Research on the application of the frequency-phase controlled AC withstand technology in GIS

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Abstract. Gas insulated SWITCHGEAR has been widely used in modern power grid with increasingly tight land use due to its advantages such as small floor space, high integration, strong security, high reliability and small maintenance workload. For the extended high-voltage GIS equipment, field insulation AC voltage withstand test must be carried out before operation to verify whether the equipment is ready for operation. In the withstand voltage test, considering the possible breakdown of the original equipment during the withstand voltage between the tested, the original equipment must be cut off and grounded. However, with the continuous improvement of the reliability requirements of power supply, the power failure will cause great economic and political losses, which requires a technology that does not require the GIS bus to stop completely, namely frequency-phase controlled AC withstand test technology. In this paper, the test principle of the frequency-phase controlled AC withstand test technology is first analyzed, and then the test process of the frequency-phase controlled AC withstand technology is illustrated by an example, which provides a reliable scheme for the field test of GIS maintenance or expansion interval.

1. Frequency-Phase Controlled AC Withstand Technology

1.1. Principle of the Frequency-Phase Controlled AC Withstand Technology

After the GIS interval expansion and maintenance, AC voltage withstand test should be carried out under the condition of power failure in the original operation part [1]. The GIS expansion interval or maintenance interval is only disconnected from the adjacent operating part through the knife brake [2] [3]. If the operating part does not lose power, the isolation switch fracture at the ac withstand voltage may be broken down due to the reverse superposition of test voltage and operating voltage, thus threatening the safe operation of the operating equipment [4], as shown in Figure 1 a). Therefore, DL/T 555, DL/T 617 and DL/T 618 stipulate that connected equipment should be disconnected (power off and grounded) during GIS withstand voltage. In order to solve this problem, the frequency-phase controlled AC withstand technique of GIS is proposed. The frequency-phase controlled AC withstand technique is based on the Phase-locked loop [5]. By keeping the same frequency and same phase state between the test voltage and the operating voltage, it realizes the AC withstand voltage test of GIS under the condition that the original adjacent parts run normally without power failure [6]. Phase-locked loop (PLL) is a technolog...
ology that realizes frequency and phase synchronization by using feedback control principle. Its function is to keep the output clock in sync with the external reference clock. When the frequency or phase of the reference clock changes, the PLL detects this change and adjusts the output frequency through an internal feedback system until the two are resynchronized.

The frequency-phase controlled AC withstand technique of GIS test with adjacent equipment operating voltage (take bus voltage transformer secondary side voltage) as a reference voltage, test voltage accessed by the resonance method, and by using phase locked loop technique to real-time dynamic tracking of its frequency and phase, the test voltage and operating voltage frequency and phase in the condition of the same frequency and phase. The voltage waveform of the fracture under this state is shown in Figure 1 b).

![Figure 1. Voltage waveform in two states](image)

As shown in the figure, in the state of frequency-phase controlled, the operation part and the subject's joints between isolating switch fracture withstand voltage for the operating voltage and the difference between the test voltage absolute value, far less than the breakdown voltage power frequency of isolating switch fracture, therefore does not lead to the breakdown, isolating switch fracture nor the other is in charged of GIS in the running state of equipment.

1.2. Test System of the Frequency-Phase Controlled AC Withstand Technology

GIS frequency-phase controlled test equipment includes frequency-phase controlled control box, frequency-phase controlled power supply, test transformer, protective resistor, reactor and voltage measuring device. The structure of the test system is shown in Figure 2:

![Figure 2. Frequency-Phase Controlled Test system structure diagram](image)
The frequency-phase controlled control box is the core control unit of the whole test equipment, which has the functions of frequency-phase controlled, protection and monitoring. The frequency-phase controlled function should be able to realize the real-time tracking and adjustment of the test voltage to the reference voltage, realize the frequency-phase controlled, and the phase difference should not be greater than 1° under the frequency-phase controlled state.

Protection monitoring can realize real-time monitoring and device protection of key parameters such as test voltage, operating voltage, fracture voltage, phase difference and frequency. The protection function should include the frequency-phase controlled failure protection, high voltage overvoltage protection and high voltage flashover protection.

a) frequency-phase controlled failure protection function: when deviation and phase displacement occur between the test voltage and the reference voltage frequency, which exceeds the fixed value of the device protection, the frequency-phase controlled failure protection function will start, the test voltage will automatically reduce, and the pressure will stop.

b) High voltage overvoltage protection function:

1) When the test voltage exceeds the set protection setting value, the system will alarm and send a fault signal, immediately turn off the power output and stop the pressure.

2) When the break voltage of the isolation switch exceeds the set protection value, the system will alarm and send a fault signal, immediately turn off the power output and stop the pressure.

c) High pressure flashover protection function:

1) Monitor the test voltage and reference voltage. Once flashover is found, the system will alarm and send a fault signal, immediately turn off the power output and stop the pressure.

2) Monitor the break voltage of the isolation switch. Once the break is found, the system alarms and sends out a fault signal, immediately shuts down the power output and stop the pressure.

Frequency-phase controlled power supply: amplify the output signal of the frequency-phase controlled control box to produce high power output voltage. The power supply should be able to meet the test requirements.

Test transformer: the output voltage of the frequency-phase controlled power supply shall be raised to the appropriate test voltage, which shall be able to meet the requirements of the test voltage of the reactor and capacitive load under the minimum quality factor.

Reactor: the reactor shall be smooth and adjustable within a wide inductance range, and the inductance of the reactor shall be able to meet the test tuning requirements.

