Research on the Measurement of Zero Sequential Equivalence Impedance of Double-circuit Transmission Lines

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Abstract. The measurement of transmission line parameters is often affected by adjacent lines, especially the measurement of zero-sequence impedance parameters is affected by mutual inductance between lines, thus affecting the measurement results. This paper establishes the double-circuit transmission line model to verify the change of zero-sequence impedance parameters of transmission lines when the spatial layout of double-circuit transmission line in different interference signal carriers and the size of interference signal are different. The variation law of zero-sequence impedance parameters of transmission line affected by interference lines is summarized. It provides a reference for the subsequent setting of relay protection devices for transmission lines.

1. Introduction
Transmission line is an important part of the power system. Inaccurate measurement of line parameters will lead to a series of problems such as protection error of the system or inaccurate fault location after line failure, thus affecting the stable operation of the power grid [1-2]. In this paper, the SIMULINK electromagnetic simulation model of double-circuit transmission line under different interference signal carriers and different interference signals is established. The variation of equivalent zero-sequence impedance parameters of the measured circuit is measured under different soil resistivity, different circuit structure and different circuit distance when the adjacent circuit passes through different zero-sequence currents. Analyse the difference of zero-sequence impedance parameters of measured lines measured by anti-interference measurement and interference decoupling measurement in different influencing factors and obtains the range of equivalent zero-sequence impedance parameters of the tested line measured, which provides reference for the setting of line relay protection device and improves the accuracy of relay protection device operation and the practicability of parameters.

2. Parameter measurement model of double-circuit transmission line
Fig.1 is a measurement model of double-circuit transmission line parameters (double circuit is completely transposed, the three-phase parameters are symmetric and the added power supply is symmetric [3]). Among them, the line N is the measured line and the line M is the live running line. Z₁ and Z₂ are the self-impedance and Z_M is the mutual impedance, Z_L is the load of operating line, I₁ is the zero-sequence current flowing over line N and I₂ is the zero-sequence current flowing over line M. U_{11} and U_{12} are the zero-sequence voltage at both ends of line N, U_{21} and U_{22} are the zero-sequence voltage at both ends of line M.
The circuit equation is:

$$\begin{bmatrix} \Delta U_1 \\ \Delta U_2 \end{bmatrix} = \begin{bmatrix} U_{11} - U_{12} \\ U_{21} - U_{22} \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_M \\ Z_M & Z_{22} \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

(1)

The equivalent zero sequence impedance of the measured transmission line after disturbance decoupling can be expressed as:

$$Z_0 = \frac{\Delta U_1}{I_1} = Z_{11} + \frac{I_1}{I_2}Z_M$$

(2)

### 3. Analysis of influence of zero-sequence impedance parameters of line

#### 3.1 The influence of mutual inductance between lines

In order to study the influencing factors and influences of the interference line on the zero-sequence impedance parameters of the measuring line, this paper simulates and analyses the four factors from the soil resistivity, the spacing between the double-circuit lines, the tower structure of the transmission line and the zero-sequence current on the interference line [4-6]. The variation of the zero-sequence impedance parameters of the tested line.

#### 3.1.1 The effects of soil resistivity

This section studies the effect of soil resistivity changes on zero sequence impedance parameters. In various engineering calculations, $D_g$ is usually taken as 1 km, the equivalent soil resistivity across the line is $\rho = 114.78 \Omega \cdot m$. However, measured results show that different soil conditions have a greater influence on soil resistivity: the minimum is $10 \Omega \cdot m$ and the maximum is up to $4,000 \Omega \cdot m$. And the soil resistivity along a transmission line is not constant. The variation of zero sequence impedance parameters under different soil resistivity is shown in the Tab.1.

| Soil resistivity | Impedance  | 10    | 114.78 | 500   | 1000  | 2000  | 3000  | 4000  |
|------------------|------------|-------|--------|-------|-------|-------|-------|-------|
| Two-circuit      | $Z_{01}$ ($\Omega \cdot km$) | 0.988 | 1.181  | 1.301 | 1.357 | 1.413 | 1.446 | 1.469 |
|                  | $Z_m$ ($\Omega \cdot km$)      | 0.612 | 0.806  | 0.925 | 0.982 | 1.036 | 1.071 | 1.094 |
| Single-circuit   | $Z_{02}$ ($\Omega \cdot km$)   | 0.989 | 1.182  | 1.301 | 1.357 | 1.413 | 1.445 | 1.468 |
|                  | $Z_0$ ($\Omega \cdot km$)       | 1.004 | 1.207  | 1.335 | 1.395 | 1.456 | 1.491 | 1.516 |

From the above table and the figure, it can be seen that the zero sequence impedance parameters in the double circuit line increase with the $\rho$, but the increase rate decreases gradually. In the process of $\rho$ increasing from 10 $\Omega \cdot m$ to 114.78 $\Omega \cdot m$, the maximum value of zero sequence self-impedance increase is 19.496 %; The maximum increase in zero sequence mutual impedance was 31.541 %. Therefore, the influence of soil resistivity on zero-order impedance parameters of transmission lines should be taken into account when calculating line parameters.

