Research on High-precision Positioning Technology for Partial Discharge of High Voltage Switchgear

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Abstract. With the advancement and development of power technology, the research of high-voltage switchgear has always been a hot issue. Countries around the world are actively conducting related research. Good high-voltage switchgear can have a positive impact on the development of the power grid. This paper studies the partial discharge positioning technology of power system switchgear, introduces the common ground wave and ultrasonic detection of partial discharge technology, and builds the space model of power switchgear, and proposes the use of hyperboloid method and space search method. The positioning technology of the partial discharge of the switchgear is combined with the multi-channel power switchgear detection equipment used in this paper. The effectiveness of the multi-channel switchgear to detect and locate the partial discharge is verified by simulation experiments. This article introduces the principles of high-voltage switchgear diagnosis and collects local high-precision positioning technology. It introduces the most widely used monitoring technology and live TEV AE real-time monitoring technology, and its complex concepts and principles. It can clearly compare two live detection technologies. Existing power companies generally use two mating devices, high-voltage switchgear, to better diagnose the PD phenomenon; they also introduce positioning methods and positioning technologies. The four-channel detection technology is mainly charged and applied positioning methods and positioning Surface space network search method.

1. Ground wave detection technology
When a partial discharge occurs in the high-voltage switchgear, the ground wave is generated, and the discharge voltage pulse is transmitted by the ground wave along the inner surface of the metal portion of the high-voltage switchgear casing[1]. The metal part of the outer casing of the high voltage switchgear will have a certain shielding effect on the discharge voltage pulse signal. However, due to the breakage of the terminals and gaskets of the high voltage switchgear and the connection gap of the metal housing of the switchgear, the shield layer will not be in a continuous state[2]-[3]. The corresponding voltage generated by the electromagnetic pulse through the shielding layer is not a continuous state in which the metal box of the switch cabinet and the ground are simultaneously grounded, and a transient voltage is generated in the metal box, which is a well-known ground wave. The ground wave can only be maintained for a short period of time[4]. The general ground wave is maintained for a few nanoseconds; the amplitude of the ground wave is also small, usually between a few millivolts and a few volts, so it can be connected by a capacitively coupled sensor. The ground wave is measured as the basis for detecting the intensity of the partial discharge[5].
The ground wave detection technology can place the detection device on the outer surface of the cabinet for the partial discharge detection in the state where the high voltage switch cabinet is not powered off. The advantage of this detection technology is that it can be detected during operation without affecting the power supply of the system. The detection can be carried out at any time. Another advantage is that the detection technology adopts a non-intrusive detection method, which does not affect the normal operation of the switchgear and facilitates detection. First, the unit of intensity generally used to describe partial discharge is dB. The specific detection method of the technology is as follows: a capacitive coupling sensor for detecting a ground wave is placed at a position where there is an opening or a gap in the cabinet of the switch cabinet, and the length of the sensor from the partial discharge point and the intensity of the partial discharge inside the switch cabinet mainly determine the magnitude of the ground wave amplitude measured by the sensor. On the one hand, the closer the distance between the measuring sensor and the discharge point is, the larger the ground wave will be. On the other hand, the stronger the discharge intensity, the larger the ground wave will be. Therefore, whether there is partial discharge inside the high-voltage switchgear is inseparable from the measurement result of the ground wave. In actual testing, it should be noted that no less than two capacitively coupled sensors should be installed in different parts of the metal cabinet of the switchgear. The purpose of this is to further analyze the sequence of ground waves reaching different sensors. In turn, the position information of the partial discharge point can be detected more accurately.

2. Ultrasonic charging detection technology
In the live detection method of partial discharge of high-voltage switchgear, TEV electrification detection technology has become the most advanced and widely used detection technology with its simple and feasible principle and uncomplicated operation steps. However, the fatal defect that is highly susceptible to electromagnetic interference determines that it must be used in conjunction with another detection technology in the prior art, and the AE charging detection technology that is completely immune to external electromagnetic fields has emerged.

