Diagnosis of partial discharge defects of 35kV cable joint based on high frequency and oscillating wave detection technology

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Abstract. Combining with a cable test case, this paper introduces the process of locating and diagnosing a partial discharge defect in the middle joint of 35kV cable by using high frequency and oscillating wave detection technology, and analyses the characteristics of partial discharge signal, and puts forward some suggestions for the later test.

1. Introduction

With the development of signal sensing and processing technologies, different wireless monitoring and fault detection is diagnosed using microwave sensor technologies. In recent years, a variety of detection methods have been developed for the detection of partial discharge electrification of cables, mainly including acoustic emission method and electromagnetic coupling method. According to the type of sensor used, the electromagnetic coupling method can be divided into capacitance type, inductance type, high frequency, ultra-high frequency, direction coupling and metal film sensor [1-2]. At present, the widely used method is to detect the high-frequency pulse current on the metal shielding layer of the cable to determine whether the cable body and accessories have partial discharge. How to effectively separate weak PD pulse signal from strong background noise is an urgent problem to be solved in detecting PD by this method [3]. At present, the common off-line test methods of cable mainly include AC withstand voltage and damped oscillation wave PD detection. The volume and weight of the AC voltage withstand test equipment are usually large, which are not easy to carry out on site, while the damping oscillation voltage has good equivalence with AC voltage. The operation of damping oscillation voltage is convenient, and the test equipment is easy to carry and transport, and the cable will not be damaged during the test [4-5]. It can find the partial discharge of all different positions in the whole cable at one time, which has a good guiding role for operation and maintenance.

Combined with the PD detection of a 35kV cable line in our daily work, this paper introduces the test method using high frequency and oscillating wave detection technology, and the process of finding the PD defect of the cable joint through signal analysis and processing.

2. Detection principle of high frequency and oscillating wave partial discharge

2.1. High frequency PD detection technology

When there is one or more defects in the cable accessories or body, with the increase of the local field strength at this point, the partial discharge will occur when the resistance strength of the insulation
exceeds, and the high frequency pulse signal with the frequency of 500kHz-30MHz will be generated, which will propagate along the metal screen of the cable [6]. For the high-voltage cable grounded with metal sheath, the high-frequency current signal can be coupled on the ground wire through the high-frequency current transformer (HFCT).

HFCT is based on the electromagnetic signal generated around the path by using Rogowski coil coupling PD pulse current. When the high-frequency partial discharge current flows through the sensor, it will sense the current signal on the secondary winding, and then obtain the partial discharge voltage signal through the self-integrating resistance [7]. The signal coupling principle is shown in Figure 1. There is no direct electrical connection between the high-voltage cable and the measurement loop, so the test method has the advantages of flexibility, convenience, operation safety, etc. Through the control software, the amplitude, phase, frequency spectrum and other data of the PD signal can be further analyzed.

**Figure 1.** HFCT signal coupling schematic diagram.

2.2. Oscillating wave PD detection technology

Oscillating wave PD detection technology uses the method of pulse reflection to locate partial discharge signals. When a cable of length \( l \) is tested, it is assumed that a PD occurs at the distance from the test end \( x \), and the discharge pulse propagates along the cable to two opposite directions, one of which passes through the time \( t_1 \) to the test end; the other is propagated to the opposite end, and then propagates to the test end after reflecting at the opposite end, and passes the time \( t_2 \) to reach the test end, as shown in Figure 2. According to the time difference \( \Delta t \) between the two pulses arriving at the test end, the location of the partial discharge can be calculated [8]. That is,

\[
\begin{align*}
  t_1 &= \frac{x}{v} \\
  t_2 &= \frac{(2l - x)}{v} \\
  \Delta t &= t_2 - t_1 = \frac{2(l - x)}{v}
\end{align*}
\]

**Figure 2.** Schematic diagram of pulse reflection method.

Among them, \( v \) is the propagation speed of the discharge pulse in the cable, \( x \) is the starting position of the partial discharge pulse, \( Q \) is the amplitude of the discharge signal, \( C_k \) is the high voltage capacitance, and the \( Z_k \) is the matching impedance.

3. Test and analysis process

3.1. Operating conditions

The operating conditions of the cable are shown in Table 1:
Table 1. Operating conditions of cable.

| Conditions    | Parameters                     |
|--------------|--------------------------------|
| Cable model  | YJV_{22}—3×300 mm²             |
| Service time | 13.8 years                     |
| Length       | 343 m                          |
| Load         | 108 A                          |

3.2. High frequency PD detection

During the high frequency PD detection of a 35kV cable line terminal, it is found that there is an abnormal PD signal at the ground wire of the cable terminal. The points in phase resolved partial discharge (PRPD) map are all the pulse signals obtained in 1 min sampling time. According to the main frequency component and duration, each pulse signal corresponds in the classification map. In order to determine the source of partial discharge signal, a high-frequency sensor is installed on each phase cable terminal for testing. The measured three-phase signals map are shown in Figure 3.

Figure 3. High frequency PD maps of three-phase terminal.
From the PRPD maps and classification maps measured at the three-phase terminals, it can be seen that each phase signal contains multiple signal groups with different center frequencies. The signals of phase A and B are distributed between 3MHz to 6MHz, and the signal of phase C is distributed between 2.3MHz to 6MHz. We need to use the analysis software named PD Processing to separate the different signals by cluster analysis method. Using the signal separation function of the analysis software, different signal groups are extracted respectively, and the characteristics of the spectrum are observed, as shown in Figure 4.

