer Switch | Breaker           | Trans_3w.dbf         | break_1 or 2 or 3      |
| Load Active Power         | Energy Consumer or AC Line Segment | Load.dbf          | pl                      |
| Load Reactive Power       | Energy Consumer or AC Line Segment | Load.dbf           | ql                      |
This test method applies SQL Sever database to establish the relation sheet for test data and PSASP when designing the interface\(^{14}\). In the correspondence table, it sets up the corresponding fields to store the test data used for program identification to screen the mark, data pretreatment coefficient and screening mark of test data. When importing the test data in PSASP, it is required initially to distribute the storage space in the memory according to the data category information in the table, and then perform the screening and pretreatment to the test data text data according to the information screening mark and data pretreatment coefficient in the correspondence table. Finally import in the basis database of PSASP according to the correspondence mark through the data interface. The data interface to be used is shown as the “Import Side” in Figure 9, and the import of test data is shown as Figure 10. If the secondary processing is required to the result data export after PSASP calculation, it is required to apply the “Export Side” shown in Figure 9 and perform the secondary processing after exporting the required data from the relevant result database.

![Figure 9. Data Interface](image)

![Figure 10. Import Process for Test Data](image)

The data analysis processing and simulation after the test belong to the function of PSASP platform, in which it includes the functions e.g. static security analysis module, load flow result demonstration module, transient state stable calculation module etc. Although the functions are different, the data invocation methods are similar. This paper takes the transient state stable calculation module for example to make a brief illustration\(^{15}\). As shown in Figure 11, and its steps include:

1. Write the path where its operation database is located in the intermediate file when PSASP is in the system initialization.
2. Record the required data through the data recording module, and store in the database file.
3. Operate the transient state stable calculation. Seek the required operation database file in the path information of intermediate file during the calculation, store the data required for the transient state stable calculation in the basic database in the intermediate database, and carry out the calculation. The simulation platform reads the data in the intermediate database for the calculation, and put the results in the result database file. It is able to check through the transient state stable calculation result module.
Figure 11. Invoke Transient State Stable Calculation

This design establishes the interface with simulation software PSASP of power system through the above-mentioned method, invokes the test data to the simulation software and performs the analysis, that is the effective application of test data. Its properties rely on taking the equipment number as the only mark for screening and processing, and storing in the database of PSASP. Import the data to the calculation model and analysis according to the requirements of research so as to realize the research on on-site fault restored by the test.

6. Conclusion

The physical model test method of power distribution network raised by this paper is designed according to the security principle of test, and guarantee the security through the self-inspection function, system stable judgement function and test module monitoring function. The test process can be observable and controllable, all staged data can be stored, and restore all details of distribution network status during the digital inversion. The test results can be calculated and analyzed at the simulation software of power system so as to realize the deep research on distribution network system.

This test method is designed through the control of physical model and application of test data so as to provide the tool of analyzing and testing the power distribution automation terminal and system for the researchers, which significantly enhances the technical research level for realistic-environment simulation test of distribution network, analysis of fault property and intelligent analysis algorithm so as to lay a solid foundation for the theoretical research, equipment test and technical training of distribution network automation.

References

[1] Liu Dong. Power Distribution Automation System Test [M] Beijing: China Electric Power Press, 2004.
[2] Tang Yong. Current Status and Development for Digital Simulation Technology of Power System [J] Power System Automation, 2002, 26(17): 66-70.
[3] Wu Junhua, Wen Yanjun, Zhao Yue, et. al. Technical Illustration for On-Line Simulation System of Power Distribution Automation [J]. Electric Power Automation Equipment, 2006, 26 (4): 50-52
[4] Lu Jian, Chen Ran, Zhang Guangqing. Discussions on Integral Testing System of Distribution Network Automation, Electronic Technology & Software Engineering, 2016, 1: 159-161.
[5] Liu Dong, Yan Hongman , Ding Zhenhua , et al. Ex-Factory Test of Feeder Automation and On-Site Test Technical Plan [J]. Automation of Power Systems, 2005, 29(3):81-85.
[6] Liu Xiaobao, Study on Security Control Issues and Measures of Power Test, China High Technology Enterprises, 2015, 8, 154-155.

[7] Liu Jian, Zhang Xiaoqing, Zhao Shuren, et. al. Master Station and Secondary Synchronously Injected Power Distribution Automation Fault Treatment and Performance Test Method, Automation of Power Systems, 2014, 38(7), 118-122.

[8] Dong Ming, Zhang Yong, Zhang Yan et. al. Fault Diagnosis and Analysis Model for Power System Containing Electric Quantity Information [J], Automation of Electric Systems, 2013, 37(6): 55-61.

[9] Zhang Yanhui, Zheng Dongliang, Xiong Wei. Discussions on Solutions for 10kV Feeder Automation [J]. Protection and Control of Power System, 2010, 38(16): 150-152, 156.

[10] Liu Tianbin, Wang Yongye, Liu Huanzhang et. al. Fault Analysis Management System Based on COMTRADE Format. Relay, 2001, 29(11): 47-49.

[11] Chen Xiaolin, Luo Yi, Wang Weiping et. al. Protection Property Analysis Method and Realization Based on Fault Recording Data, Power System Technology, 2005, 29(18): 70-74.

[12] Du Yi, Zhang Peichao, Yu Weiyong et. al. Distributed Power Network Fault Diagnosis System Based on Fault Recording Data, Automation of Power Systems, 2003, 31(1): 26-29.

[13] Wang Wushuang, Wang Xiaoru, Huang Fei et. al. Research and Application for Simulation Software PSASP Interface of Power System [J], Power System Technology, 2011, 35(7): 113—117.

[14] Xian Yi, Wang Xiaoru, Liu Yuexian, Li Zeqi, On-Line Application of Simulation Software PSASP of Power System, China Power, 2018, 47(8): 45-50.

[15] Guo Shanghua, Huang Chun, Wang Lei et. al. Detection and Control Method for Voltage Fluctuation and Flicker [J]. Hunan Electric Power, 2003, 23(5): 8-11.