The Application of Voltage Transformer Simulator in Electrical Test Training

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Abstract. The voltage transformer test is an important means to monitor its operating state. The accuracy and reliability of the test data is directly related to the test skill level of the operator. However, the risk of test instruments damage, equipment being tested damage and electric shock in operator is caused by improper operation when training the transformer test. In this paper, a simulation device of voltage transformer is set up, and a simulation model is built for the most common 500kV capacitor voltage transformer (CVT), the simulation model can realize several test items of CVT by combing with teaching guidance platform, simulation instrument, complete set of system software and auxiliary equipment in Changchun. Many successful applications show that the simulation device has good practical value and wide application prospect.

1. Introduction

It is absolutely necessary and very important to carry out preventive tests and acceptance tests for capacitor voltage transformers (CVT) according to provisions, and it is of great significance to give training to corresponding personnel on testing and technical skills so that the test results and analysis are more accurate and valid. However, the possibility of damage to test instruments and tested equipment or electric shock to personnel during the electrical test training for trainees has greatly increased due to the low skill levels of the institute and the improper operations by the operators, posing a great potential safety hazard. Therefore, a kind of simulated training aid for CVT electrical tests, which can ensure personal safety of operators and achieve the testing and training purposes, is desperately needed.

The voltage transformer testing course is one of the educational subjects for substation maintenance and testing of State Grid Corporation of China. In teaching, attention should be paid to object teaching first. Real voltage transformers should be used as teaching aids to stimulate students' thinking, cultivate students' innovation ability and sense of cooperation, help them make bold trials and explorations¹⁻², and lecture centering on theories, which can achieve the best teaching results.

In the training on the overhaul and testing of voltage transformers, we must first understand the internal structure of equipment and its operating principle. As the original state of the current device is that the capacitor components are within the insulated porcelain housing and the electromagnetic unit is within the fuel tank, it is impossible to observe its internal structure and wiring of each part. The voltage transformer simulator described herein overcomes the above disadvantages, and enables trainees to directly observe the internal structure of the CVT.
In the practical training on electrical test skills carried out in China at present, real devices are used for hot-line work in most cases, which has limitations. On the one hand, it is impossible to cut off power supply at any time for training. On the other hand, trainees can not come into contact with various kinds of failure. In contrast, electrical test emulators have greatly lagged behind in terms of their development and use, and are the training methods that have been promoted in recent years. There has been no complete practical training system based on electrical test simulation in China so far. Therefore, the voltage transformer simulator has been developed in order to increase the teaching quality and safety of the practical training on electrical tests and give more operation opportunities to trainees, which upgrades the educational concept, improves the teaching method, transforms the learning method, and increases the teaching quality. This is one of the important measures to push forward the reform of new courses, as well as a necessary means to cultivate students' creative spirit and practical ability\cite{3-6}.

2. Appearance design of voltage transformer simulator

The voltage transformer simulator can not only simulate the situations for preventive tests and commissioning tests in actual production, but also protect the personal safety of testing personnel in the low-voltage environment, which greatly increases the device utilization efficiency. It can be used in the training for the staff who are exposed to high voltage tests for the first time, and enable them to master the work flow and safety measures as soon as possible, with satisfactory training effects and strong application value.

With a single-phase single-pole structure, the CVT is composed of two parts: the capacitive voltage divider and electromagnetic unit. The electromagnetic unit is composed of the intermediate transformer, compensation reactor, and damper that restrains ferro resonance. The reactance value of the compensation reactor is equal to the equivalent capacitance of the capacitive voltage divider at the normal frequency, so that the correct phase and transformation ratio can be produced between the primary voltage and secondary voltage when the secondary loads are different.

The voltage transformer teaching aid described herein is a kind of teaching aid that can help directly observe the internal structure of the 500kV CVT and wiring of each part. It can help clearly observe the structure of each internal part, and simulate the operating state of the CVT, and is easily mobile. The model is composed of 1. Connector; 2. Expander; 3. Visual transparent porcelain housing; 4. Capacitor packet; 5. Visual transparent fuel tank; 6. Secondary terminal box; and 7. Base, as shown in Figure 1. Specifically, the equalizer ring, connector, and expander are connected with the transparent casing, the capacitor packet is fixed within the transparent casing, which jointly make up the capacitance division system. Its lower part is connected with the visual transparent fuel tank, and contains the iron core and the electromagnetic loop system composed of the primary and secondary windings. The visual transparent fuel tank is connected with the secondary terminal box and base. The surface of the equalizer ring, connector, expander and capacitor packet is equipped with the controllable LED lights. The visual transparent porcelain housing, expander enclosure, and transparent fuel tank are all made of imported highly transparent acrylic materials in thickness of 1mm. The enclosure has metal fixation feet around itself, which are connected with base through 4 fixed bolts.

