Development of three-in-one equipment for withstand voltage, partial discharge and dielectric loss

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Abstract. Many major accidents in domestic and foreign power grids were caused by cable defects, causing huge economic losses and adverse social impacts. At present, the three main tests for cable testing are withstand voltage test, dielectric loss measurement and partial discharge measurement, which require different equipment for testing, which is low in efficiency and time-consuming. Among them, the very-low frequency method is suitable for the withstand voltage test, and the damped oscillatory wave method is suitable for the measurement of dielectric loss and partial discharge. This paper is based on very-low frequency cosine square wave and damped oscillatory wave technology, implements technology integration, and realizes the three-in-one detection of withstand voltage, dielectric loss, and partial discharge for cable.

1. INTRODUCTION

Cross-linked polyethylene (XLPE) cables have become the mainstream of the urban power transmission and distribution network due to their excellent insulation properties, easy manufacture, simple installation and laying, safe and reliable power supply, and low operation and maintenance workload. Due to the harsh operating environment of distribution cables, periodic tests are required to determine their reliability [4]. Many major accidents in domestic and foreign power grids were caused by cable defects, causing huge economic losses and adverse social impacts. Effective detection of cables is of great significance for preventing cable accidents and improving the reliability of power grids. At present, the three main tests for cable testing are withstand voltage test, dielectric loss measurement and partial discharge measurement, which require different equipment for testing, which is low in efficiency and time-consuming. The available test methods mainly include resonance method, direct current method, oscillating wave method and ultra-low frequency method. Among them, the direct current method is mainly used for the withstand voltage test of oil-filled cables. Because of the accumulation of space charge, it is not suitable for the detection of cross-linked polyethylene cables. The oscillating voltage method is effective for partial discharge detection, and can also be used for dielectric loss measurement, but cannot be withstand voltage test, and it is not sensitive to defects such as water trees. The resonance method can meet the withstand voltage requirements, but for the large size and high price of the equipment, it is difficult to be popularized in the cross-linked polyethylene cable withstand voltage test.

So, at present, the three main tests for cable testing are withstand voltage test, dielectric loss measurement and partial discharge measurement, which require different equipment for testing, which is low in efficiency and time-consuming. Among them, the very-low frequency method is suitable for
the withstand voltage test [5-7], and the damped oscillatory wave method is suitable for the measurement of dielectric loss and partial discharge [8-10].

This paper is based on very-low frequency cosine square wave and damped oscillatory wave technology, implements technology integration, and realizes the three-in-one detection of withstand voltage, dielectric loss, and partial discharge for cables.

2. DEVELOPMENT OF THREE-IN-ONE EQUIPMENT

2.1. Working Principle of the Equipment

The working principle of the three-in-one device is shown in Figure 1. During the 0.1 Hz cosine test, the cable is pressurized to the test voltage of 3U₀. After 5 seconds, the charge stored in the cable is discharged through a transfer switch. The discharge process actually charges an LC circuit (composed of cable capacitance, auxiliary capacitance and inductance), followed by the cosine oscillation function of the LC circuit. Make the stored energy reverse charge the cable and reverse the polarity. The conversion slope is similar to a 50Hz sine wave, and has a similar effect to the 50Hz test.

The energy loss during the test is very small, and only a little supplementary charging is required in each cycle. Therefore, compared with the ordinary AC voltage test and other test methods, the high-voltage power supply and test equipment required by this method are very small and light. The resulting 0.1Hz very-low frequency cosine square wave waveform is shown in Figure 2.

When the device is in the damped oscillation wave working mode, the switches S1 and S4 do not work. When the voltage is boosted to the working voltage, the switch S2 is opened and the switch S3 is closed, which forms the damped oscillation wave working mode.

Dielectric loss measurement works in oscillating wave mode. The capacitance value is obtained by calculating the frequency of the oscillating wave, and the resistance value is calculated by calculating the attenuation coefficient to obtain the dielectric loss.