![PD map separated from three-phase terminal signals](image)

**Figure 4. PD map separated from three-phase terminal signals.**

In Figure 4, it is found that the right maps of three phases are similar, which have 180 ° phase correlation, asymmetric distribution and surface discharge characteristics. However, from the current test results, it is impossible to determine whether the signal comes from the terminal or other locations. Therefore, it is necessary to carry out the oscillating wave test for further confirmation.
3.3. Oscillating wave PD detection

In order to further determine the location of the partial discharge source, the detection technology of the partial discharge of the oscillating wave is used to locate the defects. According to the query of the line account, the total length of the cable line is 343 meters, which meets the test length of the oscillating wave equipment. The location map of the partial discharge of the oscillating wave test is shown in Figure 5. There are many signal spots in this figure, and each spot corresponds to a pair of incident wave and reflected wave. The spots are concentrated at 90m, where is the cable joint. Each color we choose a spot to show the partial discharge waveform, as shown in Figure 6. The three colors represent different phases, among which yellow represents phase a, green represents phase B, and red represents phase C. The X-axis means the propagation time of partial discharge waveform, and the Y-axis means the intensity of partial discharge.

![Figure 5. Location map of oscillating wave test.](image)

![Figure 6. Partial discharge waveform of three phases.](image)
Before the test, when using the low-voltage pulse reflectometer to measure the distance, it was found that the waveform changed at 90m and 225m from the test end, and it was suspected that there were two groups of intermediate connectors. After the completion of the test, it can be observed that the three phases have obvious partial discharge concentration phenomenon at 90m, the initial discharge voltage is about 0.7\(U_0\), the maximum partial discharge intensity is about 1700pc, and it is judged that there is partial discharge defect. By verifying the cable path diagram, it is confirmed that the 90m is the location of the intermediate joint, and it is judged that there are partial discharge defects in the A, B and C three-phase cable joints at this location. According to the standard of DL/T 1576-2016 [9], the joint needs to be replaced.

4. Defect disassembly and verification
After the replacement of the suspected defective joint, the disassembly inspection is carried out. The joint is a heat shrinkable cable joint, and it is found that there is a 1mm air gap between the interface of the outermost insulating tube and the inner one. Because of the partial discharge generated in the air gap, the surface of the tube has produced oily decomposition product, as shown in Figure 7.

![Figure 7](image)

**Figure 7.** Interfacial air gap and decomposition products of heat-shrinkable tubes.

We have continued to dissect the stress control pipe and we have found that there are ridges on the surface of the stress control pipe. After cutting the stress control pipe open, we found that there are impurities on the main insulation of the inner cable, as shown in Figure 8.

![Figure 8](image)

**Figure 8.** Surface protuberance and internal fouling of stress control tube.

According to the above disassembly conditions, it is judged that the heating of the heat shrinkable joint is uneven during installation, resulting in uneven contraction of stress control pipe and heat shrinkable insulation pipe, and air gap is generated at the interface. In addition, the cable was not cleaned carefully during installation, and impurity remained on the main insulation surface, resulting in partial discharge under the operating voltage, which verified the detection conclusion.

5. Conclusions
This paper introduces a case of defect diagnosis and location of PD in the middle joint of cable by using PD detection technology of high frequency and oscillation wave. The analysis process can be summarized as follows:
(1) High frequency PD detection technology is not only suitable for PD detection of 35kV cable terminals. When the cable line is short or the partial discharge signal is strong, the partial discharge signal in the cable line can be transmitted to the cable terminal, which can also be found by means of high frequency PD detection.

(2) In the detection of PD defects in cable lines, especially in cable joints, the detection technology of oscillating wave partial discharge is more effective and easier to operate than that of high frequency partial discharge, which is convenient for the tester to quickly determine the position of discharge power, but it needs to be carried out in case of power off.

(3) When it is necessary to determine the defect type and position of the PD defect in the cable line, it is suggested to combine the test results of various means for comprehensive analysis to improve the accuracy of defect determination.

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References
[1] Guo Canxin, Zhang Li, Qian Yong, Huang Chengjun, Yao Linpeng and Jiang Xiuchen 2009 Current status of partial discharge detection and location techniques in XLPE power cable *High Voltage Apparatus* 45(3) 56-60
[2] Wei Bin and Li Ying 2005 Study on the method of PD on-line detection of XLPE cable insulating joints *High Voltage Engineering* 31(10) 30-32
[3] Chen Tengbiao, Wu Tao, Wei Qianhu and Gong Peng 2014 Application of high frequency pulse current method in detecting and positioning for high pressure cable electrification partial discharge *Guangdong Electric Power* 27(1) 114-119
[4] Yang Liandian, Zhou Jundong, Sun Fu, Huang Guoqiang, Yang Lanjun and Zhang Qiaogen 2006 Use of oscillating wave voltage in the measurements of XLPE power cable *High Voltage Engineering* 32(3) 27-30
[5] Xia Rong, Zhao Jiankang, Ouyang Benhong, Jiang Wei, Liu Haizhi and Li Jun 2010 Dielectric property detection of 110kV XLPE power cables using damped AC voltages *High Voltage Engineering* 36(7) 1753-1760
[6] Zhu Liang and Li Wenwen 2009 Measuring partial discharge on XLPE ppower cable by high frequency current coupling method *Yunnan Electric Power* 37(4) 62-63
[7] Ma Cuijiao, Qiu Yuchang, Luo Junhua and Xia Mingtong 2001 Research on the electromagnetic coupling detection method of XLPE power cable partial discharge *East China Electric Power* 6 1-3
[8] Li Xu, Xi Xiaoguang, Zhu Mingzheng, Fang Jing and Xue Chao 2018 Comparative analysis of oscillating wave partial discharge defects in two 35kV cable joints with different processes *CICED* 285-289
[9] Xue Rong, et al. 2016 *The method for partial discharge testing of 6kV~35kV power cables based on oscillating wave voltage*