Working principle and testing technology of circuit breaker closing resistor for 1100kV GIS

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Abstract. The closing resistor can suppress the operation overvoltage and release the energy caused by the overvoltage generated by the power system when switching the line. It is widely used in the ultra-high voltage system AC system. Due to the complicated structure of the circuit breaker with the closing resistor, and the closing resistance of the field is placed in the sealed casing or GIS arc extinguishing chamber, regardless of whether the circuit breaker is in the closing or opening state, the closing resistance is usually not connected. The circuit breaker of GIS is more complicated than the open circuit breaker, especially the circuit breaker structure of 1100kV GIS which is the most complicated, and the maximum resistance of the closing resistor and the closing time of the closing resistor are tested. To understand this, it is very important to understand the working principle and testing technology of the ultra-high voltage circuit breaker. How to carry out preventive tests at the substation site and obtain the technical parameters of the closing resistor has become a key technical problem to be solved urgently. This paper expounds the structure of the ultra-high voltage circuit breaker, analyses the working mechanism of the closing resistor, and gives the method of on-site pre-test, combined with the Yucheng UHV ZF27-1100 (L) GIS circuit breaker to explain and give a case of on-site testing of the pre-input time of the closing resistor was made.

1. Introduction
The closing resistance of the circuit breaker can better limit the closing overvoltage in the ultra-high voltage AC system. From the perspective of controlling the overvoltage, there are mainly two types of combined over-voltage and single-phase reclosing overvoltage [1]. For a 1000kV AC system, even if the line length is a short line of 100 km, it is difficult to limit the closing overvoltage to the range specified by the regulations without using a closing resistor. In general, a longer resistance should be used for longer lines and a higher resistance for shorter lines. The closing resistor contact is generally a carbon sintered resistor sheet, and the flow capacity is very large.

During the closing process of the circuit breaker, the static and dynamic contacts must withstand the system recovery voltage. As the closing process deepens, the distance between the moving and static contacts becomes smaller and smaller. When the insulation strength between the moving and static contacts is insufficient to withstand the system recovery voltage, an arc is generated between the moving and stationary contacts. The arc can cause severe ablation of the contacts of the circuit breaker,
affecting the life of the circuit breaker. For this reason, a closing resistor is often installed on a circuit breaker for a UHV GIS. When the circuit breaker with the closing resistor is closed, the auxiliary contact in series with the closing resistor is closed ahead of the main contact for a certain time, and the oscillation energy in the absorption circuit is absorbed by the closing resistor, thereby reducing the recovery voltage between the main contacts, so the arc-extinguishing pressure of the main contact is reduced, and the auxiliary contact is automatically cut off after a few milliseconds after the main contact is closed. Generally, during the closing process of the closing contact, the return spring is continuously compressed when it is closed to a certain extent. When the closing resistance moving contact returns under the action of the compression spring force, the closing resistance auxiliary contact is opened, and when the closing resistance auxiliary contact is separated, the closing resistance mechanically exits the circuit, and the circuit breaker is opened. The closing resistor auxiliary contact does not operate [5]. The time when the auxiliary contact is closed earlier than the main contact is called the closing time of the closing resistor, which is a very important parameter for the inspection of the closing resistor circuit breaker. The effective access time of the closing resistor is generally $10\pm 2$ ms.

