Research on Partial Discharge Breakdown Location Technology of 1000kV GIS in Field Test

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Abstract. During the field test, if the input and output lines and intervals of the withstand voltage test after the GIS equipment are segmented, and a non-self-recovery discharge or breakdown occurs during the test, only the hearing of the human ear will determine the exact location of the failure. It is more difficult, and it is easy for misjudgment to waste manpower, material resources and cause unnecessary damage to equipment. Therefore, in the field AC withstand voltage test of GIS equipment, finding the location of discharge breakdown is a key technical problem that needs to be urgently solved on the site. This paper studies the propagation characteristics and detection principles of electromagnetic wave signals and vibration signals that cause breakdown faults in 1000kV GIS, and develops a positioning system based on combined acoustic-electrical detection technology for AC withstand voltage of UHV GIS in the field. In the test, it was verified through actual test cases that the method can quickly and accurately locate the location of the breakdown discharge, and provided a set of convenient and effective technical means to ensure the smooth on-site withstand voltage test of GIS equipment.

1. Introduction

Each independent unit of the UHV 1000 kV SF6 gas-insulated metal-enclosed combined electrical equipment (GIS) is shipped to the site of the UHV substation after the factory test is completed in the equipment manufacturing plant, where it is assembled on site. During the transportation and installation of GIS units, it is inevitable to leave defects inside the GIS equipment, such as incomplete cleaning and cleaning, which may cause the presence of foreign objects and inadequate assembly. Once put into operation, it is easy to cause insulation breakdown of GIS equipment [1-3]. Conducting on-site AC withstand voltage test before commissioning can timely discover equipment defects due to process, transportation, and installation [4-10].

Due to the large volume of the UHV GIS equipment, the test section was over 100 meters in the field handover test. Once the equipment breakdown occurred during the test, it was difficult to rely on traditional analysis methods to determine the discharge location. The large-scale disassembly inspection of the GIS equipment air chamber in the test section can accurately find the discharge location, but the large-scale disassembly inspection not only has a large workload and affects the construction progress, but also causes quality and safety inside the equipment due to secondary disassembly. Hidden danger.

At the same time, if the input and output lines and intervals of the withstand voltage test after the GIS segmentation are many, and non-self-recovery discharge or breakdown occurs during the test, it will be difficult to determine the exact location of the failure only by monitoring the human ear,
Misjudgement is prone to waste manpower, material resources and cause unnecessary damage to equipment. At present, the fault locator developed based on the principle of monitoring the shock wave caused by the shock generated by the discharge during the withstand voltage test and the vibration of the casing is used at home and abroad to determine the discharge interval. Before each withstand voltage test, install the probe on the part under test, especially the shell near the insulator of the circuit breaker, disconnect switch, busbar and the connection points of each interval. If the interval is not installed due to the limited number of probes, but the discharge or breakdown occurs and the monitoring device does not predict, you should move the probe after the voltage drop and power off according to the situation of monitoring the discharge, and then increase the pressure again until the discharge or breakdown location is found. Therefore, in the field withstand voltage partial discharge test of UHV 1000kV GIS equipment, it is necessary to use breakdown location technology to quickly and accurately judge the faulty gas chamber.

This paper studies the propagation characteristics and detection principles of electromagnetic wave signals and vibration signals that cause breakdown faults in 1000kV GIS, and develops a positioning system based on combined acoustic-electrical detection technology for AC withstand voltage of UHV GIS in the field. In the test, it was verified through actual test cases that the method can quickly and accurately locate the location of the breakdown discharge, and provided a set of convenient and effective technical means to ensure the smooth on-site withstand voltage test of GIS equipment.

2. Principle of breakdown positioning technology

Using ultrasonic (AE) and ultra-high frequency (UHF) detection principles, combined with wireless signal transmission technology to achieve partial discharge defect detection and location of GIS, transformers and other high-voltage electrical equipment

Ultrasonic and ultra-high frequency signals are generated when partial discharge failures occur in enclosed high-voltage electrical equipment (such as GIS, transformers, etc.). The discharge source is the source of the partial discharge signal. According to the transmission characteristics of AE and UHF signals and the structural characteristics of electrical equipment, several wireless ultrasound and UHF probes can be placed at different positions of these electrical equipment to form a test array. Get the position coordinates of the discharge source.