#### 3.1.2 The effects of the distance of the different circuits

In this section, the influence of the relative distance between lines on the zero sequence impedance parameters of transmission lines is studied. Two types of single-circuit lines with the same corridor are selected to verify the influence of distance on the zero sequence impedance parameters of transmission lines. In order to ensure the safe and reliable power supply of practical engineering lines, the minimum
safe distance between 220kV lines is 7 meters [7-8]. The zero sequence impedance parameters are measured by changing the distance between lines. The results are shown in Table 2.

| Tower structure | 7   | 14  | 28  | 56  | 112 | 224 |
|-----------------|-----|-----|-----|-----|-----|-----|
| Impedance       | Z₀₁ (Ω·km) | 1.272 | 1.279 | 1.288 | 1.298 | 1.308 | 1.319 |
|                 | Z₀₂ (Ω·km)  | 0.773 | 0.710 | 0.629 | 0.531 | 0.422 | 0.309 |
|                 | Z₀₂ (Ω·km)  | 1.272 | 1.279 | 1.288 | 1.298 | 1.308 | 1.319 |
| Two-circuit     | Z₀₁ (Ω·km) | 1.334 | 1.334 | 1.334 | 1.334 | 1.334 | 1.334 |
|                 | Z₀₂ (Ω·km)  | 1.334 | 1.334 | 1.334 | 1.334 | 1.334 | 1.334 |
| Single-circuit  | Z₀₁ (Ω·km) | 1.251 | 1.210 | 1.197 | 1.200 | 1.195 |
|                 | Z₀₂ (Ω·km)  | 1.251 | 1.210 | 1.197 | 1.200 | 1.195 |

From the table and figure above, we can see the distance between transmission line circuit had a greater influence on the mutual impedance between the lines, and the mutual impedance between the lines will decrease with the increase of the distance between the circuits. In the table, the maximum variation range of zero-sequence mutual inductance is 26.921%, and the maximum variation range of zero-sequence self-inductance is 0.779%. The table shows that the zero-sequence impedance parameters of transmission lines are seriously affected by the distance between lines, especially the zero sequence mutual impedance parameters between lines.

3.1.3 The effect of tower structure on zero sequence impedance parameters
This section discusses the effects of different spatial layouts on line impedance parameters. The zero sequence impedance parameters of double loop transmission lines under several typical structures are compared and measured. The results are shown in the table. In the table, the maximum change range of zero-order mutual inductance is 5.594%, and the maximum change range of zero-order self-inductance is 4.785%. It can be seen from table 3 that the influence of tower type on zero-sequence impedance parameters is not obvious.

| Tower structure | Horizontal | Triangular | Umbrella | Vertical | Drum |
|-----------------|------------|------------|----------|----------|------|
| Impedance       | Z₀₁ (Ω·km) | 1.226      | 1.185    | 1.172    | 1.175 | 1.170 |
|                 | Z₀₂ (Ω·km) | 0.754      | 0.761    | 0.796    | 0.762 | 0.794 |
| Two-circuit     | Z₀₁ (Ω·km) | 1.226      | 1.185    | 1.172    | 1.175 | 1.170 |
|                 | Z₀₂ (Ω·km) | 1.251      | 1.210    | 1.197    | 1.200 | 1.195 |
| Single-circuit  | Z₀₁ (Ω·km) | 1.251      | 1.210    | 1.197    | 1.200 | 1.195 |

3.2 The effect of Zero sequence current on interference Line
The induced voltage on the measured line is also affected by the running state of adjacent lines. When adjacent lines are in normal operation, the presence of adjacent lines will degaussing the mutual inductance of zero sequence measurement impedance measurement lines, reducing the measurement lines [9]. When the adjacent line itself has zero sequence current, the influence of the adjacent line on the measured line is related to the current direction of the adjacent line and the measured line, and the larger the value of zero-sequence current on the operating line, the smaller the value of zero sequence impedance on the measured line.