![Figure 1. The working principle of the three-in-one device.](image1)

![Figure 2. Principle of wiring for measuring time interval of electric stopwatch.](image2)
2.2. The Structure of the Equipment
In order to facilitate on-site testing, the design adopts an integrated structure, taking the oscillating wave and very-low frequency equipment as a whole, forming a top-down voltage-dividing structure in the damped oscillation working state, in order to improve the breakdown and creep during the DC charging process Electric voltage, increase the insulation distance from the bottom of the inductor to the shielding box.

The insulating support rod and top plate around the inductor should be as far away from the inductor as possible, at least 5cm away from the inductor. The outlet under the inductor and the position of the switch should be placed. The outlet without the corona should be used to reduce the corona during DC charging. The switch should be placed in front of the inductor to reduce the influence of the strong magnetic field and electric field of the inductor on the switch conduction and partial discharge. The overall structure of the device is shown in the Figure 3.

![Figure 3. The structure of the three-in-one device.](image)

There is no sense of partial discharge, and a top-to-bottom voltage divider structure is formed in the working state to improve the breakdown and creepage voltage of the inductor during the DC charging process. The inductor is wound with enameled copper wire with a diameter of 1m, and epoxy resin is vacuum cast. In order to reduce the parasitic capacitance of the inductance, the segmented continuous winding method is adopted, the segments are connected in series with each other, the distance between the segments is 2cm, and the designed inductance is 0.3H~0.4H. The switch adopts a split structure, which is easy to replace first, and secondly increases the insulation distance. The DC source adopts the cross-linked interlocking control method (cross-linked interlock: because the DC source works alternately, the positive DC source and the negative DC source can only work together. When the positive DC source is working, the negative DC source does not work, press After the emergency stop, the DC source cannot output DC high voltage to ensure personal safety), which is safer and more reliable. The control acquisition system adopts advanced imported components and boards to increase safety and reliability.

The upper and lower integrated structure improves the breakdown and creepage voltage of the inductance during the DC charging process, and reduces the energy attenuation; the wound reactor adopts the method of vacuum pouring epoxy resin to strengthen its insulation performance and mechanical Performance and reasonable anti-corona shielding terminals; the switch adopts a split structure for easy replacement and increases the insulation distance; the DC source adopts a cross-linked interlock control method, which is safer and more reliable; the system acquisition system adopts advanced imported components and boards to increase safety Reliable performance. A design with no partial discharge structure of the ultra-low frequency and oscillatory wave two-in-one device is realized. The appearance of the three-in-one device is shown in the Figure 4.
3. TEST RESULTS

3.1. 0.1Hz VLF withstand voltage test
The device developed in this paper is used to conduct very-low frequency cosine square wave withstand voltage test on the capacitor equivalent to the equivalent length of the cable in the laboratory. The test duration is 20min, the test frequency is 0.1Hz, and the test voltage is 3U0, as shown in Figure 5.

3.2. Dielectric loss test
The device developed in this project is used to perform an oscillation wave dielectric loss test on a 10kV cable. The applied voltage is 0.3U0, the oscillation frequency is 325.19Hz, and the cable equivalent capacitance is 0.32μF. The final test result is that the dielectric loss value is 0.01%, as shown in Figure 6.
3.3. Partial discharge detection and location test
The device developed in this project is used to perform oscillating wave partial discharge and positioning tests on 10kV cables, and the applied voltage is 1U0. The device developed in this project locates the partial discharge, the positioning result is shown in Figure 7, and the defect location is 350 meters. The cable joint at this place was disassembled and the defect was confirmed, which was in full compliance with the test result. The defect is: the wrong use of insulating tape causes the joint to discharge.

4. CONCLUSION
This paper is based on very-low frequency cosine square wave and damped oscillatory wave technology, implements technology integration, and realizes the three-in-one detection of withstand voltage, dielectric loss, and partial discharge for cables. The test result shows that the device fully realizes the designed function. The three-in-one equipment can carry out withstand voltage, partial discharge and dielectric loss tests.

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