Discussion on the method of measuring the loop resistance of high voltage circuit breaker by double-ended grounding technology

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Abstract. Loop resistance is an important technical indicator reflecting the performance and operating status of high-voltage circuit breakers. The traditional test method requires at least one side of the grounding switches of the circuit breaker be opened, and the field operation needs to wait for the dispatch approval, so the work efficiency is extremely low. According to the actual requirements of on-site measurement of high-voltage circuit breakers, a test method and test scheme have been proposed in this paper for measuring loop resistance by using the double-ended grounding technology. At the same time, according to the structural characteristics of high-voltage circuit breaker, the test deviation between the method and the traditional test method is analyzed and compared. Finally, it is concluded that the test method for measuring the loop resistance through using the double-ended grounding technology can fully meet the actual needs of the project.

1. Introduction

The high-voltage circuit breaker shoulders the dual tasks of control and protection in the power system, and its state directly affects the safe operation of the power system. The loop resistance is an important indicator reflecting the performance and operating status of the high-voltage circuit breaker, which directly affects the temperature rise of the circuit breaker while it is under rated working current and the dynamic and thermal stability under the short-circuit condition, thus affecting the reliability and security of the opening and closing of the circuit breaker. Through the measurement of the circuit breaker’s loop resistance, the wear degree of the contact and the contact condition of the circuit can be effectively evaluated, and the service life of the contact can be predicted to some extent. And the test items of circuit resistance have clear requirements in the factory test, type test, handover test and preventive test of the circuit breaker.

The traditional loop resistance measurement of high voltage circuit breaker is to open the grounding switch on one side when the circuit breaker is closed and measure it by dc voltage drop method. However, according to the relevant regulations of the power company, the on-site operation of the grounding switch needs to apply for dispatch approval, and the whole process is cumbersome, resulting in low on-site work efficiency. According to the actual requirements of on-site measurement of high-voltage circuit breakers, a test method and test scheme have been proposed in this paper for measuring loop resistance by using the double-ended grounding technology. At the same time, according to the structural characteristics of high-voltage circuit breaker, the test deviation between the method and the traditional test method is analyzed and compared. Finally, it is concluded that the test method for measuring the loop resistance through using the double-ended grounding technology can fully meet the actual needs of the project.
2. Principle of loop resistance measurement

In the substation, the loop resistance tester is often used to accurately measure the loop resistance of the high voltage circuit breaker by the voltage and current four-wire measurement method. The principle is usually based on DC voltage drop method, which generates high frequency current by switching high-frequency power supply, rectifies it into 100A DC power supply through rectifier circuit, and applies it to both sides of high voltage circuit breaker as test current. When the test current flows through the high-voltage circuit breaker, voltage drop occurs. The internal sampling circuit of the loop resistance tester simultaneously samples the voltage input terminal and the internal current shunt voltage, and the obtained signal is amplified, processed by the A/D converter, and then processed by the single-chip microcomputer, which calculates the loop resistance value according to the algorithm. The test principle is shown in Figure 1. UX is the voltage drop across the high voltage circuit breaker, RX is the loop resistance of the high voltage circuit breaker, Ur and Rr are the voltage drop and resistance of the standard shunt inside the circuit resistance tester respectively, I is the test current flowing through the shunt and the circuit of the high-voltage circuit breaker. According to the principle that the current of series circuit is equal—\(I = \frac{UX}{RX} = \frac{Ur}{Rr}\), the loop resistance can be obtained by the following formula.

\[RX = \left(\frac{UX}{Ur}\right) \ast Rr\]  \hspace{1cm} (1)

Where UX and Ur are obtained by internal sampling circuit’s sampling voltage input terminal and internal current shunt voltage.

3. Traditional test method for loop resistance value of high voltage circuit breaker

Common high-voltage circuit breakers in substations are divided into single-break circuit breakers and multi-break circuit breakers according to the fracture structure of interrupter. Single-break circuit breakers are generally used in power systems of 220 kV and below, and multi-break high voltage circuit breakers are generally used in power systems of 500 kV and above, as shown in Figure 2. The traditional loop resistance measurement, whether the high-voltage circuit breaker is single-break or multi-break, has consistent measurement method and principle.
voltage line and current line are connected to both sides of high voltage circuit breaker according to the requirement of four-wire method. When the circuit breaker is closed, one side of the grounding switch is opened and the other side of the grounding switch is grounded. At the same time, the DC voltage drop method is used for measurement. The test principle is shown in Figure 3. R1 and R2 are circuit resistances of the double-break high-voltage circuit breaker, which are in series in the circuit. The grounding switch on one side of the circuit breaker is grounded and the one on the other side is opened. That is to say, the potential UP2 at P2 is 0, and the current flows to the ground through the grounding switch.

