How to Use the OSW Voltage in the Measurement of XLPE Power Cable

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Abstract: The paper presents a kind of oscillating wave voltage test system based on oscillating wave theory and its research status at home and abroad and discusses its application in the withstand voltage test and PD detection of power cables. It is proved that the oscillating wave voltage and AC voltage have good equivalence. Compared with AC voltage and ultra-low frequency voltage (0.1Hz), it has some advantages such as shorter operating time and easy to operate and so on. It can find most kinds of defects in the XLPE cable effectively and does no harm to the cable.

Key words: oscillating wave voltage, XLPE power cable, withstand voltage test, partial discharge (PD)

Introduction

The XLPE cable is widely applied in the electric system but it is extremely difficult to conduct the power frequency withstand voltage test on site. It becomes a key problem which needs to be fixed urgently. In the past, the DC withstand voltage test was used for oil-filled cable, minimizing the requirements for power supply. The XLPE electric cable has high insulation resistance and the voltage distributes differently at AC or DC. After the DC withstand voltage test, a large quantity of space charges left at the cable defect especially in the XLPE cable. After the cable is put into operation, space charges often cause insulation breakdown of cables. Studies have shown that it is not suitable to use DC voltage to carry out the withstand voltage test for XLPE cable.

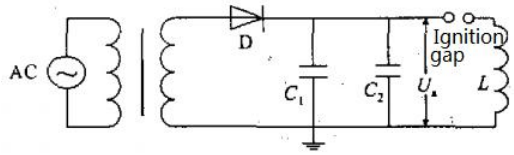
As for the ultra-low frequency (ULF) voltage, the test time should be long; the damage to cable insulation is big, which may cause new defects in the cable. The variable frequency resonant voltage generator can address the problem of power capacity. In addition, the test voltage and power frequency voltage have equivalence. However, its volume is large and it is heavy so it is difficult to realize on site.

The oscillating wave (OSW) voltage is a kind of voltage used for measuring the voltage of XLPE cable, which has been much studied in recent years. Advantages are as follows: ① The operation time is short; ② it is easy to operate and carry; ③ most kinds of defects can be detected in the XLPE electric cables and no damage to cable can be caused in the test. At present, relevant standards about using OSW

measuring system to do withstand voltage test are being made by IEEE and some countries.

1. Generation of OSW Voltage

The OSW device is based on the L-C resonant principle. There are 2 kinds of generating circuits, which are shown in Fig.1 and 2.



C_1: charging capacitance

C_2: equivalent capacitance of cable

L: inductance coil

Fig.1 Test circuit of oscillating wave voltage

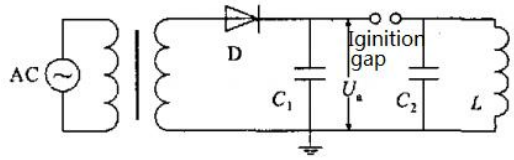


Fig.2 Test circuit of oscillating wave voltage

In the first kind of test circuit, C_1 and C_2 charge in parallel and then discharge to inductance coils. The maximum voltage (U) is equal to the charging voltage (Un). The frequency of power supply is listed:

$$f = 1/2\pi\sqrt{L(C_1+C_2)}$$

In the second kind of testing circuit, the AC high voltage is rectified through the rectifying conduit and then charges C_1; discharges to parallel circuit C_2 and L through ignition gap.

$$f \approx 1/2\pi\sqrt{L(C_1+C_2)}$$

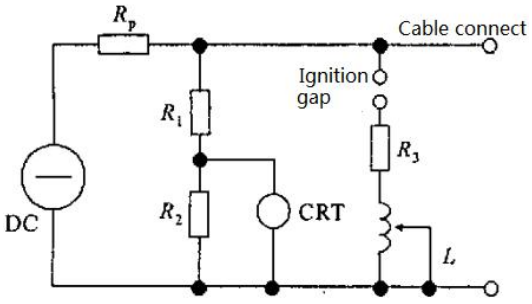
$$U = U_u C_1/(C_1+C_2) < Ua$$

Hence, the C_1 should be big enough to make the voltage of cable high enough.

J.Y.KOO studied the two models and obtained the OSW under two kinds of circuits. When the cable is C_1, all kinds of waveforms do not distort even because of difference in the length of cables; there is no difference in the waveforms of both ends; it is also observed that the shift current increases as the length of cable increases. When the cable is not engaged in the process of charging, the first impulse of generated OSW has obvious overvoltage; its amplitude is proportional to the length of cable; compared with the waveform of head end, waveforms of tail end attenuate and distort obviously; as the cable is longer, the distortion becomes severer. Hence, when the cable is charging, the OSW is more smooth and practical without overcurrent and distortion.

