The Development and Application of Simulative Insulation Resistance Tester

Jia Yan¹, Chai Ziqi¹, Wang Bo¹, Ma Hao²
¹State Power Company Limited Training Center, Changchun, 130062
²State Grid Tianjin Electric Power Research Institute, Tianjin, 300190

Abstract. The insulation state determines the performance and insulation life of electrical equipment, so it has to be judged in a timely and accurate manner. Insulation resistance test, as the simplest and most basic test of high voltage electric tests, can measure the insulation resistance and absorption ratio which are effective criterion of part or whole damp or dirty, breakdown, severe overheating aging and other insulation defects. It means that the electrical test personnel need to be familiar with the principle of insulation resistance test, and able to operate the insulation resistance tester correctly. At present, like the insulation resistance test, most of electrical tests are trained by physical devices with the real high voltage. Although this allows the students to truly experience the test process and notes on security, it also has certain limitations in terms of safety and test efficiency, especially for a large number of new staves needing induction training every year. This paper presents a new kind of electrical test training system based on the simulative device of dielectric loss measurement and simulative electrical testing devices. It can not only overcome the defects of current training methods, but also provide other advantages in economical efficiency and scalability. That makes it possible for the system to be allied in widespread.

1. Introduction
During the operation of the power grid, the insulating property of electrical appliances has an important impact on the reliability and stability of the entire electrical power system. The decline in insulating property results in performance depreciation or even failure of devices under the working voltage, and may cause power grid accidents in serious cases. Therefore, enhanced monitoring over and testing of the insulating property of devices is required in order to reduce losses in power grids, people and devices etc. caused by the decreased insulativity of electrical appliances[1].

The insulation resistance refers to the resistance value that is produced when high voltage is applied to the conductors at different positions inside the devices, or to the insulation materials between the conductors and earth. Under the impact of the high-voltage DC power, the current that flows through the insulation materials includes the charging current, absorption current and leakage current[2]. With the capacity effect and polarization effect weakened, the charging current and absorption current will gradually taper and eventually disappear. Only the leakage current always exists and its magnitude remains unchanged, which characterizes the conductance parameters of insulation materials. The resistance value after the current is stabilized is the insulation resistance. Its change can effectively and directly help discover any local or overall moist or smudge of the device insulation, as well as such insulating property defects as breakdown and serious overheat or aging, and thus help determine whether the electrical appliances work within the safety indexes. Therefore, as the most fundamental electrical test[3,4], insulation measurement is prescribed as a madatory testing item in
the safety testing for electrical appliances by the metrological law in China, and must be carried out in the works test, commissioning test and preventive test for various kinds of devices, and has priority over other electrical tests as the base\textsuperscript{5-7}.

The insulation resistance tester is specifically used to measure the insulation resistance of an electrical appliance. It is easy to wire and operate, and may accurately measure the insulation value, absorption ratio and polarization index of the tested device, which helps the testing personnel quickly determine the state of insulation of the device. However, due to the operators' skill level, implementation of the standardized workflow, proficiency level in the use of the insulation resistance tester, the accuracy of the measurement result will often be affected to some extent, which may lead to deviation in determining the state of insulation of the electrical appliance. Therefore, operators must receive electrical test skill training concerning insulation measurement, etc.\textsuperscript{8} so as to increase their work efficiency and professional competence, and make the test results and defect cause analysis more accurate and effective.

The electrical test skill training carried out in China so far is mostly in the form of hot-line work on real devices, and has the following disadvantages:

1) High risks. As high voltage is often used in the electrical tests, improper operations in the training may easily lead to damage of the test instruments and tested devices, or even personal injury accidents such as electric shock. In particular, the risks greatly increase for those new employees who are inexperienced.

2) Single state of tested device. In practical training, it is impossible to artificially damage the tested device, and the state of insulation remains invariable. Therefore, the test results are relatively single for the trainees, which restrains trainees from improving their ability to analyze and determine the state of insulation of the devices, with low training effects and efficiency.

