Measurement and Analysis of 220kV Overhead Transmission Line Parameters

Minhu Xu1,*, Yun Guo1, Yubo Shen1, Kexin Zhang1, Dewen Zhang1, Siwei Han1, Sen Lan1, Heqian Liu1, Hang Zhang1, and Chao Xu1

1State Grid Heilongjiang Electric Power Co., Ltd. Electric Power Research Institute, Harbin, Heilongjiang, China

*Corresponding author e-mail: 474668221@qq.com

Abstract. This paper introduces the items and principles of transmission line parameter test, finds out the interference factors through the detailed analysis of the field test results, and puts forward the relevant precautions.

1. Introduction
Before the newly-built, rebuilt, broken and diameter changed 220kV and above transmission lines are put into operation, in addition to checking the line insulation and checking the phase, various power frequency parameter values should be measured as the actual basis for calculating the system short-circuit current, relay protection setting, calculating power flow distribution and selecting reasonable operation mode. The line power frequency parameters include DC resistance R, positive sequence impedance Z1, zero sequence impedance Z0, positive sequence capacitance C1, zero sequence capacitance C0 and zero sequence mutual inductance impedance ZM of adjacent lines [1-4].

Although the line power frequency parameters can be obtained by calculation, there is often deviation between the calculated value and the actual value due to the factors such as the environment, geology and erection mode of the line. Before line parameter test, the original data of relevant lines shall be collected, such as line name, line length, tower type, conductor model and number of split pieces, three-phase arrangement, average distance between phases and ground wire specifications, etc., and the commissioning scheme shall be prepared in combination with the actual situation on site [5-7].

2. Testing principle and method

2.1. Insulation Resistance Measurement

The measurement of insulation resistance is to check the insulation condition of the line and whether there are defects such as grounding or short circuit between phases. When measuring, short-circuit the two non-measured phases to the ground, and use a 2500~5000V megger to measure the insulation resistance between each phase and the ground in turn. After the measurement, the circuit should be discharged. The wiring diagram is shown in Figure 1.
2.2. Check Phase

It is usually necessary to check whether the phases at both ends of the line are the same to avoid short-circuit accidents when it is put into operation. The test terminal energizes one of the phases, the end is grounded, and both ends of the other two phases are suspended. If the megohmmeter indicates zero, the head and the end belong to the same phase. The wiring diagram is shown in Figure 2.

2.3. DC Resistance Measurement

The purpose of measuring DC resistance is to check the line connection and the quality of the wires. The test adopts the DC current and voltmeter method, and the three-phase reliable short-circuit with a short-circuit wire with sufficient cross-sectional area at the end, as shown in Figure 3. Measure the DC resistance R_AB, R_BC, R_CA between AB, BC, and CA, and then convert them into DC resistances R_A, R_B, R_C for each phase per kilometer. The conversion formula is as follows:

\[
R_A = \frac{(R_{AB} + R_{AC} - R_{BC})}{2L} (\Omega/\text{ph\cdot km}) \tag{1}
\]

\[
R_B = \frac{(R_{BC} + R_{AB} - R_{AC})}{2L} (\Omega/\text{ph\cdot km}) \tag{2}
\]

\[
R_C = \frac{(R_{AC} + R_{BC} - R_{AB})}{2L} (\Omega/\text{ph\cdot km}) \tag{3}
\]

2.4. Positive Sequence Impedance Measurement

As shown in Figure 4, short-circuit the three phases to the ground at the end of the line and apply a three-phase symmetrical voltage at the head end of the line. When the applied test current reaches 12A, the instrument will automatically calculate it according to the measured voltage, current, power and test frequency. The positive sequence impedance Z_1, the positive sequence resistance R_1, the positive
sequence reactance $X_1$ and the impedance angle $\Phi_1$ are obtained. The unit length value of $R_1$ (\(\Omega/km\)) mainly depends on the wire diameter, the unit length value of $X_1$ is within the range of $0.36\pm25\%$, and the positive sequence impedance angle $\Phi_1$ is approximately between $70^\circ$ and $85^\circ$.

![Figure 4. Wiring diagram of positive sequence impedance test](image)

2.5. Zero Sequence Impedance Measurement

The wiring is shown in Figure 5. The single-phase voltage is applied to the three phases of the line from the output of the variable frequency power supply through the input-output end of the tester, and the corresponding zero sequence impedance $Z_0$, zero sequence resistance $R_0$, zero sequence reactance $X_0$ and impedance angle $\Phi_0$ are measured. Generally, the zero sequence impedance is about 3 times the positive sequence impedance, but due to the different types of overhead ground wires, estimate the zero sequence impedance $X_0 = (2.0\sim4.6)X_1$.

![Figure 5. Wiring diagram of zero sequence impedance test](image)

2.6. Positive Sequence Capacitance Measurement

The test wiring is shown in Figure 6. During the test, the end of the line is open, and the head end of the line applies a three-phase symmetrical voltage to the three phases of the line. When the test voltage reaches 750V, the corresponding data is sampled to obtain the positive sequence capacitor $C_1$. The overhead general positive sequence capacitor $C_1$ is about 9000PF/km.

