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New Method of Measuring the Positive-sequence Capacitance of T-connection Transmission Lines

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ABSTRACT

A novel method of measuring the positive-sequence capacitance of T-connection transmission lines is proposed. The mathematical model of the new method is explained in detail. In order to obtain enough independent equations, three independent operation modes of T-connection transmission lines during the line measurement are introduced. The digital simulation results and field measurement results are shown. The simulation and measurement results have validated that the new method can meet the needs of measuring the positive-sequence capacitance of T-connection transmission lines. This method has been implemented in the newly developed measurement instrument.

Keywords: T-connection Transmission Lines; Line Parameter; Positive-sequence Capacitance; Measurement

1. Introduction

With the rapid development of power systems, line corridors become more and more crowed. In order to reduce synthetic cost of the line construction and limited objective conditions, T-connection transmission lines are always applied in HV/EHV. The reliable operation of power systems depends on the correct operation of relaying protection devices [1].

It is well known that the computation for parameters of T-connection transmission lines is derived from Carson formula [2]. It is influenced by many practical factors, such as the resistance of earth, the equivalent depth of the lines and, etc. So the parameters should be practically measured rather than theoretically calculated.

There are many related literatures discussing about measuring the impedance parameters of T-connection transmission lines [3-5]. The capacitance parameters are always ignored. But the capacitance is very important for transmission line protection. When it exceeds certain length, because the numerical value of capacity current is big, the current flow on both sides of the lines and phase relation will change according with the increase of capacity current value. Especially, when load current and short-circuit current are small, it can lead to the maloperation of high frequency protection [6, 7]. If we use the traditional method to measure the capacitance of T-connection transmission lines, it can only calculate parallel values of three branches. When the parameters of three branches are different, the traditional method no longer works. So, new measurement method needs to be found out for the positive-sequence capacitance of T-connection transmission lines.

In this paper, a new method of measuring positive-sequence capacitance of T-connection lines is proposed. The method has been applied to the newly developed measurement instrument.

2. The Theory of the Measurement Method

Usually, the length of T-connection transmission lines is less than 50 km. So it can use the lumped parameter model. Each branch can be equivalent to T-form circuit. The lumped parameter model of T-form equivalent circuit is shown in **Figure 1**.

When the length and impedance of transmission lines are known, the susceptance can be calculated. Three phases end is opening circuit, $\dot{I}_2 = 0$, the susceptance y is as follows,

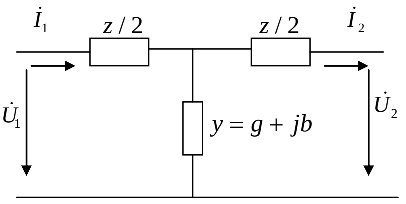

Figure 1. The lumped parameter model of T-form equivalent circuit.

$$y = \frac{1}{(\dot{U}_1 / \dot{I}_1) - (z/2)} = g + jb \tag{1}$$

where, $\dot{U}_1$ is the positive-sequence voltage vector at the head of the line; $\dot{I}_1$ is the positive-sequence current vector at the head of the line.

Then, the capacitance can be written as follows,

$$c = \frac{b}{Lw} \tag{2}$$

where, L is the length of the transmission lines; w equals to $2\pi f$ and f is power frequency.

Figure 1 can be applied to three branches of T-connection transmission lines. The equivalent model is shown in **Figure 2**.

The impedance parameters of three branches are known. In order to obtain enough independent equations, three independent operation modes of T-connection transmission lines during the measurement are shown in **Table 1**. In order to simplify the equations, substitute half of the impedance parameters of three branches with Z_1, Z_2 and Z_3. Then, we have,