Protective resistors: The high-voltage output end of the test transformer shall be connected in series with protective resistors to reduce the overvoltage at the outlet of the high-voltage winding of the transformer during the test flashover or breakdown, and to limit the short-circuit current. The protection of resistance value generally is 0.1Ω/V~0.5Ω/V, and should have enough heat capacity and length. The resistance of the resistance value should not be more than 30kΩ, otherwise it will cause the normal work of the loop when produce larger pressure drop and power consumption. Protective resistors may be wound resistors or wire-wound resistors that shall pay attention to the strength of inter-turn insulation to prevent inter-turn flashover. The length of the protection resistor is chosen such that, in the event of a test breakdown or flashover, the protection resistor shall be free from surface flashover, and shall be of a length capable of withstanding the maximum test voltage and with an appropriate margin.

Voltage measuring device: Voltage measuring device should adopt the capacitive voltage divider with small phase error and good stability. At the same time, considering the reliability of the voltage divider, there should be no adjustable device on the low voltage measuring arm.

1.3. Test method of the Frequency-Phase Controlled AC Withstand Technology

1.3.1. Single bus connection GIS Test method for interval expansion or disassembly maintenance. For single busbar connection mode of GIS equipment, single or multiple interval extension or after repair of the same frequency and phase pressure test method as shown in figure 3, the test voltage by the expansion of the interval (or overhaul interval) for casing join, run the original bus keep running,
isolating switch busbar side DS2 disconnect, part from the run (e.g., secondary connection of busbar voltage transformer terminal) reference voltage.

![Diagram of Frequency-Phase Controlled AC withstand of Single bus GIS](image1)

**Figure 3.** Diagram of Frequency-Phase Controlled AC withstand of Single bus GIS

1.3.2. *Double-bus connection GIS Test method for interval expansion or disassembly maintenance.* For GIS equipment with double-bus connection mode, the single or multiple interval expansion or maintenance after the voltage withstand test method is shown in Figure 4. Test voltage by the expansion of the interval (or overhaul interval) for casing join (cable wire casing interval can be mounted to the test or from other overhead line interval to join), the original running bus I mother, II mother keep running, isolating switch busbar side DS2 and DS3 disconnect, bus coupler circuit breaker and isolating switch between disconnect, part from the run mother mother (such as I or II voltage transformer secondary terminal) reference voltage.

![Diagram of Frequency-Phase Controlled AC withstand of double bus GIS](image2)

**Figure 4.** Diagram of Frequency-Phase Controlled AC withstand of double bus GIS

2. **The application of Frequency-Phase Controlled AC Withstand Technology**
A power plant expanded the single bus 220kV GIS interval, but the GIS bus of the test could not be cut off. After discussion, it decided to adopt the frequency-phase controlled withstand voltage scheme. The GIS nameplates of the subjects are shown in the figure below:
The reference voltage should be selected from the adjacent operation part. The reference voltage can be extracted from the secondary terminals of the busbar voltage transformer or the secondary terminals of the line side voltage transformer. This test is extracted from the lower end of the test protection screen, as shown in the figure below. Special attention should be paid to avoid short circuit of secondary terminals of the voltage transformer during the process.

Figure 5. Information of GIS

Start up the device and adjust the reactor under low voltage to find the resonance point. The following figure shows the adjustable reactor and its control system.

Figure 6. Secondary signal sampling

Figure 7. Adjustable reactor
When the test voltage and reference voltage reach the state of frequency-phase controlled, the test equipment will be automatically adjusted. When the test voltage and reference voltage reach the state of same frequency and same phase, the voltage value and phase Angle will be observed during the boosting process. If there are many phase Angle deviations during the boosting process, the reactor can be fine-tuned to find the resonance point again. The withstand voltage scheme adopts the experience test. The sophistication test refers to the gradual application of alternating current voltage to the equipment, which can be applied in a stepped or continuous manner, for the purpose of:

a) Transfer the active particle impurities that may exist in the equipment to the low electric field area, where the risk of these particles to the equipment is reduced or even no harm;

b) Burn off fine particles or burrs on electrodes and dust attached by discharge.

Sophisticated test is the basic principle of both to achieve the purpose of purification equipment, and try to reduce the breakdown particles trigger in the process of purification, but also reduce the damage to the test equipment, which reduce the time of the equipment under high voltage function, so the pressure step by step, at low voltage can keep a long time, does not allow for a long time under high voltage withstand voltage. The sophistication test may be conducted as follows: $U_m/\sqrt{3}$ 5min→$U_m$ 3min→$U_f$ 1min, As shown in the figure below:

![Figure 8. Experienced test compression program diagram](image)

The specified test voltage shall be applied between each phase loop and the housing, one phase at a time, and the primary circuits of the other phases shall be connected to the ground housing. The voltage withstand test shall be applied to each component at least once, but care shall be taken to minimize the number of repeated voltages of solid insulation, and the test voltage may be introduced to different parts of the GIS main loop as far as possible. GIS ex-factory withstand voltage 460kV, according to the requirements of the regulations, the handover test withstand voltage value is 80% of ex-factory value, namely 460*0.8=368kV, as shown in the figure below:

![Figure 9. Control platform](image)
After the test, reduce the voltage and disconnect the power supply. The layout of the test site is shown in the figure. GIS withstands the specified test voltage without breakdown discharge according to the selected test procedure, and the test is passed.

Figure 10. Site layout

3. Conclusion
This paper first analyzes the test principle and method of the frequency-phase controlled withstand voltage technology, and then analyzes the test flow and its advantages according to the practical application of a power plant, which provides theoretical support and practical reference for insulation test during the extension or maintenance of GIS without power failure.

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