4. Simulation analysis
The electromagnetic simulation model of the transmission line is built according to the above mathematical model, as shown in Fig. 2. Where, line N is the measured line, on which single-phase power supply is applied to provide zero-sequence signal for the line. Line M is the live operating line. Record the variation range of zero sequence impedance parameters on line N when changing the mutual inductance between line M and line N and the zero-sequence current on line M.
4.1 Simulation Analysis of Zero-sequence Impedance of Lines With Different Soil Resistivity

The values of line impedance parameters of 220kV double-circuit drum tower erected under different soil resistivity obtained above are imported into the simulation model of double-loop transmission line. The zero-sequence current on the operating line is measured respectively and the zero-sequence impedance parameters range of different tested lines is taken to verify the inference above. As shown in Tab.4:

| Soil resistivity (Ω·m) | 50 | 10 | -5 | -1 | 0  | 1  | 5  | 10 | 50 | 100 |
|------------------------|----|----|----|----|----|----|----|----|----|-----|
| 114.78                 | 1.131 | 1.131 | 1.131 | 1.131 | 1.131 | 1.131 | 1.131 | 1.131 | 1.131 | 1.131 |
| 10                    | 0.025 | 0.135 | 0.241 | 0.656 | 1.016 | 1.042 | 0.335 | 0.161 | 0.036 | 0.022 |
| 114.78                 | 0.027 | 0.147 | 0.262 | 0.717 | 1.107 | 1.135 | 0.365 | 0.174 | 0.039 | 0.022 |
| 500                    | 0.027 | 0.153 | 0.275 | 0.748 | 1.157 | 1.185 | 0.383 | 0.182 | 0.043 | 0.024 |
| 2000                   | 0.029 | 0.158 | 0.283 | 0.773 | 1.194 | 1.225 | 0.394 | 0.188 | 0.042 | 0.024 |

From the above results, the equivalent zero-sequence impedance of the measured circuit increases with the increase of soil resistivity under the same zero-sequence current; Measured lines under the same soil resistivity, the equivalent zero-sequence impedance values and decreases with the adjacent lines on the current value of the minimum measured circuit zero-sequence impedance of single parameter value of 1/71, when adjacent lines with the circuit to be tested on synthetic size is about 1A zero sequence current, circuit under test of the zero-sequence impedance values, the largest about single line operating parameter values.
4.2 Simulation analysis of zero-sequence impedance parameters of different circuit spacing

The above measured parameter values at different circuit distances are imported into the double-circuit transmission line simulation model, and the zero-sequence impedance parameter range of the tested line when the transmission line with different circuit spacing passes through different zero-sequence current is measured respectively, so as to verify the inference above. Simulation results are shown in table 5:

| Circuit distance | L₀ (A)          |
|------------------|----------------|
|                  | -50  | -10  | -5   | -1   | 0    | 1    | 5    | 10   | 50   | 100  |
| Single           | 1.334| 1.334| 1.334| 1.334| 1.334| 1.334| 1.334| 1.334| 1.334| 1.334|
| 10 m             | 0.056| 0.263| 0.429| 0.831| 1.017| 1.331| 0.685| 0.334| 0.071| 0.034|
| 50 m             | 0.090| 0.357| 0.606| 1.017| 1.161| 1.421| 0.922| 0.558| 0.106| 0.052|
| 100 m            | 0.136| 0.454| 0.733| 1.112| 1.224| 1.464| 1.051| 0.698| 0.126| 0.068|

Fig. 5 Change of zero-sequence resistance of line with circuit distances

Fig. 6 Change of zero-sequence inductance of line with Circuit Distances

From the above results, it can be obtained that the equivalent zero-sequence impedance value of the measured circuit increases with the increase of the distance between two circuits under the same zero-sequence current; At the same circuit spacing, the equivalent zero-sequence impedance value of the measured line decreases with the increase of the current value on the adjacent line, and the minimum is 1/52 of the value of the zero-sequence impedance parameter of the single circuit being measured. When the zero-sequence current with the same size of 1A is passed on the adjacent line, the zero-sequence impedance value of the measured line is the largest, which is about the operating parameter value of the single line.

5. Conclusion

Through the correlation analysis of the measurement results of zero-sequence impedance parameters affecting the line, the following conclusions can be drawn:

1) With the double circuit line on the road in the zero sequence current increase, be measured on line measuring the equivalent zero sequence impedance value decreased, a minimum of about 1/71 times of measurement value of single line, then if the measured single return circuit zero sequence impedance parameters for relevant setting calculation of the system, fault location can cause a great error results, such as impact protection maloperation system of power supply reliability.

2) In the case of larger soil resistivity or larger loop spacing, when the zero-sequence current flowing on the operating line has the same direction as the zero-sequence current on the measured line and the size is about 1A, the equivalent zero sequence impedance value measured by the measured line may be larger than the zero-sequence impedance parameter value of the single circuit. At this time, relay protection of the system will cause protection resistance and affect the safety and stability of the system.

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