3) Comparatively speaking, the simulated training system for electrical tests is a training method for electrical tests that has been promoted in recent years. The electric power simulation device and electrical test simulation instrument may easily simulate various states of devices without the need to apply real high voltage for tests, which has prominent advantages. However, most of experts and scholars have proposed theoretical conceptions only\textsuperscript{9,10}, relevant inventions and applications have developed relatively slowly, and there have been no complete simulated practical training systems for electrical tests in China. Therefore, this article has introduced a kind of simulated circuit-based simulated insulation resistance loss tester which, together with the supporting simulated high-voltage electrical appliance and teaching guidance platform, make up the electrical test training system, so as to increase the effects and safety of the electrical test training, allow trainees to directly observe the operational processes of the electrical tests, and avoid the disadvantages of the existing electrical training methods. Upon examination, this simulated electrical test training system can not only increase the utilization efficiency of instruments and devices, decrease teaching risks, but also greatly increase the training efficiency.

2. Basic conditions
The operating panel of the simulated insulation resistance tester proposed herein is as shown in Figure 1:
The interior of the instrument is composed of such electronic components as the industrial control computer and WLAN card, and the instrument is made up of the test control module, wiring test module, and wireless communication module. Specifically, the test control module simulates the electrical test process of the device, and by outputting the 12V direct voltage, simulates the result of the insulation resistance test; The wiring test module is used to check the wiring at the instrument side and the tested device side during the test; The wireless communication module communicates with the teaching guidance platform and simulated tested device, which transmits the following data:

1) Wiring conditions of the simulated insulation resistance tester;
2) Insulation resistance and absorption ratio of the tested device.

The teaching guidance platform is the control center of the entire simulated training system, with its primary functions as follows:

1) It can be used by teachers to set the parameters of the tested devices, so as to simulate the normal operations and various failure states of the tested devices.
2) It can display the wiring conditions and instrumental operations of trainees in a real-time manner, and keep records and give reminders if it detects any errors.
3) It can display the test results of trainees, compare them to the parameters set, and assess and guide trainees.
4) It can prestore typical data sets concerning test results for ease of training for a large number of trainees.

The supporting tested devices include the simulated voltage transformer, transformer bushing, vertical current transformer, reverse type current transform, capacitor voltage transformer, zinc oxide arrester, and power supply cable, whose insulation resistance and absorption ratio can all be measured with the simulated insulation resistance tester.

The above three parts make up a wireless communication network through the internal wireless communication module or external wireless signal projector, which realizes data interaction among the parts.

During the test, trainees start test connection after finishing preparations, such as personal protective measures, and checking of labor tools and instruments. At this point, the wiring test modules inside the test instruments and tested devices act jointly to test the wiring conditions between instruments and devices, then feed the test results to the teacher guidance platform. Teachers view the wiring conditions displayed on the platform, and meanwhile run the internal procedure to assess the accuracy of wiring. If wiring is correct, teachers set the parameters of the tested devices and remained trainees to start testing. If wiring is wrong, the instrument interface displays the alarm signals and positions with wiring problems. At this point, trainees can not proceed with the next step, and can only carry out tests after they correct the wrong wiring methods.

Measurement starts after wiring is completely correct. The tester interface is displayed on the teaching guidance platform through the wireless communication system in a real-time manner. In this way, teachers may remotely view trainees' setting and operations of test instruments. If their
operations are correct, the insulation resistance and absorption ratio of the tested devices will be displayed after the start button is pressed. If their operations are wrong, the teacher guidance platform will highlight the positions with wrong parameters. Messages on operation mistakes will prompt after trainees press the button at this point, and the test parameters or operation steps need to be adjusted before trainees can proceed.

3. Simulation test

The simulation of measurement of the insulation resistance and absorption ratio of the three-phase 66kV voltage transformer is taken as an example. The instrument operation of this simulation test is described according to the standard workflow of electrical tests.

