Comparative study of 0.1Hz very-low frequency withstand voltage test method and traditional method

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Abstract. The 0.1Hz very-low frequency withstand voltage test method has the advantages of small equipment size and low power demand, and is used more and more in the power grid, especially in withstand voltage test. However, the effect of this voltage waveform and the traditional test waveform on the insulation assessment is still unclear. This paper compares the difference between 0.1Hz very-low frequency and DC voltage, resonance voltage and oscillating wave voltage in the withstand voltage test. Research indicates that the 0.1Hz very-low frequency withstand voltage test has good equivalence in cables with mechanical "faults", water tree defects in cables and power frequency, and relatively poor equivalence in terms of needle plate electrode insulation defects.

1. INTRODUCTION

Cross-linked polyethylene (XLPE) cables have become the mainstream of urban power transmission and distribution networks 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. Many major accidents in domestic and foreign power grids were caused by cable defects, causing huge economic losses and adverse social impacts[1-4].

Effective detection of cables is of great significance for preventing cable accidents and improving the reliability of power grids. The three most important tests for cable testing are voltage withstand test, dielectric loss measurement and partial discharge measurement[5-7]. Different equipment is required for testing, which is inefficient and takes a long time. The available test methods mainly include resonance method, direct current method, oscillating wave method and very-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 it can also be used for dielectric loss measurement, but it 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.

The 0.1Hz very-low frequency test method can meet the requirements of withstand voltage, dielectric loss and partial discharge tests at the same time, and is sensitive to defects such as water trees[8-10]. It is a medium and low voltage cross-linked polyethylene power cable withstand voltage
test recommended by the International Electrotechnical Commission (IEC) technology. However, the equivalence between this waveform and the traditional test waveform is a general concern.

2. VERY-LOW FREQUENCY VOLTAGE WAVEFORM GENERATION AND TEST METHOD

2.1. Very-low frequency voltage waveform generation
The very-low frequency voltage is realized by repeated DC charging and discharging of the cable by power electronic equipment, which is divided into two voltage waveforms: sine wave and cosine-square wave. The cosine-square wave voltage waveform polarity conversion process is a cosine waveform simulated by a power electronic switch. Generally, the frequency of the very-low frequency voltage is less than 1 Hz, and the most commonly used is 0.01~0.1 Hz. The typical very-low frequency voltage waveform is shown in Figure 1.

![Waveform Diagram](image)

Figure 1. Typical very-low frequency voltage waveform

2.2. Very-low frequency voltage test method
Based on the actual operation and maintenance experience of North American cables, IEEE has given the recommended voltage value of 0.1 Hz very-low frequency withstand voltage for cables with voltage levels of 69kV and below. The typical values of the selected parts are shown in Table 1. The very-low frequency withstand voltage time is usually 30 minutes, and it can be appropriately extended to 60 minutes on some important cable lines. When the cable line is long, the frequency can be appropriately reduced to reduce the reactive power demand.

| Voltage (kV) | Sine | Cosine |
|-------------|------|--------|
| 8           | 13   | 18     |
| 20          | 26   | 37     |
| 35          | 44   | 62     |
| 69          | 84   | 119    |

3. EQUIVALENCE ANALYSIS OF CROSS-LINKED POLYETHYLENE CABLE WITHSTAND VOLTAGE TEST
At present, domestic and foreign cross-linked polyethylene cable withstand voltage test methods mainly include: traditional power frequency series resonance (50Hz) variable frequency series resonance test (30-300Hz) oscillating wave voltage test (kHz), 0.1Hz very-low frequency withstand voltage test (0.1 Hz) these categories. Regarding the equivalence of the XLPE cable withstand voltage test under these types of frequency conditions, the relevant article of the ISH99 London conference
gave the results of the breakdown voltage study of the XLPE power cable at different frequencies, different waveforms and different types of faults. as shown in picture Figure 2.

From the figure, the power frequency series resonance has the best power frequency equivalence under different defects, followed by the frequency conversion series resonance test, but there are relatively large reactors in both the power frequency series resonance and the frequency conversion series resonance test. And the high-voltage excitation transformer, so the equipment is relatively heavy and expensive, and the equipment of the same capacity has the shortest detection electricity, which is not suitable for long-distance cable maintenance; the oscillation wave voltage test has short action time, small equipment size, good mobility, and cable The test has the characteristics of no damage, but it can be seen from the figure that it has the worst equivalence with power frequency, especially the equivalence is not very good in terms of needle tip and water tree insulation defects. CIGRE WG21.0 also pointed out that although the oscillating wave test method is worse than the DC withstand voltage test, it is not as effective as the power frequency test.

The 0.1Hz very-low frequency withstand voltage test has good equivalence in cables with mechanical "faults", water tree defects in cables and power frequency, and relatively poor equivalence in terms of needle plate electrode insulation defects, and its equivalence is 4 Centered in the class. This fact has also been confirmed by the German electric power department. In their large number of practical tests, they also found that the 0.1Hz very-low frequency withstand voltage test is very effective in detecting mechanical "faults" and water tree defects in XLPE power cables. Because it is not only effective for defect detection, but also has the characteristics of small size and good mobility of the oscillation wave voltage test equipment, so many countries including the United States and Germany are currently developing and researching very-low frequency withstand voltage test equipment.