The fuel tank is equipped with the voltage transformer inside. The control box is hung on the outer side of the fuel tank. The control box is equipped with six loops made up of capacitors and resistors in series. Each loop is equipped with the control switch. Specifically, every three groups of capacitors and resistors and the control switch form a parallel control loop, which is connected in series between the head of the primary end of the voltage transformer in the fuel tank and the upper connector of CVT, forming a loop. Likewise, the other three groups of capacitors and resistors and the control switch form a series-parallel control circuit, which is connected in series between the head of the primary end of the voltage transformer in the fuel tank and the δ connector in the secondary connection box, forming a series-parallel connection circuit. The 1a, 1n, 2a, 2n, da, dn of the secondary three coils of the voltage transformer in the fuel tank, the capacitor terminal δ, the X at the end of the primary end of the voltage transformer in the fuel tank, and the corresponding connectors in the secondary connection
box are connected with each other.

In terms of the profile and structure, the voltage transformer simulator described herein has the same appearance, wiring, operating panel, display interface, terminal and identification as the widely used 500kV CVT. It uses the circuit to replace the complicated winding iron core structure, runs reliably, is easy to operate, and can be used to carry out routine CVT tests. The simulator is a kind of device that minimizes operators' exposure to electric shock and damage of devices and instruments, and increases the teaching quality and safety when testing personnel carry out the electrical tests on the tested CVT.

The voltage transformer simulator has been applied in practical training. A large number of applications show that the device can achieve satisfactory teaching results, and greatly increase the training quality concerning voltage transformer tests.

In addition, during the test, the acousto-optic simulator in the simulation teaching aid can also simulate the sound of coronae, and the flash and sound of flashover strike, so that the simulated training site is closer to the effects of the real tests.

The signal transmission of the electrical test simulation system is based on the wireless local area networks (WLAN). Therefore, a number of wireless routers are set in the lobby for electrical test training to form the local area network (LAN), the teaching guidance platform, simulation instruments and simulated tested devices are equipped with wireless signal receivers, and they are included into the LAN to realize interconnection.

The voltage transformer simulator described herein is equipped with the acousto-optic simulator which is used to simulate the sound of coronae, sound of electric discharge and effects of discharge flash in high-voltage test projects, so that the process of the simulated practical training test is closer to the site scenario. It simulates the gradual increase of the sound of coronae when the testing voltage increases gradually. When the current test data received by the test project are the data concerning abnormal discharge of the tested object and the testing voltage increases to the discharge voltage value set, the device will automatically make the corresponding sound of discharge and flash. The acousto-optic simulator is as shown in Figure 3.

The wireless communications are used between the teaching guidance platform and simulation
instrument, which form an integral LAN and realize interconnection between the platform and instrument. The entire system is free from high voltage, and has no faradic electricity and residual charge which hurt people, which reduces potential safety hazards, increases the training efficiency to a greater extent, increases the skill and operational capability of trainees in electrical tests, and truly combines the simulation model for mutual inductor high-voltage equipment with the software simulation training system.

The system is composed of 1 set of teaching guidance platform, 12 kinds of simulation instruments, 6 types of simulated tested devices, integrated system software, LAN, and other auxiliary devices, and can finish 26 electrical test items. All the simulation instruments are almost the same as real instruments in terms of appearance, wiring, operating panel, display interface, etc. The simulated tested devices are also basically the same as real power grid devices in terms of appearance, terminal and identification. Its degree of simulation is similar to or equivalent to the real electrical test process.

The display interface of each simulation instrument may be fed back to the teaching guidance platform in a real-time manner, and teachers may monitor trainees's operations in a real-time manner. A number of sets of normal data and typical failure data are prestored in the test database. Teachers may randomly send a set of data to trainees. In this way, the same test object may be defined as different states (normal or failure state. Meanwhile, data of different failure types may be defined). Teachers may require trainees to analyze and judge the state of the test object according to the test results.

3. Functional design of voltage transformer simulator

As far as the CVT is concerned, the voltage transformer simulator described herein may finish the following tests in training:

1. Measurement of insulation resistance between poles and between secondary windings of capacitive voltage divider;
2. Measurement of dielectric loss and electric capacity of main capacitance and voltage division capacitance of CVT.