![Figure 6. Wiring diagram of positive sequence capacitance test](image)
2.7. Zero Sequence Capacitance Measurement
The wiring is shown in Figure 7. The output of the variable frequency power supply applies a single-phase voltage to the three phases of the line through the input-output end of the tester, and the corresponding test voltage, current, and frequency are measured to obtain the zero sequence capacitance $C_0$. The zero sequence capacitance $C_0$ of the overhead line is approximately 0.6 to 0.8 times the positive sequence capacitance $C_1$ of the line.

![Figure 7. Wiring diagram of zero sequence capacitance test](image)

2.8. Mutual Inductance Impedance Measurement
In two parallel circuits, if an asymmetric short-circuit current flows through one circuit, the other circuit will have induced voltage or current due to mutual inductance, which may cause the relay protection to malfunction. Therefore, the influence of mutual inductance must be considered. The wiring for measuring mutual inductance is shown in Figure 8. When measuring, short-circuit the first and last three phases of the two circuits, and ground the ends. Apply a single-phase voltage to one of the circuits, when the current reaches 12A, measure the induced voltage on the other circuit, and calculate the corresponding mutual inductance $Z_m$ through the instrument.

![Figure 8. Zero-sequence mutual inductance impedance and mutual inductance wiring diagram of double-circuit line](image)

3. Data analysis
When the transmission line passes zero-sequence current, the three-phase zero-sequence current has the same magnitude and phase. Therefore, it is necessary to use the earth and overhead ground wires to form the path of the zero sequence current, so that the zero sequence impedance of the transmission line is related to the distribution of the current in the ground. During the field test, the zero sequence impedance test value often differs from the theoretical estimate value, which brings a lot of trouble to the test work. The following will focus on this issue, analyze the 220kV xiqian line field test data, and find out the cause of the data deviation. The outline of the route is as follows:

The line is 2.222 kilometers long and has 11 base towers. Newly built overhead line 4 base double circuit iron tower, 1 base single circuit iron tower "π" out xiqian substation is connected with yuancheng west line No. 14, length 1.268 km, conductor type LGJ-240/40, ground wire type 2 OPGW optical cables; yuancheng west The length of yuancheng west line No. 14 to haxi for the primary transformation is 0.954 kilometers, the wire type is $2 \times$ LGJ-300, the ground wire type is GJ-50 steel stranded wire and OPGW optical cable.
Table 1. Parameter data with wave trap.

| Xiqian A line | Test value (per phase / km) |
|---------------|----------------------------|
| R (Ω)         | X (Ω)                      | Z (Ω) | Φ (0)   |
| Positive order| 0.0750                     | 0.5180 | 0.5234 | 81.755 |
| Zero sequence | 0.4709                     | 1.1537 | 1.2462 | 67.795 |

After analysis, the large reactance is caused by the short distance of the line and the excessive proportion of the reactance value of the wave traps at the B and C phases at the end of the line test to the total reactance value. The inductance value of each wave trap is 2mH, calculated by $X=2\pi fL$. After removing the influence of the wave trap, the data is shown in Table 2. The zero-sequence resistance is large because the zero-sequence current forms a loop through the earth and overhead ground wires. The grounding resistance of the tower and the grounding resistance of the substation at both ends are also included in the zero-sequence resistance value. From $\Phi=\tan^{-1}(X/R)$, we can see that the increase of resistance leads to the decrease of angle.

Table 2. Parameter data after calculating and eliminating the wave trap.

| Xiqian A line | Test value (per phase / km) |
|---------------|----------------------------|
| R (Ω)         | X (Ω)                      | Z (Ω) | Φ (0)   |
| Positive order| 0.0750                     | 0.3296 | 0.3380 | 77.181 |
| Zero sequence | 0.4709                     | 0.9653 | 1.0740 | 63.996 |

4. Precautions
Before testing, if you need to ground, you must first confirm that the ground is good to prevent induced voltage shock and instrument damage. At the same time, all short circuits, grounding and lead wires should have sufficient cross-sections;

In the process of short circuit test, for the circuit with wave trap, it should be thrown off during the test, which can be realized by opening the ground and lower lead;

The line PT has an impact on the capacitance test and should be discarded;

During the test, it was also found that when measuring one circuit of the double circuit line on the same pole, the other non-tested circuit was open at one end and grounded at the other end and grounded at both ends. The measurement results are quite different in these two states. In order to reduce the influence of mutual inductance on the measured value, it is advisable to ground one end of the non-test line and the other end to be suspended.

5. Conclusion
Although the physical parameters of the line will not change for a considerable period of time, after long-term operation, due to the aging of the wire, the change of high soil resistivity, or the influence of factors such as climate, environment and geography, the line parameters may change. The zero sequence impedance parameters of overhead transmission lines are related to factors such as the tower structure, geology and grounding grid. The greater the soil resistivity and ground resistance, the greater the zero sequence impedance.

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