2.1 UHF breakdown positioning technology

Partial discharges in GIS equipment can generate electromagnetic wave signals with steep rising edges, with a frequency of up to 1 GHz. The electromagnetic wave signals generated by partial discharges propagate in the GIS equipment and radiate outward through discontinuous parts such as basin insulators. This signal can be detected by the UHF sensor probe at the non-metal shielding position of the GIS equipment. The high-speed acquisition card and high-speed oscilloscope are used to compare and analyse the collected multi-channel UHF signals, and the position of the local power supply in the GIS device is calculated based on the time difference between the electromagnetic wave reaching the different sensors during the GIS device transmission.

The method of positioning the time difference by using multiple ultra-high frequency partial discharge signals has high sensitivity, and can determine the type of the fault by the characteristics of the discharge waveform, which can be used for on-line monitoring of equipment. However, the positioning of the UHF time difference positioning method requires a higher level of detection by the inspectors, higher requirements on the detection equipment, and the full coverage of the entire pressure range is expensive. Therefore, in the GIS breakdown test breakdown positioning technology, the UHF time difference positioning method is often used as an auxiliary means for ultrasonic breakdown positioning to improve the accuracy of on-site positioning.

2.2 Ultrasonic breakdown positioning technology

When there is a partial discharge inside a GIS device, while generating an electromagnetic wave signal, it will cause a change in the volume of SF6 gas, generate an ultrasonic signal, and detect the internal
ultrasonic signal of the GIS through an ultrasonic sensor to indirectly obtain the partial discharge information inside the GIS device. The ultrasonic sensor detection signal is a non-electromagnetic wave signal, which can effectively avoid electromagnetic interference signals in the substation. Therefore, it has strong anti-interference ability and high positioning accuracy.

In the application of ultrasonic breakdown positioning, the ultrasonic sensors are arranged on the surface of the GIS shell according to a specific arrangement to ensure that both sides of each insulated basin and each independent air chamber can be detected. When a discharge breakdown occurs, an ultrasonic signal near the discharge point will detect the ultrasonic signal. The position and time of the breakdown fault will be determined by detecting and analysing the trigger time and trigger peak of the ultrasonic sensor probe on the surface of the GIS cylinder.

The ultrasonic breakdown positioning system uses multiple ultrasonic sensors for signal acquisition. Each sensor unit detects ultrasonic signals on the surface of the GIS case through an ultrasonic probe, processes the signals, converts them into digital signals, and stores the digital signals in the sensor’s internal storage. At the same time, the wireless transmission technology is used to transmit digital signals to the nearby terminal computer monitoring system in real time, in order to use the computer terminal to detect multiple sensor signals in real time, so as to achieve online monitoring of partial discharge signals inside the GIS equipment.

Table 1 shows the parameter information of a GIS equipment discharge breakdown location system. With multi-detection unit timing function, the sensor and monitoring unit are integrated. The breakdown positioning devices currently used have the function of expanding wireless nodes, which can expand the number of wireless nodes according to the actual pressure range of GIS equipment. Wireless nodes can act as relays between each other, expanding the range of data transmission, and with built-in local storage and display functions, can back up and verify the judgment conclusions obtained by the terminal computer.

| Parameters                          | Value               |
|------------------------------------|---------------------|
| Frequency/kHz                      | 10~200              |
| Maximum sampling rate / MHz        | 40, Adjustable      |
| AD conversion bits / bit           | 12                  |
| Single sensor detection radius / m | 3                   |