2. Withstand Voltage Test for XLPE Electric Cable

The AC, DC voltage, ULF and OSW are applied to carry out withstand voltage test for XLPE electric cable. The circuit of OSW test is shown in Fig.3. The frequency of OSW is designed between 5 and 6kHz.



R_p: protection resistance

R_1&R_2: resistance voltage divider
CRT: oscilloscope
R_3: damping resistance
L: adjustable inductance
Fig.3 Oscillating wave voltage test circuit

The AC and DC voltage 0.1HzULF and 5~8kHz OSW are used to withstand to verify the equivalence of cables. Those cables have operated for 12 years and large quantities of water trees exist. The equivalence factor K=Ux/Uac. Results are shown in Tab.1.

Tab.1. Equivalence of AC voltage

Defect type	U_{dc}	U_{ac}	U_{vlf}	U_{owv}
Needlepoint	4.3	1	1.5	1.5
notch	2.8	1	2.6	1.1
Mental protrusion	3.9	1	2.2	1.6
Water tree	2.6	1	1.2	1.4

Based on the Tab, it is found that DC and AC voltage do not have equivalence. The K value of OSW test is evenly distributed between 1.1 and 1.5. It indicates that defects of cable media can be fully detected and have good equivalence with AC voltage. The K value of ULF test varies between 1.2 and 2.6 because of the difference in defect. Its equivalence with AC voltage needs further research.

The OSW and ULF voltage were studied by Katsumi Uchida et al. Two kinds of defects are set on the XLPE cable (shown in Fig.4). Results of withstand voltage test are shown in Fig.5. When applying the OSW, electric tree's inception voltage of 2 kinds of defects is far less than breakdown voltage; under the influence of ULF, electric tree's inception voltage of 2 kinds of defects is close to breakdown voltage, that is, the breakdown occurs following electric tree; when using the voltage superposition method to do the test, the inception and breakdown voltage of electric tree are much less than those at ULF. The comparison of the above three methods indicates that it is more convenient to realize OSW and its result is close to AC voltage.

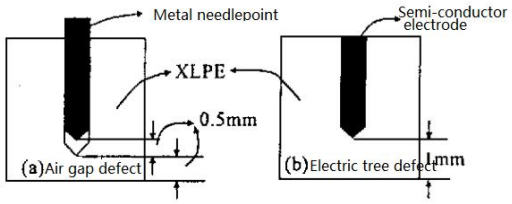


Fig.4 Two kinds of man-made defects in XLPE cable

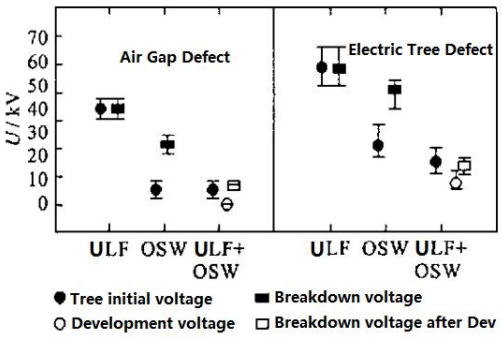


Fig.5 Influence of the voltage form on the test results

3. PD Measurement of XLPE Cable

Now, the PD measurement serves as one of methods to judge insulation conditions of XLPE cable at home and abroad. Methods mainly include finite difference method, capacitive sensor method, coupling sensor method and current sensor method.

3.1 Comparison of PD characteristics at OSW and AC voltage

The PD characteristics at OSW and AC voltage are compared by Edward Gulski et al. The schematic diagram of test system is shown in Fig.6.

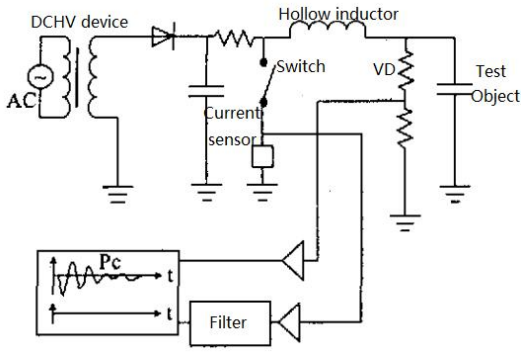


Fig.6 Schematic diagram of OWT

Tab.2 presents the comparison of inception voltage and PD quantity at AC voltage and OSW under the conditions of the same test object and defect. Except wrong installation of stress hammer, as for other two defects, the PD inception voltage at OSW is more than AC. What is more, at OSW the wrong installation of stress hammer is sensitive. For different defects, there is difference in PD inception voltage under OSW. Even if inception voltage is similar, Q is different. The PD type and position can be found out through these elements.