3.1 Preparations

Before a test, the person in charge of a team[11] should hold a pre-shift meeting to check the personal safety measures and physical and mental state of the testers. After that, they should study the work orders and operation instructions for safety management training. The dangerous points and corresponding safety measures as well as other precautions in the training operations will be emphasized. The person in charge will ask the testers questions to confirm all the dangerous points and safety measures, then the work orders will be signed.

After the testing tasks are determined, the person in charge will divide the work to the testers. A test team is made up of one person in charge, one wirer, one operator and one recorder. The person in charge issues the order and guides the wirer to carry out electric discharge, earthing and visual examination on the tested devices. The operator counts the testing tools and instruments, and checks the safety tools and instruments and test instruments. The recorder sets the safety measures on the site, and keeps records of the nameplates of tested devices and test environment parameters.

3.2 Test process

After preparations are made, the person in charge assigns the wirer and operator to switch on the test power and start test connection.

First the insulation resistance of the low-voltage winding to the high-voltage winding and earth is measured. According to the order of the person in charge, the wirer earths the tested transformer shell, short circuits the high-voltage winding and neutral point to earth and connects the testing wire, and short circuits the low-voltage winding and connects the testing wire. Then the operator connects the connecting terminal "E" to the ground terminal of the tested voltage transformer. The connecting terminal "L" is connected with the high-voltage side of the tested voltage transformer (There is no need to connect the terminal "G", as the indoor humidity meets the requirements, and the external surface of the tested voltage transformer is normal). After confirming that wiring is correct, the person in charge assigns the wirer to remove the discharging rod, and asks all the testers to withdraw from the fence and be ready to start testing. After the operator confirms that the high voltage output switch on the instrument panel is in the OFF state, he switches on the test power. He opens the test instrument, conducts self-checking to make sure it is acceptable, then presses the "View" button, chooses 2500V as the test voltage, chooses 1 minute as the voltage applying time, and asks the person in charge whether voltage applying can start. The person in charge reconfirms wiring and site safety, then issues the order: "Start the voltage applying test." After replying, the operator presses the "On/Off" button on the instrument to start applying voltage. At this point, the operator must put his finger on the "Emergency Stop" button for any contingency. The recorder is beside the operator to keep records and monitor the operator. 1 minute later, the operator reads the insulation value and absorption ratio, and the recorder repeats and keep records of them. The operator presses the "On/Off" button, and unplug the "L" terminated line. The person in charge assigns the wirer to conduct electric discharge and earthing.

The wirer fully discharges the tested voltage transformer, then changes wiring, and connects the earth wire that was connected to the high-voltage winding to the low-voltage winding to measure the insulation resistance of the high-voltage winding to the low-voltage winding and earth, and terminates
the instrument "E" to the low-voltage winding and the instrument "L" to the high-voltage winding. The above test process is repeated. 1 minute later, the insulation resistance and absorption ratio of the high-voltage winding to the low-voltage winding and earth is acquired. After the test is over, the operator presses the "On/Off" button to switch off the instrument. The person in charge assigns the wirer to conduct electric discharge and earthing.

3.3 Test result and analysis

The test result of this insulation measurement of the voltage transformer is as shown in Table 1.

| Figure 5 Low-voltage winding to high-voltage winding and earth | High-voltage winding to low-voltage winding and earth |
|---------------------------------------------------------------|-------------------------------------------------------|
| Insulation resistance (MΩ) | Absorption ratio |
| 20000 | 1.120 |
| 24000 | 1.120 |

The insulation resistance and absorption ratio are respectively 20000 MΩ and 1.120 for the low-voltage winding to high-voltage winding and earth, and 24000 MΩ and 1.120 for the high-voltage winding to low-voltage winding and earth. According to "Q/GDW 1168-2013 Test Specifications for Condition Maintenance of Power Transmission and Transformation Equipment", it is not necessary to consider the impact of the absorption ratio and polarization index when the insulation value is greater than 10000 MΩ. Therefore, the test data are acceptable, and the state of insulation of the voltage transformer is satisfactory.