3. Live application

The AC high voltage partial discharge detection test of 1000 kV GIS equipment was carried out in the UHV substation. At the same time, the GIS sound-electric breakdown positioning technology was used to carry out the discharge positioning. The 1000 kV GIS equipment of this UHV station uses a 3/2 connection method. The main transformer plus lines have a total of 8 outgoing lines and 14 intervals. According to the calculation, the power frequency withstand voltage test is divided into 4 stages. During the test, breakdown failure occurred during the first stage withstand voltage. The first pressure test is carried out from the inlet bushing of No. 1 main transformer, as shown in Figure 1. The red marked area in the figure is the pressure position for the first pressure test. The test pressure procedure is: boost to 635 kV for 10 min; then boost to 762 kV for 20 min; then boost to 1000 kV for 1 min. After the 1100 kV 1 min withstand voltage test passes, the voltage is reduced to 762 kV, and the device is tested for UHF and ultrasonic partial discharge after 30 minutes, as shown in Figure 2.
Before the start of pressurization, arrange the ultrasonic sensor probe and UHF sensor probe on the GIS equipment housing. By measuring the time sequence and amplitude of the signals received by each position sensor of the GIS shell, you can locate the location of the breakdown point and its distribution as shown in Figure 3. In the figure, the red marks are the positions of the ultrasonic sensors, and the green marks are the positions of the UHF sensors. When the phase B is pressurized, after the aging test of 635 kV / 10 min and 762 kV / 10 min is completed, the pressure is increased to 1100 kV. During the step-up process, when the voltage was increased to 1036 kV, a huge noise was heard inside the GIS, and a preliminary judgment was made that a breakdown discharge occurred within the GIS. After the device breaks down, the background terminal control computer displays that the ultrasonic sensor units No. 30, No. 2 and No. 3 all exceed the alarm value, and sends an alarm signal.
According to the ultrasonic amplitude signal, there are two possible puncture positions. The terminal control computer calls up the sensor trigger information. Combined with the ultrasonic sensor trigger time, it can be seen that the No. 2 ultrasonic sensor triggers first, but the probe No. 30 has the largest amplitude. As shown in Table 2 and Table 3. It is not possible to confirm through the ultrasonic signal whether the air cell in which the No. 30 probe is located or the air cell in which the No. 2 and No. 3 probes have a breakdown failure. When observing the UHF sensor probe signals, it was found that the UHF sensor probes 2-1 and 2-2 detected signals that were close to the air chamber where the ultrasonic probe No. 30 was located, so the combined ultrasound and UHF signals were used to determine the breakdown discharge. The location is at the red circle mark in Figure 4. The signals detected by sensors 2 and 3 may be counter-strikes caused by the overvoltage generated after the breakdown of the discharge, causing the sensors to capture the signals.

### Table 2. Sensor signal amplitude during breakdown.

| Measuring point number | Sensor No. | Signal amplitude | Amplitude difference |
|------------------------|------------|------------------|---------------------|
| 1                      | AE30       | 76               | -                   |
| 2                      | AE2        | 67               | -7                  |
| 3                      | AE30       | 58               | -11                 |
| 4                      | AE3        | 52               | -4                  |
| 5                      | AE30       | 50               | -2                  |
| 6                      | AE30       | 47               | -5                  |
| 7                      | AE30       | 45               | -1                  |

### Table 3. Sensor signal time during breakdown.

| Measuring point number | Sensor No. | Signal amplitude | Amplitude difference |
|------------------------|------------|------------------|---------------------|
| 1                      | AE2        | 26.470           | -                   |
| 2                      | AE3        | 26.615           | 0.145               |
| 3                      | AE30       | 26.270           | 0.055               |
| 4                      | AE30       | 37.750           | 11.080              |
| 5                      | AE30       | 45.230           | 7.480               |
| 6                      | AE30       | 49.145           | 3.915               |
| 7                      | AE30       | 61.475           | 12.330              |

The on-site inspection found that the fault location was a section of busbar air chamber according to the breakdown positioning system. After the discharge occurred, the faulty section busbar was disassembled. During the on-site disassembly, a noticeable discharge trace was found on the conductor, as shown in Figure 5, its location is consistent with the fault point determined by the breakdown positioning system.
4. Conclusion

The special handover test of UHV 1000 kV GIS equipment can timely find potential defects in the equipment before it is put into operation. The breakdown discharge positioning technology provides technical support for quickly determining the discharge gas chamber during the test. The auxiliary joint breakdown positioning technology is more suitable for breakdown location of UHV GIS equipment on-site withstand voltage test. In the field withstand voltage test of a 1000 kV GIS device in an UHV substation, this method was used to successfully determine the gas chamber that has a breakdown discharge during the test, which shortened the time for on-site confirmation and maintenance of the faulty gas chamber. This method can be used to perform breakdown positioning. This method can effectively avoid damage to GIS equipment, ensure the construction period on site, and provide a basis for the subsequent selection of UHV GIS positioning methods.

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