AE live detection technology is one of the partial discharge test technologies for high-voltage switchgear, that is, the technology for determining whether a partial discharge phenomenon occurs in a high-voltage switchgear by detecting ultrasonic waves generated by collision of charged particles during partial discharge of a high-voltage switchgear (that is, a frequency greater than or equal to 20,000 Hz). method. In the partial discharge process of the high-voltage switchgear, although it is affected by various external factors, from the statistical point of view, the discharge energy has a relatively stable positive correlation with the acoustic energy generated. In essence, the partial discharge generated from the high-voltage switchgear generally shows a relatively weak glow discharge state at the beginning, and a severe arc discharge at the middle and later stages, and the corresponding discharge energy also increases greatly. It can be seen that during the partial discharge of the high-voltage switchgear, the release of energy shows a weak to strong trend. According to the stable proportional relationship between the discharge energy and the acoustic energy generated above, the change in the discharge energy of the partial discharge of the high voltage switchgear can be represented by the change in the sound pressure of the ultrasonic signal. The technique for detecting partial discharge of high voltage switchgear based on the sound pressure of an ultrasonic signal is an AE detection technique.

3. Hyperboloid positioning
Figure 1 shows the partial discharge positioning coordinate diagram of the high-voltage switchgear. The left-right corner of a compartment is used as the coordinate origin to establish a space rectangular coordinate system. Let the local discharge source P(x, y, z) to the sensor Si (xi, yi, zi) (i = 1, 2, 3, 4) travel time ti, then have the following formula:

$$t_i = \sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2}/C_0$$

(1)
Where \( c \) represents the speed of light and is: \( 3 \times 10^8 \text{ m/s} \).

**Figure 1.** Location coordinate map of partial discharge in high voltage switchgear

When positioning, the sensor that first arrives at the signal is selected as the reference signal (assuming that the sensor 1 is selected as the reference signal), and the reference between the partial discharge signal \( S_i \) measured by the \( i \)-th sensor and the partial discharge signal \( S_1 \) measured by the reference sensor is used as a reference. The arrival time difference is \( t_{1i} = t_i - t_1 \) (\( i = 2, 3, 4 \)).

\[
f_i(x, y, z) = \sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} - \sqrt{(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2}c * t_{1i} \tag{2}
\]

Where \( i = 2, 3, 4 \). The corresponding trajectories in equation (2) are three rotating hyperboloids with \((S_1, S_2)\), \((S_1, S_3)\), \((S_1, S_4)\) as the focus, and the intersection of these hyperboloids is the high-voltage switch cabinet’s position. In order to verify the accuracy of the hyperboloid positioning method, the FDTD simulation analysis of a certain compartment was carried out. The simulation model was established according to Fig. 2.3. The Gaussian current source with amplitude \( I_0 \) of 1A and pulse width of 1 ns was used as the PD source for simulation analysis.

Four sensors are placed near the four vertices of the surface of a compartment. The spatial coordinates of the PD source and sensor are shown in Table 1. The signal arrival time difference determined by the threshold method is shown in Table 2.

**Table 1.** The spatial coordinates of the partial discharge source and the sensor

| PD source coordinates/cm | \( S_1/cm \) | \( S_2/cm \) | \( S_3/cm \) | \( S_4/cm \) |
|--------------------------|-------------|-------------|-------------|-------------|
| (20,20,20)              | (101,4,4)   | (101,76,4)  | (101,4,156) | (101,76,156) |

**Table 2.** Contrast of the signal arrival time difference

| time difference          | \( t_{12} \) | \( t_{13} \) | \( t_{14} \) |
|--------------------------|-------------|-------------|-------------|
| Signal arrival theoretical time difference /ns | 0.500 7       | 2.526 9       | 2.808 0       |
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The solution of the nonlinear equations is transformed into an unconstrained optimization problem. The objective function is:

\[
\text{min} F(x, y, z) = \sum_{i=2}^{4} f_i(x, y, z)^2 \tag{3}
\]
The quasi-Newton-corrected BFGS method is selected to optimize the objective function formula (3). Select different initial values for calculation. The calculated results are shown in Table 3. The position of the actual partial discharge source is \( P(x, y, z) = (20 \text{ cm}, 20 \text{ cm}, 20 \text{ cm}) \).

| X0/cm   | Number of iterations | \( P^*(x^*,y^*,z^*)/\text{cm} \) | error/cm |
|---------|----------------------|----------------------------------|-----------|
| (50,50,50) | 23                   | (18.6,20.6,18.6)                | 1.4       |
| (80,80,80) | 29                   | (18.6,20.6,18.6)                | 1.4       |
| (5,5,5)    | 17                   | (18.6,20.6,18.6)                | 1.4       |

From the positioning results in Table 3, the quasi-Newton-corrected BFGS method avoids the computational failure caused by the Hessian matrix singularity. The iteration position when the initial value \( X_0 \) is (5 cm, 5 cm, 5 cm) is shown in Figure 2.