The test results of Kalkner et al. of the Technical University of Berlin showed that the growth rate of electrical tree defects of 0.1Hz ultra-low frequency cosine square wave and sine wave reached above 7.8mm/h, which is the electrical tree defect growth rate of 1.7mm/h in power frequency withstand voltage test More than 4 times of h, it is considered that the ultra-low frequency voltage is a better test method for exposing the defects of XLPE cables[11]. Japanese scholar Katsumi Uchida et al. carried out the withstand voltage breakdown test of power frequency, DC voltage, 0.1Hz ultra-low frequency voltage and 1.7kHz oscillating wave voltage on various cable defects made, and found that different defects are in these 3 voltages. Under the breakdown voltage (peak) and power frequency (peak) equivalent coefficient radar distribution graph[12]. German scholar E. Gockenbach and others used 0.1Hz ultra-low frequency, 50Hz power frequency, 250Hz series resonance voltage and oscillating wave voltage to test needle plate electrodes, non-defective cable samples, mechanically defective cable samples and water tree defective cable samples. In the withstand voltage test, the relative breakdown voltage of the four test methods based on the breakdown voltage of the 50Hz non-defective cable was obtained[13]. Luo Junhua of Xi’an Jiaotong University and others have conducted parallel comparison breakdown experiments of power frequency, DC, oscillating wave and ultra-low frequency voltage on XLPE cables with artificial simulation defects and actual operating defects respectively, and determined the other three test methods for the first time. The equivalent coefficient of the power frequency voltage test method and the breakdown voltage of each defective medium [14].
Some studies have found that the strength of the cosine square wave for insulation is insufficient. The test shows that under the condition of the needle plate electrode model, the strength of the 0.1Hz cosine square wave voltage to the cable withstand voltage is significantly lower than the power frequency voltage. When the power frequency voltage is at 2U₀ voltage and 60min breakdown time limit, the defect of 0.5mm insulation thickness can be found, while the 0.1Hz cosine square wave voltage can only find the defect of 0.2mm insulation remaining thickness under the action of 2.5U₀ voltage. 349min. As mentioned earlier, the insignificant cumulative effect of the 0.1Hz cosine square wave voltage may be one of the reasons why the strength of the 0.1Hz cosine square wave voltage to the cable withstand voltage assessment is significantly lower than the power frequency voltage. The reduction of the combined electric field intensity caused by the space charge injected in the DC phase of the cosine square wave may be another reason for the above phenomenon.

Taking 0.5mm residual insulation thickness as an example, simulation calculation shows that under the action of 2.5U₀ voltage, the electric field strength at the needle tip position exceeds 300kV/mm, which is much higher than the space charge injection field strength of 30kV/mm XLPE material. The injection of space charge is affected by the strength of the electric field and the time of action. Due to the high field strength at the defect location, even though the injection time is only 5s, there will be considerable space charge injection, which will significantly reduce the actual field strength at the defect location.

But in the phase of polarity change, the voltage on the defect is reversed and the space charge injected under the action of the last polarity voltage forms an electric field superimposed, which increases the actual electric field in the defect. The above two processes will make the combined field strength of the defect position under the action of the cosine square wave voltage as shown in Figure 8. Its characteristic is that in the DC voltage stage, the combined field strength is lower than the original field strength when space charge injection is not considered, while in the polarity change stage, the combined field strength is higher than the original field strength when space charge injection is not considered, which is an assessment of insulation It is mainly reflected in the polarity conversion phase, which is consistent with the experimental phenomenon that the cosine square wave breakdown time is mainly in the polarity conversion phase.

4. TEST PROCEDURE
Separate all the electrical equipment connected with the test cable from the test cable, and use bare copper wires to reliably ground the grounding electrodes of the test equipment and test cable. Record the test environmental conditions.

Use a 10000V megohmmeter to conduct insulation resistance tests on each phase of the cable under test, and record the test values.

Peak test voltage: 3U₀; test time: 60min.
When the capacitance of the test cable is within the load capacitance capacity of the test equipment, the three cores of the test cable can be connected in parallel, and the withstand voltage test to the ground at the same time.

Connect the test equipment with the test cable with a flexible connecting cable, and turn on the power supply to start the test. During the boosting process, closely monitor the high-voltage circuit and monitor whether there is any abnormal noise in the cable of the test product. When the test voltage is increased, the test time will be recorded and the test voltage value will be read.

After the test time is up, first reduce the voltage to zero, then cut off the power supply and connect the grounding wire. If no destructive discharge occurs during the test, it is considered to have passed the withstand voltage test.

In the process of boosting and withstand voltage, if it is found that the pointer of the voltmeter swings greatly, the indication of the ammeter increases sharply, and the boost value of the voltage regulator continues to increase. The voltage is basically unchanged or even shows a downward trend, while the current increases by a large amplitude. If there are phenomena such as peculiar smell, smoke or abnormal noise or flashover, stop boosting immediately, and find out the cause after the voltage drop and power failure. If these phenomena are found to be caused by the weak insulation of the cable of the test sample, the withstand voltage test is considered unqualified. If it is determined that the test cable is caused by air humidity or surface dirt, the test cable should be cleaned and dried before the test.

During the test, if the power supply is lost due to the insulation defect of the non-test sample cable, the test is interrupted. After the cause is found to restore the power supply, the full-time continuous withstand voltage test shall be performed again, and the supplementary time test shall not be performed only.

5. CONCLUSION
This paper compares the difference between 0.1Hz very-low frequency and DC voltage, resonance voltage and oscillating wave voltage in the withstand voltage test. The 0.1Hz very-low frequency withstand voltage test has good equivalence in cables with mechanical "faults", water tree defects in cables and power frequency, and relatively poor equivalence in terms of needle plate electrode insulation defects.

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