Statistical Characteristics of Partial Discharge Caused by Typical Defects in Cable Joint under Oscillating Voltage

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Abstract: The oscillating voltage test is a nondestructive detection method for partial discharge of XLPE (cross linked polyethylene) cable and has been applied recently. This paper made three kinds of varying severity artificial defect models of cable joints in 10 kV XLPE cable. Oscillating voltage is applied to the model, by use of pulse current method to detect partial discharge signals. In order to study the statistical characteristics of partial discharge of cable joint under the oscillating voltage, three-dimensional statistical map has been made. The results show that for the same kind of defects, with the increases of the defect severity, the discharge interval extended, the magnitude and the number of partial discharge increase, for different kinds of defects, obvious differences exist among the maps, this may established a foundation for the further study of the partial discharge pattern recognition of XLPE cable under oscillating voltage.

Key words: XLPE cable, cable joint defect model, partial discharge, oscillating voltage, three-dimensional statistical map.

1. Introduction

With the advantage of simple process, reasonable structure and excellent electrical performance, XLPE (cross linked polyethylene) cable has gradually replace the traditional paper oil insulation cable and widely applied around the world. Bad construction technology, artificial destruction and severe environment may cause insulation defect after cable leave factories, especially for the cable accessory defect, which will affect its insulating property [1].

Researches have shown that, the severity of partial discharge in XLPE cable can indicate the change of its insulation state. Partial discharge test is recommended as the main diagnostic method of the XLPE cable insulation by international authority such as IEEE (Institute of Electrical and Electronic Engineers) and CIGRE (International Council on Large Electric Systems) [2, 3].

It has been found that it is difficult to carry the partial discharge test for the power source is usually too big because of the long length and high equivalent electric capacity of XLPE cable [4]. The current XLPE cable handover and preventive test such as ultra-low frequency voltage (0.1 HZ) method and DC (direct current) voltage method cannot work effectively in the off-line partial discharge detection test, because they all need long action time and may cause other defects [5, 6]. However, OWTS (oscillating wave testing system) is now widely used in partial discharge detection in the off-line state of XLPE cable [7, 8]. This method has advantages such as short action time, harmless to the insulation and its voltage waveform meet the demand of IEC (International Electrotechnical Commission).
testing voltage characteristic. Due to the favorable equivalence to power frequency voltage, oscillating voltage has been widely applied as it could accomplish the cable insulation defect test under the circumstance similar to power frequency. Studies have shown that the application of OWTS mainly concentrates on the detection and locates of cable insulation defect, but the research on the statistical property of partial discharge signal under the oscillatory wave is insufficient [10-14]. This paper made three kinds of varying severity artificial defect models of cable joints in real 10 kV XLPE cable, oscillating wave testing system is used to carry out partial discharge test. In order to study the effectiveness of partial discharge test in detecting cable defect and the characteristic of partial discharge signal under oscillating voltage, three-dimensional statistical map of the partial discharge is made to analyze the data.

2. Testing Circuit and Defect Making

2.1 Oscillating Voltage Testing Circuit

In order to study the characteristic of partial discharge signal under oscillating voltage, the testing adopt oscillating wave testing system to generate oscillating voltage, three kinds of varying severity artificial defects on the cable joint which is of high fault rate are made at the same time.

As shown in Fig. 1, the OWTS constitutes of high voltage DC source, resistance \( R \), no halo reactor \( L \), high voltage switch \( S \) and test cable, etc. The basic principle of oscillating voltage test method is to build an L-R-C (inductance-resistance-capacitance) underdamped oscillator circuit with inductance \( L \), resistance \( R \) and the equivalent capacitance \( C \) of the test cable [15]. According to the state of switch \( S \), the generation of oscillating voltage can be divided into two stages. First, off state of high voltage switch \( S \). High voltage DC source, no halo reactor \( L \) and test cable \( C \) will act as a DC circuit till the cable reaches the preset voltage. In the second stage, the high voltage switch \( S \) immediately closed when the preset voltage is reached. The equivalent capacitance \( C \) of the cable, inductor \( L \) and the resistance \( R \) formed an LRC underdamping oscillation circuit and generated oscillating voltage. The decay rate of oscillating voltage is rather high which only last for about 20-30 ms, however, it is enough to stimulate the partial discharge signal in the cable insulation defects without destroy the cable at the same time. A sensor is used to collect the partial discharge signal, the cable insulation detection could be accomplished [16].