**Figure 2.** Schematic diagram of the iterative process of the BFGS method

4. Spatial network search
The hypersurface method requires solving equations, while the spatial grid search algorithm does not need to solve equations. The principle of the method is as follows: the length of the selected positioning space on the three coordinate axes is \( L_x, L_y, L_z \), and the size of the selected mesh is \( \Delta 1 \times \Delta 1 \times \Delta 1 \), then the grid space is \( n = (L_x / \Delta 1 + 1)(L_y / \Delta 1 + 1)(L_z / \Delta 1 + 1) \) nodes. After the spatial coordinates of the four sensors are marked, the \( n \) nodes in the grid space are used as the PD sources. Take the three theoretical signal arrival time differences \( (t_{12}, t_{13}, t_{14}) \) corresponding to \( n \) nodes, and take \( n, 1, 2, ..., n \). Let the actual signal arrival time difference be compared, and find the minimum value of \( (|t_{12} - t_{12}| + |t_{13} - t_{13}| + |t_{14} - t_{14}|) \), then the actual power supply is located in the small cube area centered on the node, positioning. The spatial division is shown in Figure 3.

**Figure 3.** Location spatial dissection diagram
The time differences $t_{12}$, $t_{13}$, and $t_{14}$ of the arrival of the three signals calculated by the threshold method in Table 2.2 are respectively substituted into the operation process, and two different network sizes are selected, and the calculated results are also different. The minimum value $\min(|t_{iL_{12}}-t_{12}|+|t_{iL_{13}}-t_{13}|+|t_{iL_{14}}-t_{14}|) (i=1,2,\ldots,n)$ obtained by comparison is shown in Table 4. The actual local discharge source position is $P(x, y, z) = (20 \text{ cm}, 20 \text{ cm}, 20 \text{ cm})$.

| Network size /cm | Number of nodes (n) | Calculation results $P*(x^*,y^*,z^*)$/cm | Minimum value /ns |
|------------------|---------------------|------------------------------------------|------------------|
| 10×10×10         | 1 683               | (20,20,20)                               | 0.062 8         |
| 5×5×5            | 11 781              | (10,20,15)                               | 0.043 6         |

It can be seen from the calculation results in Table 4 that compared with the hyperboloid positioning method, the spatial grid search method needs to mesh the solution space, and the calculation result will produce discrete errors, but the time difference of signal arrival is not high. In addition, the space grid search method is significantly better than the hyperboloid positioning method in calculation speed, which greatly saves computation time. The positioning calculation results when the grid length is 5 cm × 5 cm × 5 cm are shown in Figure 4. It can be clearly seen from Figure 4 that the results of the spatial grid search method and the actual position of the local point are compared, and the calculation results are deviated from the actual position. The experiment fully validates the method.

![Figure 4. Results of spatial grid search method](image)

5. Conclusion
This paper introduces the principle of high-precision positioning technology for high-voltage switchgear power supply diagnosis, introduces the most widely used TEV live monitoring technology and AE live monitoring technology, and expounds its concept and principle, which can clearly compare two kinds of charging detection technology. The existing power company generally uses two kinds of equipment to cooperate, which can better diagnose the partial discharge phenomenon of the high-voltage switch cabinet. At the same time, it also introduces the positioning technology and positioning method. The four-channel charging detection technology is mainly used in this paper. The hyperboloid positioning method and the spatial network search method are used for positioning.

References
[1] Wang L, Ning W, Wang L, et al. Experimental investigation of partial discharge detection in medium-voltage switchgear based on ultra-high-frequency sensor[C]. International Conference on Electric Power Equipment - Switching Technology, 2014:1-4.
[2] Li J, Che B, Han X, et al. Field impulse withstand test and partial discharge detection for ultra high voltage gas insulated switchgear equipment[J]. Gaodianya Jishu/High Voltage Engineering,
2015:9-11.

[3] Shin J Y, Lee Y S, Hong J W. Partial discharge detection of high voltage switchgear using a ultra high frequency sensor[J]. Transactions on Electrical & Electronic Materials, 2013, 14(4):211-215.

[4] Li Y X, Wang T, Jin T, et al. Detection and analysis of high voltage switchgear internal partial discharge based on multiple detection technology[J]. High Voltage Apparatus, 2017:15-17.

[5] Luo H, Cheng P, Liu H, et al. Research on the UHF microstrip antenna for partial discharge detection in high voltage switchgear[C]. Industrial Electronics and Applications., 2016, 1(6):2273-2276.