Tab.2

Defect	AC50Hz		OWTS1066Hz	
Wrong connection between hammer and semi-conductor	U_{inc}/kV	Q/pC	U_{inc}/kV	Q/pC
	2.6	25	3	30
Wrong installation of stress hammer	15	20	13	40
Inner hole	13	150	14	70

In the test, the PD quantity of the same test object (3235m, 50kV three-phase cable) at different levels of voltage is shown in Tab.3. From the table, it can be seen that different phases of test object have good equivalence at different voltage levels.

Tab.3 PD quantity of the same test object at different voltages

Voltage	12 kV			16 kV		
	A	B	C	A	B	C
AC 50 Hz	450	370	500	850	700	770
OWTS 220 Hz	500	450	650	950	850	900

3.2 Influence of OSW frequency on PD

The oscillating wave measuring system is used to perform on-line detection of electric cable; the influence of frequency of oscillating wave on inception voltage and PD quantity is shown in Fig.7. From Fig.7, the PD inception voltage at OSW is more than at AC; the reason is that OSW time is short and quantity of PD at different frequencies is greater than at AC; the frequency of OSW does not affect the PD inception voltage; the PD inception voltage for all frequencies at OSW is the same; the OSW frequency is in inverse proportion to quantity of PD. In other words,

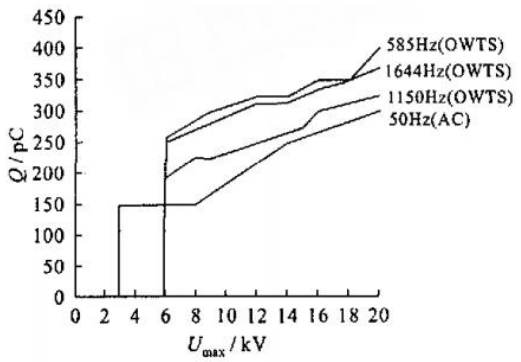


Fig.7 PD inception voltage and PD quantity at power frequency and OWTS

3.3 PD location

There are two methods to obtain the PD location: traveling wave method and drawing a diagram via q measurement at different positions. At present, the latter method is adopted for PD location of OSW measuring system at home and abroad. Fig.8 and 9 present the PD location diagrams by using OSW and AC voltage. The test object is 840m oil-paper cable, which has operated for 17 years. The rated voltage is 10kV. It can be seen that the PD occurs at the joint between 100m and 200m and the two methods is equivalent to determine the position of PD source.

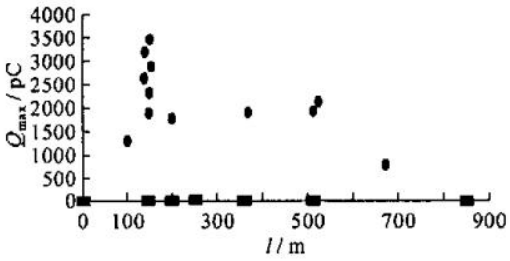


Fig.8 PD location diagram by using AC voltage

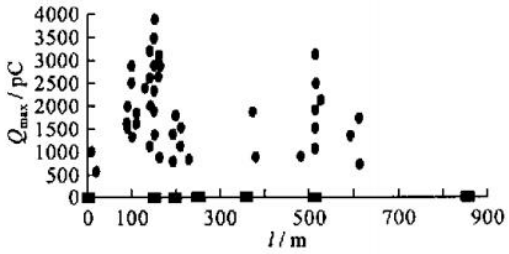


Fig.9 PD location diagram by using OWS

4. Conclusions

a) The equivalence of oscillating wave voltage and AC voltage's insulation test is good. The operating time of OSW is short and it is easy to operate. Even if the applied voltage exceeds the limit, no new defects will be caused. It is effective to use the OSW voltage to detect air gap defects and other left defects; there is a certain difference between inception voltage and breakdown voltage. Hence, the OSW voltage is a ideal method.

b) The results of PD location at oscillating wave voltage and 50Hz AC voltage are consistent, showing the equivalence between OSW voltage and AC voltage. At OSW voltage, there is no relation between inception voltage and OSW voltage frequency. However, as the frequency declines, the PD quantity increases. Through reasonable selection of OSW voltage frequency, the XLPE PD can be detected. It has some advantages such as shorter operating time and easy to operate and so on. It can find most kinds of defects in the XLPE cable effectively and does no harm to the cable.