Multi-source partial discharge detection and rapid localization of switchgear based on comprehensive diagnosis method

Jianxin Wang¹, *, Zhichong Zhang¹, b, Zhaoguang Zhang¹, c and Wenxu Si², *

¹State Grid Lang fang Power Supply Company, Lang fang, China
²PDStars Electric Co., Ltd., Shanghai, China

*Corresponding author e-mail: siwenxu@pdstars.com, a13722660325@139.com, b921974315@qq.com, btwsllf@sina.com

Abstract. Partial discharge detection is an effective method to find potential insulation defects in switchgear. At present, the switchgear is mainly composed of busbars, circuit breakers, grounding knives, cables and other components, which leads to multiple faults and simultaneous discharges in the partial discharge detection process of the switchgear. In order to realize the partial discharge detection and rapid location of the switchgear, based on the introduction of the detection methods and location principles of ultrasonic, transient ground voltage and UHF partial discharge, this paper proposes to use ultrasonic, transient ground voltage and UHF detection technology to diagnose and analyse the multi-source partial discharge of the switchgear and realize the detection of partial discharge; the multi-source partial discharge of the switchgear is realized by the rapid localization method combining the UHF time difference method and the flat surface method. Through partial discharge detection and localization analysis of a 35kV switchgear, the feasibility of multi-source partial discharge diagnosis and rapid localization method is verified, which provides a basis for on-site inspection personnel to realize multi-source partial discharge detection and localization of switchgear.

1. Introduction

The switchgear is a power device that directly supplies power to the user in the power system. The safe and reliable operation directly affects the reliability of the user's power consumption. Therefore, the switchgear occupies a pivotal position in the distribution network [1]. According to the statistics of the high-voltage switch industry yearbook data for the past 3 years, switchgear insulation defects are the most common types of faults. The partial discharge detection can effectively detect the early deterioration of the equipment, and eliminate the shortage of the switchgear with insulation defects to avoid major power outages in the switchgear [2-4].

The phenomenon that the insulating portion of the power device appears to break through the charge discharge channel under the action of the electromagnetic field is called partial discharge. Partial discharge is accompanied by the transformation of electricity, magnetism, heat and sound field. The corresponding partial discharge detection method of the switchgear has UHF electromagnetic wave detection method [5-7], ultrasonic detection method [8], transient ground voltage detection [9-10], etc. The main factors causing partial discharge of high-voltage equipment are insulation air gap, creeping
surface, suspension, and free particle discharge. The discharge patterns detected by different discharge principles are also different [11]. At present, a lot of work has been done on the map identification of the single discharge power supply of the switchgear at home and abroad, and good results have been obtained [12-13], but the research on the multiple partial discharge sources of the switchgear is very obvious. However, research on multi-source partial discharge of switchgear is rare. When multi-source partial discharge occurs in the switchgear, the detected discharge pattern is the superposition of multiple discharge patterns. Therefore, there will be mutual coverage of discharge patterns, which will increase the difficulty of partial discharge type diagnosis. Therefore, the research on multi-source partial discharge at home and abroad mostly focuses on the separation technology of multi-source partial discharge signals [14-16], but the above research only stays in the research or experimental stage, and has not been applied in the detection of switchgear insulation. In this paper, according to the shortcomings of the existing technology research, through the study of multi-source partial discharge spectrum characteristics and positioning methods, a comprehensive spectrum judgment method of UHF, ultrasonic and transient ground voltage is proposed to realize the diagnosis of multi-source partial discharge in switchgear. For the multi-source partial discharge localization of the switchgear, the rapid localization method combining the UHF time difference method and the bisector method is adopted, and the correctness of the method is verified by the 35 kV Switch Cabinet multi-source partial discharge case.

2. Switchgear partial discharge detection method

According to the different detection objects in the partial discharge of the switchgear, the electric measurement method and the acoustic measurement method are the two most commonly used detection methods for partial discharge of the switchgear. The electric measurement method includes the UHF detection method and the transient ground voltage detection method. The sound measurement method mainly refers to the ultrasonic detection method. Different detection methods can detect different partial discharge types.