![Figure 3. Traditional loop resistance test schematic](image_url)

According to the figure:

\[ U_X = U_{P1} - U_{P2} = U_{P1} \]

\[ R_X = (R_1 + R_2) \]

According to the principle that the current of series circuit is equal:

\[ I = \frac{U_X}{R_X} = \frac{U_r}{R_r} \]

That is, the loop resistance can be obtained by the following formula.

\[ R_X = (R_1 + R_2) = (U_{P1} / U_r) \times R_r \]

(2)

For a single-break circuit breaker, there is only one loop resistance, so one of R1 or R2 is 0, and the formula 2 can still be used. To test the loop resistance value of fracture 1 or 2 separately, simply connect the voltage line to the fracture to be tested.

The traditional loop resistance measurement requires the operation of grounding switches. Since the field operation needs to wait for the dispatch approval according to the relevant regulations of the power company, which requires cumbersome process and long waiting time, the work efficiency is low. Therefore, according to the actual requirements of on-site measurement of high-voltage circuit breakers, a test method and test scheme have been proposed in this paper for measuring loop resistance by using the double-ended grounding technology.

4. Double-ended grounding technology for measuring circuit breake’s loop resistance

Loop resistance is generally the physical quantity which is measured when the high-voltage circuit breaker is in the maintenance state. At this time, the high-voltage circuit breaker is grounded at both ends, that is, the grounding switches on both sides are in the closing position, as shown in the following figure.
The equivalent schematic diagram that high voltage circuit breakers with different fractures are grounded at both sides is shown as follows.

As shown above, RJD1 and RJD2 are grounding resistors of grounding switches on both sides, and RX is circuit resistance of high voltage circuit breaker. Taking the double-break high-voltage circuit breaker as an example, when the grounding switches at both ends are closed, R2, RJD1 and RJD2 circuits and R1 circuits are in parallel:

\[ U_1 = I_1 \times R_1 = I_2 \times (R_2 + R_{JD1} + R_{JD2}) \]
\[ I = I_1 + I_2 = \frac{U_r}{R_r} \]

According to the literature, when the high-voltage circuit breaker is in the maintenance state, the grounding switches at both ends are grounded at the same time, and the earth conduction resistance is generally about 200mΩ, while the circuit resistance of the high voltage circuit breaker, such as one that is 500kV, is about 50μΩ. The difference between the two is nearly 1000 times, so I2 will be very small, the current mainly goes through the R1 loop, and the R2, RJD1, and RJD2 loops can be approximated as open circuit. As a result, it can be concluded that:

\[ I \approx I_1 = \frac{U_r}{R_1} = \frac{U_r}{R_r} \]
\[ R_1 \approx \left( \frac{U_1}{U_r} \right) \times R_r \]  \hspace{1cm} (4)

The same procedure may be easily adapted to obtain \( R_2 \) and \( R_X \).

5. Measures to improve measurement accuracy

When the two ends of the circuit breaker are grounded, the following conditions may affect the measurement of loop resistance of the high voltage circuit breaker.

(1) Overcome the influence of lead resistance of voltage and current. The loop resistance measurement for high-voltage circuit breakers is required to be accurate, and the influence of the voltage and current lead resistance of the loop-resistance measuring instrument on the measurement results cannot be ignored, so effective measures must be taken to overcome the influence. To achieve this goal, the common four-terminal lead mode is adopted in this paper, as shown in the figure below.

![Figure 6. Design of four-terminal lead](image)

R1 ~ R4 are the voltage and current lead resistance of loop-resistance measuring instrument (including contact resistance), RX is the measuring resistance, AP is the instrument amplifier. Normally, due to the high input impedance of AP, the current flows only through R1 and R2 and is added to RX. R3 and R4 have no current flow, the voltage drops to 0, and the input voltage of AP is the voltage across RX, thus the influence of R3 and R4 is overcome.

(2) The influence of poor contact of the grounding switch. When the high-voltage circuit breaker is closed, the through-flow part composed of the earthing network, switch, cable, and high-voltage circuit breaker is complete. If the grounding switch is in poor contact, the grounding resistance will increase. According to equation (3), the shunt of the grounding switch is smaller, so the error of measured loop resistance by the double-ended grounding method is smaller.