Generally speaking, a circuit breaker equipped with a closing resistor is more prone to accidents due to its complicated structure. After repeated flow, the characteristics of the closing resistor may change or be damaged by the impact of the current, which affects its function, so it is required to monitor the change of the resistance value. If the circuit breaker continues to be used, the high-voltage circuit breaker may explode if there is a defect in the closing resistance. Under normal circumstances, the allowable range of the resistance change of the closing resistor should not exceed $\pm 5\%$ of the rated value, whichever is determined by the equipment manufacturer. The circuit breaker closing resistor is generally placed inside the circuit breaker. It can only be opened during overhaul. It cannot be dissected normally. Therefore, it is impossible to use a single-arm bridge or a multimeter to directly connect the two ends of the gate resistor for resistance test during the pre-test. When the circuit breaker is in the open or closed state, the contact resistance of the closing resistor cannot be detected. The method of measuring the resistance of the closing resistor is generally divided into the resistance meter method and the S16 ray oscilloscope method [2]. The principle of the electric resistance method is to use the slow-coupled slow-sorting device of the circuit breaker provided by the manufacturer to slow down the circuit breaker, so that the circuit breaker works in an abnormal working state, and a multimeter or a single-arm bridge is used on both sides of the circuit breaker fracture. Phase test. The S16 ray oscilloscope method can be analysed from the waveform, and the signal is weak. In the region where the induced current is strong, the oscilloscope's vibrator deflects to cause the waveform of the oscilloscope to be distorted. If a standard non-inductive resistor is strung at the breaker break, the size and rated closing resistance are equivalent. The circuit breaker is actuated until the closing resistor is closed and then the port is closed. The shorting of the closing resistor causes the resistance of the total circuit to change. As long as the current or voltage on the standard resistor will also change, because the voltage equalization capacitance between the fractures is straight through, it is completely possible to treat the double fracture as a whole, and test it by external resistance oscilloscope method [6], as long as the standard is The current signal or voltage signal of the resistor is connected to the oscilloscope, and the size of the closing resistor and the effective access time can be analysed from the total current of the loop or the voltage drop oscillogram on the standard resistor. The voltage ratio method measures the closing resistor wiring as shown in Figure 1. The current ratio method is used to measure the closing resistor wiring as shown in Figure 2. The difference is that the former measures the voltage change across the standard resistor, while the latter measures the current change across the loop [3].
If the two sides of the circuit breaker and the closing resistor are connected to the equalizing ring by the connecting piece, for example, in the 500kV AC system, the insulating plate can be used to isolate them from the test, and the main contact and the closing resistor auxiliary contact are regarded as independent ports. Carrying out, usually the double-breaking with the closing resistor circuit breaker, can be divided into 4 separate ports according to the 5 L-box or T-joint for separate testing, using the slow-sort slow-synchronization to test the closing resistance resistance [4]. Because of the physical connection of the open circuit breaker, the test is relatively easy and will not be elaborated here. This paper will focus on the analysis of GIS breakers, parallel closing resistors, and the analysis of GIS series closing resistors.

2. Circuit breaker structure for 1100kV GIS

2.1. Arc extinguishing chamber and breaking structure

The main rated technical parameters of the ZF27-1100(L) type GIS breaker are: single pole parallel resistance value 600, the range is between -10% and 0, the shunt capacitance of each fracture is 1080±54pF, and the resistance fracture is closed in advance. The time is 8 to 11 ms. Under the rated oil pressure rated voltage, the opening time is 23.0±5, the closing time is 102±17ms, the opening speed is 8.0±1.0 m/s, and the closing speed is 3.0±1.0m/s [7].

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Figure 3. Internal structure of the ZF27-1100(L) GIS breaker body

Remarks: 2-1 tank, 2-2 conductor, 2-3 resistor unit, 2-4 main fracture, 2-5 resistance fracture, 2-6 resistor unit 2-8 conductor, 2-9 resistance measurement terminal 2 -10 pressure accumulator, 2-11 working cylinder, 2-12 adsorben t placement position, 2-13 support insulation cylinder, 2-14 hydraulic pump unit, 2-15 capacitor assembly.

The arc extinguishing chamber is placed in a tank filled with SF6 gas (2-1), and the breaking portion is mainly divided into a main fracture and a resistance fracture, and the two main fractures are arranged horizontally in series (2-4), and the two resistors are respectively arranged in two Directly below the main break (2-5), the resistor units (2-3) and (2-6) on both sides of the main break. After removing (2-2) and (2-3) at both ends of the circuit breaker, the remaining breaking parts can be supported and fixed by the supporting insulation barrel (2-13), and the conductors (2-2, 2-8) form an energizing circuit. The intermediate bottom position (2-12) of the casing is provided with an adsorbent for maintaining the normal state of the SF6 gas. As can be seen from Fig. 3, the single-pole parallel resistance value includes four resistors, both of which are 150 Ω. Such as 2-3 or 2-6.

Figure 4. Measuring terminal internal structure

Remarks: 2-9 measuring terminal (unit), 2-9-1 cover, 2-9-2 bolt, 2-9-3 measuring rod, 2-9-4 nut, 2-9-5 measuring terminal.

In the test of the opening and closing characteristics of the circuit breaker, the potential is drawn from the middle of the fracture, and the measuring terminal (2-9) is mounted on the can body (2-1). (Refer to Figure 3, the internal structure of this terminal (2-9) is shown in Figure 4. The following is how to use this terminal. Note: Do not use wires.