2.1. Transient ground voltage detection

The electromagnetic wave signal generated when the switch cabinet is partially discharged generates a transient voltage signal on the surface of the switchgear cabinet. Capacitive coupled sensors detect the amplitude and number of pulses of a partial discharge. Transient ground waves propagate along the surface of the switchgear cabinet, and the attenuation paths of the same type of switchgear are the same. Since the propagation law of transient ground waves in the switch cabinet and between the cabinets is not clear, in many cases, the transient voltage detection method cannot determine the source of the discharge signal.

2.2. UHF detection method

The frequency band of UHF electromagnetic wave signal generated by partial discharge of switchgear is 300MHz~1500MHz, which can be detected by UHF sensor. The detected data type is PRPD / PRPS spectrum, and the type of partial discharge can be identified according to the spectrum. Because the UHF electromagnetic wave signal will be blocked by the metal parts in the transmission process, the partial discharge UHF signal of the switchgear will be transmitted from the cabinet slot, window and other positions, so the UHF sensor cannot be blocked by the metal parts to effectively detect the partial discharge. This method is widely used in PD detection of switchgear because of its strong anti-interference.

2.3. Ultrasonic detection method

When a partial discharge occurs in the switchgear, the acoustic signal generated from the partial discharge point will propagate around. The acoustic signal propagates through the gap of the cabinet after repeated reflection and reflection in the cabinet. Non-contact ultrasonic sensors can be used to detect along the gap of the cabinet. The detected signal types include periodic maximum value, signal
waveform and frequency component. Combined with the sound characteristics of the ultrasonic signal in the earphone, the discharge signal can be comprehensively detected and judged.

3. Switchgear partial discharge positioning method

The papers [17] use the time difference method, the grading method, the amplitude method and the acoustic-electric combined method to carry out partial discharge positioning of the medium voltage switchgear. The time difference method and the amplitude method refer to the use of a plurality of transient ground voltage sensors, ultrasonic sensors or UHF sensors. The general position of the local discharge source is determined by the time difference and amplitude of the signal acquisition signal [18]. According to the ultrasonic detection technical specification, the judgment is based on Table 1. The bisector method is to realize the localization of the partial discharge source by the same time when the partial discharge source reaches the two sensors, and through the three processes of the local discharge source, namely, the plane, the line and the fixed point. The acoustic-electric combined localization method is to obtain the distance between the partial discharge signal and the electric signal detection sensor by multiplying the propagation time between the acoustic signal and the electric signal generated by partial discharge, thereby realizing the precise positioning of the local discharge source. Figure 1 is a schematic diagram of the joint positioning of sound and electricity.

| Sound intensity                        | Detected value /dB | Levels of danger |
|----------------------------------------|--------------------|------------------|
| No partial discharge sound in headset  | Regardless of value size | Normal           |
|                                        | P≤8                | Normal           |
| Obvious partial discharge sound in headset | 8<P≤20     | Abnormal         |
|                                        | 20<P≤30            | Abnormal         |
|                                        | P>30               | Danger           |

Table 1. Reference criteria for ultrasonic testing

![Figure 1. The acoustic-electric combined positioning method](image)

4. Diagnosis and localization methods of multisource partial discharge

4.1. Diagnostic method of multisource partial discharge spectrum

Different detection methods can identify different types of switchgear partial discharge. A single detection method can’t reflect the fault defects of the switchgear. At the same time, the transient ground
The voltage monitoring method of the switchgear is widely used as a general measurement method, while the ultrasonic and UHF detection methods can find most of the insulation defects of the switchgear. Therefore, the comprehensive detection methods of ultrasonic, transient ground voltage and UHF can find many types of partial discharge in switchgear. In this paper, the three-in-one intelligent sensor and UHF intelligent sensor are used to monitor the partial discharge of the switchgear.

The display forms of ultrasonic sensor detection data from different manufacturers are different. Partial discharge can be identified according to the characteristics of amplitude spectrum, waveform spectrum and eigenvalue spectrum. The typical single partial discharge sources, such as corona discharge, suspended discharge and free metal particle discharge, have obvious polarity characteristics of effective value and periodic peak value of ultrasonic amplitude spectrum. However, the ultrasonic spectrum of a single partial discharge shows a certain regularity, that is, "single peak" or "double peak" signal in a power frequency cycle.

Threshold analysis, transverse analysis and longitudinal analysis are commonly used to judge the partial discharge detection data of transient ground voltage. However, it is greatly affected by background noise, which is easy to cause the measured amplitude to exceed the standard. Therefore, the influence of background noise should be eliminated first, and then the insulation state of switchgear should be judged according to the threshold value in the specification.