4. Conclusion and prospect

The above descriptions demonstrate the following features of this simulated insulation resistance tester and the supporting simulated training system:

1) Authenticity. The tested devices and instruments in the entire simulated teaching system are highly similar to the real devices in terms of the appearance and structure. The test connection and test process completely follow the standard workflows of electrical tests, so that trainees can really master the details and safety precautions of the entire process of an electrical test, which helps them get integrated into work as soon as possible.

2) Effectiveness. Setting the parameters of the tested devices helps trainees master various parameter changes and failure types that they may often encounter at work. This can not only increase trainees's ability of analytical judgement, but also expand ways of handling accidents, and help trainees master more practical skills.

3) Safety. The input and output of the devices and instruments in the entire simulated teaching system employ the DC 12V voltage, which not only avoids possible damage caused by the high voltage that is frequently applied to real devices, but also ensures safety of devices and personnel. For new employees, in particular, they may be trained in a large-scale and effective way with extremely low safety risks.

4) Economy. The simulated insulation resistance tester and supporting simulated tested devices are both made up of the enclosure of the real device and the interior industrial control computer. The enclosure structure does not need to bear the mass of the insulation media, so it does not employ high-quality materials, and the interior is made up of the industrial control computer and simple circuits only. Therefore, the manufacturing cost of the device and instrument is relatively low, which is suitable for popularization.

5) Expandability. The supporting simulation devices for this simulated insulation resistance tester include 6 categories of devices and 12 kinds of test instruments, such as voltage transformer and current transformer. The primary equipment such as the capacitor and electric reactor have not been introduced. The simulation device is built on the computer-simulated device characteristics for engineering control. Therefore, only the appearance design of relevant devices and the establishment of simulation models are required if we need to enrich the types of devices and test instruments and expand the instrumental functions. 26 kinds of electrical test training can be carried out at present,
which further increases the training effects.

In conclusion, this simulated insulation resistance tester 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. A number of invention patents are going to be applied for this system so that it can be promoted in more electric power training institutions.

References
[1] Huang Jianhua. Present situation of status overhaul of high-voltage electrical equipment at substations and its development [J]. Transformer, 2002, 39(z1):11-15.
[2] Liu Zhiwan. Features of insulating media and insulating property tests for electrical appliances [J]. Electrical Measurement & Instrumentation, 1994(6):18-21.
[3] Chen Tianxiang, Wang Yinzong, Hai Shijie. Electrical Testing (second edition) [M]. China Electric Power Press. 2008.
[4] Li Jianming. Test methods for high-voltage electrical appliances [M]. China Electric Power Press, 2001.
[5] DL/T 309—2010 Guideline for conducting field tests for power equipment of 1000kV alternating-current system [M]. China Electric Power Press, 2011.
[6] Q/GDW 1168—2013 Test specifications for status overhaul of electric transmission and transformation equipment [M]. China Electric Power Press, 2014.
[7] GB50150-2006 Standards for commissioning tests for electrical appliances in electrical installation works [M]. China Planning Press, 2011.
[8] Gao Nannan, Song Rongwei, Pei Ying et al. Application of 3D simulated training system in professional training on electrical tests [J]. Journal of Shandong Electric Power College, 2014, 17(2):32-34.
[9] Chi Shuangling. Practice of electrical test training in cultivation of electric power talents [J]. China Electric Power Education, 2011(7):120-121.
[10] Zhu Jinhua. Simulated training system for high-voltage electrical tests [J]. Jiangsu Electrical Engineering, 2005, 24(1):36-37.
[11] Working Regulations on Electric Power Safety of State Grid Corporation of China [M]. Substation part [M]. China Electric Power Press, 2009.