Please ensure that affiliations are as full and complete as possible and include the country [4]. The addresses of the authors’ affiliations follow the list of authors and should also be indented 25 mm to match the abstract. If the authors are at different addresses, numbered superscripts should be used after each surname to reference an author to his/her address. The numbered superscripts should not be inserted using Word’s footnote command because this will place the reference in the wrong place—at the bottom of the page (or end of the document) rather than next to the address. Ensure that any numbered superscripts used to link author names and addresses start at 1 and continue on to the number of affiliations. Do not add any footnotes until all the author names are linked to the addresses. For example, to format.
Figure 5. Breaking diagram of the ZF27-1100(L) GIS breaker body

Remarks: 2-4 main break, 2-4-1 movable static arc contact, 2-4-2 movable static main contact, 2-4-3 spout, 2-4-4 arc contact, 2-4-5 moving main contact, 2-4-6 pressure cylinder, 2-4-7 compression piston, 2-4-8 compression chamber, 2-4-9 insulation rod, 2-4-10 transmission linkage, 2-5 resistance fracture, 2-5-1 resistance moving contact, 2-5-2 resistance static contact, 2-15 capacitor bank assembly.

The breaking part is mainly divided into a main fracture and a resistance fracture. The main fracture (2-4) is composed of a movable contact and a movable contact on the opposite side, and the movable contact is driven by the main contact (2-4-5) and the moving arc. The contact (2-4-4) is configured, and the movable static contact is composed of a movable static main contact (2-4-1) and a movable static arc contact (2-4-2). The moving main contact (2-4-5) and the movable static main contact (2-4-2) are collectively referred to as the main contact, the moving arc contact (2-4-4) and the movable static arc contact (2-4-1) is collectively referred to as an arc contact. Since the main contacts and the arc contacts are separated at the time of breaking, the arc contacts are separated, and the main contacts are effectively protected. The moving contact side is designed with a pressure chamber (2-4-8) consisting of a pressure cylinder (2-4-6) and a compression piston (2-4-7). When the moving contact is driven in the opening direction, SF6 gas is compressed and the high pressure SF6 gas is blown out through the nozzle (2-4-3) to extinguish the arc. When splitting, the movable static contact passes through the double-action linkage device of the transmission link and the movable contact of the transmission link (2-4-10), so that the movable static contact and the movable contact simultaneously move in opposite directions (refer to the figure 4). The speed of the movement of the contact device by the link device does not necessarily increase, but the relative speed between the movable contact and the movable static contact is improved. The main fracture has a resistance fracture in parallel, and the resistance moving contact (2-5-1) and the resistance static contact (2-5-2) are in contact with the main fracture 8ms~11ms in advance, which can effectively limit the operation overvoltage. In addition, the capacitor unit (2-15) is installed in parallel with the main arc extinguishing chamber in the arc chamber, which improves the voltage sharing.

2.2. Closing resistor switching process

2.2.1. Internal equivalent electrical diagram

Figure 6. ZF27-1100 (L) GIS circuit breaker equivalent electrical diagram
Referring to the case of Figs. 3 and 5, an equivalent electrical diagram of Fig. 6 is depicted.

2.2.2. Main contact and auxiliary contact action diagram

- **a. Opening state (main break S2 is disconnected, auxiliary break S1 is open)**

  ![Diagram](image1)

  Voltage dividing capacitor C
  
  Main break S2
  
  Auxiliary fracture S1

- **b. Closing process (main break S2 is disconnected, auxiliary fracture S1 is closed)**

  ![Diagram](image2)

  Voltage dividing capacitor C
  
  Main break S2
  
  Auxiliary fracture S1

- **c. Closing state (main break S2 closed, auxiliary fracture S1 closed)**

  ![Diagram](image3)

  Voltage dividing capacitor C
  
  Main break S2
  
  Auxiliary fracture S1

- **d. Opening process (main break S2 closed, auxiliary fracture S1 open)**

  ![Diagram](image4)

  Voltage dividing capacitor C
  
  Main break S2
  
  Auxiliary fracture S1

Figure 7. Sequence of action of the main and auxiliary contacts of the closing resistor

**Closing action:** The sequence of the closing operation of the circuit breaker from the opening state is a→b→c, where the auxiliary fracture S1 in b is closed 8 ms~11 ms earlier than the main fracture S2, and the current flows through the main fracture S2, to limit the overvoltage generated by the closing operation; and when the closing resistor S1 is closed, the main breaker S2 is closed within 8ms~11ms, because the loop resistance of the main circuit is 100μΩ, which is far less than the gate resistance is several hundred ohms, causing the closing resistor auxiliary circuit to be short-circuited and current flowing through the main circuit. At this time, the circuit breaker reaches the state shown in Figure c. At this time, the auxiliary circuit S1 can open S1 within tens of milliseconds without current, and the circuit breaker reaches the d state, which is the closing state.