UHF detection data display forms include UHF original spectrum, PRPS spectrum, PRPD spectrum and peak detection spectrum. Different types of partial discharge, the characteristics of the spectrum will also be different, but the UHF detection spectrum of a single partial discharge has some common characteristics. For example, the PRPS& PRPD spectrum of a single partial discharge source is "double peak" in one period. The partial discharge source can be judged according to the amplitude of the discharge signal and the characteristics of the double peak. For multi-source partial discharge of the same type, the phase determination of partial discharge source can also be made by the phase of discharge pulse in PRPS spectrum. Therefore, whether ultrasonic or UHF, the spectral characteristics of a single partial discharge source are generally characterized by the existence of "single peak" or "double peak" signals in a single partial discharge period. If there are more than two clusters, it can definitely be the spectral superposition of multi-source partial discharge.

4.2. Location method of multi-source partial discharge

Due to the limited internal space of the switchgear and various components, the ultrasonic signal generated during partial discharge will be reflected and blocked multiple times. Therefore, the acoustic-electric combined and ultrasonic time difference positioning methods will be affected. When the switchgear is partially discharged, the ultrasonic and ultra-high frequency detection can generally determine the switchgear where partial discharge occurs. In order to accurately locate it, a high-performance oscilloscope and ultra-high-frequency time difference positioning technology are required. When the switchgear is partially discharged, the ultrasonic and ultra-high frequency detection can generally determine the position where the partial discharge occurs. In order to accurately locate it, a high-performance oscilloscope and ultra-high-frequency time difference positioning technology are required.

4.2.1. UHF time difference positioning principle. The electromagnetic wave signal generated by partial discharge of the switchgear is about the speed of light in the air. The time when the signal reaches the sensor is the time it takes to travel. The position of the signal source can be judged according to the chronological order of the UHF electromagnetic wave signal reaching different sensors. When the UHF sensor finds the abnormal signal, the high-speed sampling technique can be used to locate the discharge source by calculating the rising edge time difference of the pulse signals received by the two UHF sensors. Figure 2 is the principle diagram of the UHF time difference positioning. The spatial distance between the two UHF sensors is D, the distance between the discharge source and the UHF sensor S1 is X, and the distance between the discharge source and the UHF sensor S2 is D-X. The time when the discharge pulse reaches the sensor S1 is t1, the time to reach the sensor S2 is t2, and the time difference
between the signals received by the two sensors is $\Delta t$, the specific position of the signal source can be calculated according to the formula (1).

$$\Delta t = t_2 - t_1 = \frac{(D-x)}{c} - \frac{x}{c}$$ (1)

Then

$$X = \frac{1}{2} (D - c \times \Delta t)$$ (2)

In the formula, $c$ is the speed of electromagnetic waves in the air, $3 \times 10^8$ m/s, $\Delta t$ can be read from the high performance oscilloscope.

4.2.2. The bisector plane positioning method. The bisector plane positioning method is divided into three processes: fixed plane, fixed line and fixed point.

The fixed plane process is to move two sensors on the detected power device. When the time at which the discharge signal reaches the UHF sensor is the same, it can be determined that the power source is located on the bisector of the two UHF sensors.

The fixed line process is to move two UHF sensor positions on the determined plane. When the discharge signal reaches the two sensors at the same time, it can be determined that the discharge source is located on the bisector of the two partial discharge sensors.

The fixed point process is to move the positions of the two sensors on the determined line. When the time at which the discharge signal reaches the two sensors is the same, it can be determined that the discharge point is at the midpoint of the vertical bisector.

5. Insulation fault diagnosis of switchgear

The UHF, transient ground voltage and ultrasonic comprehensive diagnostic technology are used to analyze the partial discharge type of the switchgear, and the UHF time difference method and the
bisector plane method are used to location the partial discharge source. Further explain the pattern diagnosis and fault location method of multi-source partial discharge.