(3) Reduce the influence of electromagnetic interference generated by the power frequency signal on the measurement accuracy. For the influence of electromagnetic interference that may be generated by the power frequency signal on the measurement accuracy, a battery power supply scheme and a power frequency filtering circuit are used from the hardware perspective, and multiple data sampling and digital filtering are used from the software perspective, and average value is obtained after filtering interference.

6. Example Analysis

In this paper, double-terminal grounding technology is adopted to carry out loop resistance test for five 500kV high-voltage circuit breakers in a substation of Guangxi Power Grid. The measurement principle is shown in Figure 7. According to the manufacturer's design drawings, the design values of R1 and R2, that is, the loop resistance of 550kV circuit breaker’s fracture, as well as the on-site measured conduction resistance R3 and R4 of 5 circuit breakers’ spacer grounding switches and earthing network are shown in table 1.
Figure 7. Loop resistance measurement diagram of high voltage circuit breaker in a station of Guangxi Power Grid

Table 1. Measured on-resistance of the grounding switch and the earthing network

| Circuit Breaker | Voltage Grade | \( R_1 \) (\( \mu \Omega \)) | \( R_2 \) (\( \mu \Omega \)) | \( R_3 \) (\( m \Omega \)) | \( R_4 \) (\( m \Omega \)) |
|-----------------|---------------|-----------------|-----------------|-----------------|-----------------|
| 1               | 500kV         | 50              | 50              | 200             | 210             |
| 2               | 500kV         | 50              | 50              | 205             | 210             |
| 3               | 500kV         | 50              | 50              | 210             | 215             |
| 4               | 500kV         | 50              | 50              | 220             | 220             |
| 5               | 500kV         | 50              | 50              | 208             | 210             |

From the field measurement results, it can be seen that the on-resistance \( R_3 \) and \( R_4 \) of the grounding switch and the earthing network are not exactly equal, which is mainly due to the good condition of the grounding switch’s contact. Moreover, according to the numerical values of \( R_3 \), \( R_4 \), \( R_1 \) and \( R_2 \), the on-resistance of the grounding switch and the earthing network is about 4,000 times higher than the circuit breaker’s loop resistance. Assuming that the contacts of the circuit breaker are in good condition, the measured data of the traditional method should be close to the design value. Then the above principle formula (4) of measuring the loop resistance of the circuit breaker by the two-terminal grounding technology can be used to calculate the circuit breaker’s loop resistance and its error accuracy under the two-terminal grounding technology, the results are shown in Table 2.

Table 2. Measured on-resistance of the grounding switch and the earthing network

| Circuit Breaker | Voltage Grade | Design Value | Calculated Value | Error Precision |
|-----------------|---------------|--------------|------------------|----------------|
|                 |               | \( R_1 \) (\( \mu \Omega \)) | \( R_2 \) (\( \mu \Omega \)) | \( R_1 \) (\( m \Omega \)) | \( R_2 \) (\( m \Omega \)) |
| 1               | 500kV         | 50           | 50              | 49.975          | 49.975          | 0.001%          |
| 2               | 500kV         | 50           | 50              | 49.985          | 49.985          | 0.001%          |
| 3               | 500kV         | 50           | 50              | 49.975          | 49.975          | 0.001%          |
| 4               | 500kV         | 50           | 50              | 49.995          | 49.995          | 0.001%          |
| 5               | 500kV         | 50           | 50              | 49.965          | 49.965          | 0.001%          |

It can be seen from the results that the error accuracy of measuring circuit breaker’s loop resistance using the double-terminal grounding technology is 0.001%, which is less than the error accuracy requirement of 0.05% and meets the accuracy requirement of field test. Therefore, the test method of measuring circuit resistance using the double-terminal grounding technology can fully meet the requirements of engineering practice.

7. Conclusion
In this paper, the test method and test scheme for measuring loop resistance by double-ended grounding technology are proposed. At the same time, according to the structural characteristics of high-voltage circuit breaker, the loop resistance of five 500kV high-voltage circuit breakers in a substation of Guangxi Power Grid is calculated by double-ended grounding technology. This method and traditional method are verified through the results of the loop resistance and the error precision. The result shows that the method of measuring loop resistance by using double-terminal grounding technology proposed in this paper can fully meet the needs of engineering practice, and can effectively
improve the work efficiency on site.

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