**Opening action:** The sequence of the circuit breaker starting from the closing state is c→d→a. At this time, the auxiliary circuit S1 can disconnect S1 within tens of milliseconds without current, and the circuit breaker reaches the d state. That is, the closing state. Then directly disconnect the main break S2.
It is worth noting that many documents show the closing state of Figure d, but the closing state of this closing state when it is not running. Because the circuit breaker is running, the circuit breaker's closing resistor auxiliary circuit has no current flowing. That is, the closing resistor auxiliary circuit S1 is disconnected.

2.2.3. Structural action
Closing action:
   a) Closing action of the electric blocking port—the resistance breaking contact (2-5-1) is moved in the closing direction by the insulating rod, and the resistance static contact (2-5-2) is also closed. Directional movement. Because the opening distance of the resistance fracture is smaller than the opening distance of the main fracture, the contact between the dynamic fracture and the static contact is 8 ms ~ 11ms, the dynamic and static contacts of the main fracture contact, and the resistor body is short-circuited. When the resistance is broken and the static contact is contacted, the resistance moving contact (2-5-1) continues to move against the resistance static contact (2-5-2) until the stroke is completed, and the closing operation of the resistance fracture is completed.
   b) After the closing action of the main break is transmitted to the moving main contact (2-4-5), the moving arc contact (2-4-4), the spout (2-4-3) and the pressure cylinder are driven. (2-4-6) Move to the left together. When moving to a certain position, the movable static arc contact (2-4-1) is first inserted into the arcing contact (2-4-4), that is, the moving arc contact. First closed. Immediately after the moving main contact (2-4-5) is inserted into the movable static main contact (2-4-2), the main conductive loop is turned on, and the main break closing operation is completed.

Opening action: When the hydraulic operating mechanism moves in the opening direction, the insulating rod (2-4-9) moves downward, and the main and resistance fractures are realized by the arm and the transmission link (2-4-10) brake.
   a) Main break: First, the movable main contact (2-4-2) and the moving main contact (2-4-5) are disengaged, then the movable static arc contact (2-4-1) and the moving arc contact the head (2-4-4) is separated. If the circuit breaker has a high voltage, an arc will occur between the arc contacts. When the moving main contact (2-4-5) moves in the opening direction, the SF6 gas in the cylinder (2-4-6) is compressed and then blown into the arc region through the nozzle (2-4-3). The arc is cooled and deliberated to extinguish, so that the strength of the medium between the fractures is quickly restored to achieve the purpose of breaking the rated current and various fault currents.
   b) Electric blocking port: The resistance moving contact (2-5-1) moves to the right at high speed under the tension of the opening. At this time, the resistive static contact (2-5-2) which is pressed is also under the action of the spring force. Move to the right, when moving to a certain position, the resistive moving contact (2-5-1) and the resistive static contact (2-5-2) are disengaged, and then the resistive static contact (2-5-2) is restored to the original position. After the trip, the opening action is completed. When the brake is opened, the resistance fracture is disconnected ahead of the main fracture for a certain time, and no current flows through the resistor during the opening process.

3. Field Test Technology for Circuit Breaker Closing Resistor for GIS
After the circuit breaker is installed in the field, the resistance of the closing resistor can only be tested when the can is inspected and cleaned. Under normal circumstances, only the external resistance oscilloscope method can be used. For details, please refer to Figure 1 and Figure 2. It is worth noting that if DC voltage test is used, it is recommended to use 220VDC, use QJ23 type single-arm bridge, and the oscilloscope adopts FLUKE196B type oscilloscope. The oscilloscope adopts frequency of 100 MHz and the maximum time base speed can reach 2ns/div. It can meet the test requirements. Because the circuit breaker closing time is short, if the manual manual wave recording method is adopted, it is difficult to capture the effective waveform. Therefore, the oscilloscope should use the pulse trigger mode. When the external signal is abrupt, the recording can be automatically started.