5.1. Multi-source partial discharge type diagnosis

The three-in-one intelligent sensor and UHF intelligent sensor with low power consumption and micro power are arranged on the switchgear to monitor the insulation state of the switchgear. The type of partial discharge is determined by comprehensively analyzing the ultrasonic amplitude spectrum, transient ground voltage amplitude spectrum and UHF waveform spectrum. When there are partial discharge defects, the sampling frequency of the intelligent sensor can be increased, the attention degree of the defective equipment can be adjusted, and the problems found can be solved in time. Through the analysis of the three-in-one sensor and ultra-high frequency intelligent sensor spectrum of a station switchgear, an abnormality is detected in the 35kV switchgear. The test data is analyzed as follows:

5.1.1. Three-in-one sensor test results

![Figure 4. The ultrasonic amplitude spectrum](image)
Figure 5. The transient ground voltage amplitude spectrum

The ultrasonic amplitude test results are shown in Figure 4. The maximum amplitude of the ultrasonic wave is 21 dB and the discharge sound can be clearly heard in the headset, and the 50 Hz frequency correlation is less than the 100 Hz frequency correlation. According to the criteria in Table 1, it can be seen that there is a partial discharge abnormality in the switchgear. The spectrum of the transient ground voltage is shown in Figure 5. It can be seen from the figure that the amplitude of the transient ground voltage reaches 35 dB, which exceeds the threshold of 20 dB, and it can be judged that there is a partial discharge abnormality in the switchgear.

5.1.2. UHF sensor test results

Figure 6. The UHF PRPS&PRPD spectrum

The detected UHF PRPS & PRPD spectrum is shown in Figure 6. The maximum amplitude of the UHF signal is 64 dB. A cluster of obvious pulse signals appears in one power frequency cycle, and the amplitude of the pulse is not uniform. After comprehensive judgment, the PD type is a multi-point
insulating surface discharge. Therefore, through the comprehensive diagnosis of ultrasonic, transient ground voltage and ultra-high frequency spectrum of the switchgear intelligent sensor, it is determined that the 35kV switchgear is a multi-source insulation discharge type.

5.2. Multi-source partial discharge localization analysis
The positioning process includes three steps: horizontal alignment, vertical alignment and depth fixed point. In the process of depth location, the time difference of partial discharge signal received by two UHF Sensors is used for location. The positioning process of multi-source partial discharge is as follows:

5.2.1. Horizontal fixed surface

![Figure 7. Sensor position and positioning waveform](image)

In figure 7, the yellow solid and the red solid are the locations of the UHF sensor. As can be seen from the positioning waveform, the starting points of the yellow and red signal waveforms coincide, indicating that the discharge source is equal to the distance between the two sensors, that is, the discharge source is located on the vertical bisector between the two sensors, as indicated by the blue line in the figure.

5.2.2. Vertical alignment

![Figure 8. Sensor position and positioning waveform](image)

The yellow solid and red solid in the figure are two UHF sensors. It can be seen from the positioning waveform that the initial edges of the yellow and red signal waveforms coincide, indicating that the
distance from the discharge source to the two sensors is equal, and that is, the discharge source is located on the vertical bisector between the two sensors.

5.2.3. Depth fixed point

![Figure 9. Sensor position and positioning waveform](image)

Yellow is the UHF sensor placed in front of the switchgear and red is the UHF sensor placed behind the switchgear. It can be seen from the positioning waveform diagram that the red UHF sensor signal leads the yellow UHF sensor signal by 550 ns. According to the time difference method, it can be known that the discharge source is near 7 cm behind the middle of the switchgear.

Combined with the above positioning steps, it is determined that the multi-point insulation discharge position of the 35kV switchgear is in the middle and lower three-phase dynamic and static contact bushing area in the switchgear.

5.3. Verification situation
The 35kV switchgear was subjected to the overall power failure maintenance process. It was found that there was a white discharge trace in the joint area of the switch contact box in the switchgear, which was the white powder decomposed by the epoxy discharge. The disintegration picture of the switchgear is shown in Figure 10.

![Figure 10. Multi-source partial discharge disintegration picture of the switchgear](image)

6. Conclusion
Based on the research of partial discharge detection and discharge source localization technology of switchgear, this paper proposes a method for judging the multi-source partial discharge of switchgear.
using UHF, transient ground voltage and ultrasonic comprehensive spectrum. For the multi-source partial discharge localization of the switchgear, the rapid location method combining the UHF time difference method and the flat surface method is adopted. Through partial discharge detection and localization analysis of 35kV switchgear, the feasibility of multi-source partial discharge diagnosis and rapid location method is verified, which provides a basis for on-site inspection personnel to realize multi-source partial discharge detection and location of switchgear.

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