Attention should be paid to the following during the test:
1. Relevant provisions of DL408-91 Safety Code of Electric Power Industry (Power Plant and Substation Electrical Part) should be strictly observed during the test in order to ensure personal and device safety;
2. The tested object should be subject to electric discharge after insulation measurement;
3. Attention should be paid to grounding insulation of the test lead at the high-voltage side when the dielectric loss and electric capacity are measured;
4. The 2500V insulation testing set should be used in the measurement of the electrode insulation resistance of the capacitive voltage divider;
5. The ambient temperature and humidity should be recorded at the time of testing. The non-tested windings and terminals should be earthed in the measurement of the insulation resistance of the primary and secondary windings and Terminal N. The correct connection state of each terminal of the intermediate substation should be restored after measurement is finished.

The CVT is mainly composed of the capacitive voltage divider and electromagnetic unit. Structurally, it is divided into the segmental type and stack-up type. As far as the dielectric loss test of the segmental CVT is concerned, as the capacitive voltage divider and electromagnetic unit are both independent, they are not susceptible to external disturbance in the test. Normally conventional methods are used, and the data measured are relatively close to real data. By the structure of the lower-segment capacitor, the stack-up CVT may be divided into the CVT with the center tap terminal and the CVT without the center tap terminal. The former may also be tested with conventional methods at the site, with a high accuracy.
The latter can not be measured with conventional methods, and are normally measured in two ways:
(1) The C1, C2 overall testing method (positive wiring method), which can only measure the overall value of C1 and C2; (2) The self-excitation method, which may measure the value of C1 and C2 respectively. As shown in Figure 4, L is the compensation reactor, T is the medium-voltage transformer, and D is the damping resistance.

Judgment criteria for CVT test results:
(1) Insulation resistance: The value of the electrode insulation resistance of the capacitive voltage divider should not be lower than 5000M ohm. The insulation resistance of the primary winding of the intermediate substation to the secondary winding and earth should be greater than 1000M ohm. The grounding insulation resistance between the secondary windings should be greater than 10M ohm.

(2) Electric capacity: The value of each capacitor should not exceed the rated value by -5% ~ +10%. The test period should be shortened when the capacitor value is greater than the factory default by 102%. The actually measured capacitor value differences between any two capacitors in one phase should not exceed 5%.

(3) Dielectric loss: At the time of handover, it should not exceed 0.0015 for the membrane-paper compound insulation type, and should not exceed 0.005 for the oil-paper insulation type. For the membrane-paper compound insulation type in the operation, it should not exceed 0.003, and it should be subject to enhanced inspection if it exceeds 0.0015, and be replaced if it exceeds 0.003. For the oil-paper insulation type, it should not exceed 0.005, and may be subject to supervised operation if it exceeds such value but does not change obviously compared to historical data and is not more than 0.008.

In conclusion, the voltage transformer simulator developed can not only build up trainees’ field test capability, but also effectively decrease training costs, and ensure the long and frequent use of the teaching aids. The simulation device has the identical appearance as the actual device, and meets the requirements of State Grid Corporation of China for training devices [7-9].

4. Significance voltage transformer simulator in training applications
Advantages of voltage transformer simulator:
(1) The voltage transformer simulator has been applied in practical training teaching, and has produced satisfactory teaching results.

(2) The voltage transformer simulator described herein has the identical appearance as the operational device of CVT in actual substations, which helps trainees establish a concept of the actual device during the operation.

(3) Different from the voltage grade and operation mode of the actual device, the simulation device prevents trainees from getting an electric shock or carrying out misoperations when they are not familiar with the device or test instrument, and increases safety of teaching and training.

(4) The simulation device greatly increases the teaching efficiency, and increases trainees’ ability to analyze and process data.
(5) Based on the voltage transformer simulator described herein, further combination with actual situations is possible for trainees in their subsequent work.

In conclusion, the voltage transformer simulator described herein has remarkable advantages in terms of authenticity, effectiveness, safety, economy, and expansibility etc. Together with the supporting simulated teaching equipment and other auxiliary devices, it has been used to build a more advanced, effective and safer simulated electrical test training system, and has been successfully applied in the training teaching of Jilin Electric Power Training Institute, which has greatly increased the training efficiency and effects, decreased the risks and equipment failure rate in electrical test teaching, and been unanimously recognized by the teachers and trainees.

5. Conclusion
This article proposes and designs a kind of voltage transformer simulator which is applied to the overhaul and tests of the most commonly used 500kV CVT. With the same appearance as the actual device, the simulation device can not only be used to clearly observe the structure and wiring of each part in the device, but also simulate the operating status of the CVT. The voltage transformer simulator described herein can finish measurement of the insulation resistance between poles and between secondary windings of capacitive voltage dividers, as well as measurement of the dielectric loss and electric capacity of the main capacitance and voltage division capacitance of the CVT. The device helps trainees understand the voltage transformer in a conceptual way, and increases the training safety and efficiency. Its multiple successful applications in actual training show that the voltage transformer simulator has good practical value and popularization prospects.

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