2.2 Defect Making

The testing cable is copper core with cross-linked polyethylene insulation tape armored PVC (polyvinyl chloride) sheathed flame-retardant power cable, the type is ZC-YJV22, with rated voltage 8.7/15 kV and specifications is 3 × 70 mm². The testing cables all are new cable have not been put into operation, before made detect. In order to guarantee the unicity of test variable, we made artificial defect model in cable joint after the testing cable has been confirmed that there is no partial discharge with OWTS partial discharge test. Three kinds of typical artificial defects are made separately at the middle of three 8-m cables with cold shrink joint. The armor layers and copper shielding layers of XLPE cable joint were well-connected. The specific defects are show in Figs. 2a-2c:

(1) Air gap in outer semi-conductive layer defect: the poor quality of cable or improper over stripping of outer semi-conductive layer may cause air gap. As shown in Fig. 2a, this defect can be simulated by scraping 5 mm, 10 mm and 17 mm gap on the outer semi-conductive layer;

(2) Metal cusp at high potential defect: to simulate metal particle mixed on the core between insulation and compression coupling by accident, twin copper wire on the surface of core to form 2 mm, 3 mm and 5 mm tips. It is showed in Fig. 2b;

(3) Too short or long lap of stress cone defect: simulate the improper installment that cause too long or
short lap of stress cone and outer semi-conductive layer. As shown in Fig. 2c, phase A represents too short lap of stress cone by 40 mm, phases B and C represent too long lap of stress cone by 12 mm, 17 mm.

3. Oscillating Voltage Test

The test cable was connected to OWTS by high voltage connection cable, the copper shielding layer joined OWTS grounding by one-point grounding. Calibration of discharge quantity is required for the test of partial discharge in XLPE cable. To get a more accurate apparent discharge magnitude, the test cable was injected by different quantity of calibration pulse signal by partial discharge calibrator after the testing circuit is connected. According to electromagnetic wave theory, the incident calibration pulse will refracted and reflected when it reached the end of cable. The calibration of apparent discharge magnitude could be realized by figuring out its calibration factor extracting peak value of incident and reflected impulse.

Partial discharge test starts when the calibration is done. Applied oscillating voltage to main insulation of XLPE cable, increase voltage by step and the voltage should be no more than 2.0 $U_0$. Select two voltage classes above the partial discharge inception voltage to collect partial discharge signals. One hundred partial discharge tests had been done for each voltage class and the data have been saved for further analysis.

4. Test Results Analysis

To study the statistical property of partial discharge signal under oscillating voltage, three-dimensional statistical maps which base on statistical method for oscillating voltage phase feature are built for the three defects [17]. It is shown in Figs. 3-11.

By comparing the three-dimensional statistical maps of the same kind defect, for the defect of air gap in outer semiconductive layer, the severity positive increase with the length of air gap. The partial discharge inception voltage drops from $0.9 U_0$ to $0.7 U_0$ together with larger magnitude and number. For the defect of high potential metal tip, its discharge magnitude is little less than the former one while the defect of stress cone is the lowest one which has positive increase with the malposition.

By comparing the three-dimensional statistical maps of three different kinds of defects, the developing process as well as the shape is vary from each other. The higher voltage classes, the larger magnitude and number of apparent discharge magnitude in partial discharge. Air gap in outer semiconductive layer and high potential metal tip, these two defects has rather acute partial discharge under high voltage classes. The bimodal characteristics showed up in corresponding maps, which based on the statistical method for oscillating voltage phase feature is a result of the amplitude in different period changed its phase when
Fig. 3  Phase A of air gap in outer semi-conductive layer defect.

Fig. 4  Phase B of air gap in outer semi-conductive layer defect.

Fig. 5  Phase C of air gap in outer semi-conductive layer defect.

Fig. 6  Phase A of metal cusp at high potential defect.
Fig. 7  Phase B of metal cusp at high potential defect.

Fig. 8  Phase C of metal cusp at high potential defect.

Fig. 9  Phase A of too short or long lap of stress cone defect.

Fig. 10  Phase B of too short or long lap of stress cone defect.
the oscillating voltage attenuation. For the defect of stress cone, it has not show bimodal characteristics because the apparent discharge magnitude and number of partial discharge is quite small.

5. Conclusions

This paper make three artificial defects in the joint of 10 kV XLPE, oscillating voltage is applied to the test cable and partial discharge signal which caused by defect has been detected. The three-dimensional statistical maps for partial discharge signal are made, statistical property of partial discharge under the oscillating voltage has been studied, conclusions are as below:

(1) Oscillating voltage can stimulate the partial discharge of defect in the cable joint, and can detect it effectively;

(2) Partial discharge will become severe when the oscillating voltage amplitude become larger, obvious bimodal characteristics can be seen in the three-dimensional statistical maps at the same time;

(3) The distinguish differences lie in three-dimensional maps of three defects may lay a foundation for the further research in pattern recognition.

References


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