The ZF27-1100(L) GIS circuit breaker, which is mainly explained in this paper, is tested by Handy GKC443E test instrument. The basic principle of the instrument is to capture the current signal in the
test circuit during the closing process of the circuit breaker. The method is similar. Figures 1 and 2, where the instrument has a sampling frequency of 100 kHz. The sampling frequency is lower than that of the oscilloscope, which results in weak data signals in Figures 8 and 9. Because the collected signal is the current signal between the fractures, it is recommended to increase the voltage between the fractures, and more obvious data has been obtained.

The field circuit breaker is in the state of inspection, and the ground knives on both sides are closed. In order to extract the ports on both sides of the circuit breaker, the grounding piece of the grounding knife gate is removed, and the test wire is directly inserted into the grounding side of the grounding knife gate. A knife on one side can be used on site. If it is necessary to test the closing resistance of the individual fractures, it is recommended to refer to the extraction potential in the middle of the fracture using the measuring rod in Figure 4. The two-sided grounding tool does not need to remove the connecting piece between the grounding knife gate and the grounding. In this example, the grounding lug of the one-sided grounding knife is removed. The test data is shown in Figures 8, 9, and 10.

![Figure 8. Field test data 1](image)

![Figure 9. Field test data 2](image)
It can be seen from Fig. 7 and Fig. 8 that during the closing of the closing resistor, the current in the loop has undergone a great change. The specific data is in Table 1.

Table 1. Field loop monitoring current status.

| Test time (ms) | 91.7 | 92.6 | 94.3 | 95.2 | 102.21 | 106.5 |
|---------------|------|------|------|------|--------|-------|
| Number of current peaks in the loop | 1    | 2    | 3    | 4    | 5      | 18    |

Among them, the first to fourth currents have the same magnitude, so it is recognized that the first time is the pre-input time of the closing resistor, the second to fourth times is the process of the closing contact of the closing resistor, and the fifth pole of the current appears. Large value (the first maximum value, about 25 times of the first time), the main fracture is closed, and the closing resistance is shorted, so that the current value of the whole circuit has a maximum value, and the subsequent 6-18 The current value in the secondary circuit fluctuated, and it was determined that the main contact bounced process 13 times. After the last time, the current became stable and the closing process was completed. The instrument analysis data shows that the closing time is 102.21ms, the number of bounces is 13 times, the bounce time is 4.23ms, and the pre-input time of the closing resistor is 10.5ms, which satisfies the test requirements.

4. Conclusion

An electrical circuit is constructed using a high-speed sampling frequency, supplemented by a series-connected sampling resistor. Whether it is excited by voltage source or current source, setting the relevant judgment threshold for the change of current signal or voltage signal in the loop is the key technology to solve the pre-input time of the test closing resistor and the resistance value of the closing resistor. Comparing the amplitude and timing of the captured signal during the test, it will be possible to directly use the relevant data operation to obtain the resistance of the closing resistor, which is feasible.

The position of the test break used is different for the structure in the circuit breaker, but the detailed circuit breaker working principle is the basis of the test no matter how the test position is selected. The common structure is divided into two types: the closing resistance of the closing resistor is a series connection with the main fracture and the closing resistance is connected in series with the auxiliary fracture and then connected in parallel with the main fracture.

Affected by various factors such as on-site interference, equipment structure and test equipment, the field test of the closing resistor is still in a blind spot. At present, there is no mature one, and the instrument that can test the resistance of the closing resistor and the pre-input time appears.


References

[1] Rongrong J., Qiang Y., Fei S., Ke S., Jiamiao C., Hao Z. (2011) Applicability of closing resistors for super/UHV AC transmission line circuit breakers. Power Grid Technology, (1): 18-25.

[2] Sheng B L, Jansson E, Blomberg A, et al. A new synthetic test circuit for the operational tests of HVDC thyristor modules. IEEE Applied Power Electronics Conference and Exposition, Anaheim California, USA, 2001.

[3] Luping J., Xiangjun Z., Guoxiang L. (2010) Measurement method of closing resistance of ultra-high voltage circuit breaker. Journal of Electric Power Science and Technology, 25(4): 87-90, 95.

[4] Kaiku W., Chao H. (2010) Field Test of Characteristic Parameters of Circuit Breaker with Closing Resistor. Journal of Anhui Vocational College of Electrical Engineering, 15(3): 39-42.

[5] Wei Z., Yunxue Z., Yuhong Z. (2013) Research and development of SF6 circuit breaker for 1100kV GIS. High Voltage Apparatus, 49(10): 26-31.

[6] Yi L. (2010) Field Test of Closing Resistor of 750kV Circuit Breaker. Sichuan Hydropower, 29(6): 269-272.