$$\begin{cases} \dfrac{\dot{U}_{11}}{\dot{I}_{11}} = \dfrac{\left[\dfrac{(Z_2+Y_2)(Z_3+Y_3)}{Z_2+Y_2+Z_3+Y_3} + Z_1\right] \times Y_1}{\left[\dfrac{(Z_2+Y_2)(Z_3+Y_3)}{Z_2+Y_2+Z_3+Y_3} + Z_1\right] + Y_1} + Z_1 \\ \dfrac{\dot{U}_{22}}{\dot{I}_{22}} = \dfrac{\left[\dfrac{(Z_1+Y_1)(Z_3+Y_3)}{Z_1+Y_1+Z_3+Y_3} + Z_2\right] \times Y_2}{\left[\dfrac{(Z_1+Y_1)(Z_3+Y_3)}{Z_1+Y_1+Z_3+Y_3} + Z_2\right] + Y_2} + Z_2 \\ \dfrac{\dot{U}_{33}}{\dot{I}_{33}} = \dfrac{\left[\dfrac{(Z_1+Y_1)(Z_2+Y_2)}{Z_1+Y_1+Z_2+Y_2} + Z_3\right] \times Y_3}{\left[\dfrac{(Z_1+Y_1)(Z_2+Y_2)}{Z_1+Y_1+Z_2+Y_2} + Z_3\right] + Y_3} + Z_3 \end{cases} \tag{3}$$

Equation (3) can be simplified as,

$$\begin{cases} \dfrac{\dot{U}_{11}}{\dot{I}_{11}} = Z_1 + \dfrac{(Z_1Z_2 + Z_2Z_3 + Z_1Z_3)Y_1 + (Z_1+Z_2)Y_1Y_3 + (Z_1+Z_3)Y_1Y_2 + Y_1Y_2Y_3}{(Z_1Z_2 + Z_2Z_3 + Z_1Z_3)Y_1 + (Z_1+Z_2)Y_3 + (Z_1+Z_3)Y_2 + (Z_2+Z_3)Y_1 + Y_1Y_2 + Y_2Y_3 + Y_1Y_3} \\ \dfrac{\dot{U}_{22}}{\dot{I}_{22}} = Z_2 + \dfrac{(Z_1Z_2 + Z_2Z_3 + Z_1Z_3)Y_2 + (Z_2+Z_3)Y_1Y_2 + (Z_1+Z_2)Y_2Y_3 + Y_1Y_2Y_3}{(Z_1Z_2 + Z_2Z_3 + Z_1Z_3)Y_1 + (Z_1+Z_2)Y_3 + (Z_1+Z_3)Y_2 + (Z_2+Z_3)Y_1 + Y_1Y_2 + Y_2Y_3 + Y_1Y_3} \\ \dfrac{\dot{U}_{33}}{\dot{I}_{33}} = Z_3 + \dfrac{(Z_1Z_2 + Z_2Z_3 + Z_1Z_3)Y_3 + (Z_1+Z_3)Y_2Y_3 + (Z_2+Z_3)Y_1Y_3) + Y_1Y_2Y_3}{(Z_1Z_2 + Z_2Z_3 + Z_1Z_3)Y_1 + (Z_1+Z_2)Y_3 + (Z_1+Z_3)Y_2 + (Z_2+Z_3)Y_1 + Y_1Y_2 + Y_2Y_3 + Y_1Y_3} \end{cases} \tag{4}$$

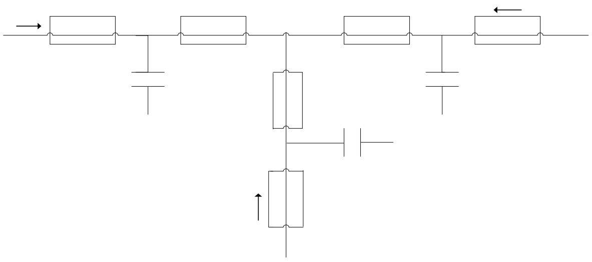

Figure 2. The equivalent model of T-connect transmission lines.

Table 1. The Measurement Modes of Three Braches.

Cases	Branch 1	Branch 2	Branch 3
1	Applied with an external positive-sequence voltage source	Open circuit	Open circuit
2	Open circuit	Applied with an external positive-sequence voltage source	Open circuit
3	Open circuit	Open circuit	Applied with an external positive-sequence voltage source

Where Z_1, Z_2 and Z_3 are half of the positive-sequence impedance parameters of three branches; Y_1, Y_2 and Y_3 are the reciprocal of the positive-sequence susceptance parameters of three branches; $\dot{U}_{11}$, $\dot{U}_{22}$ and $\dot{U}_{33}$ are the positive-sequence voltage vectors of three branches; $\dot{I}_{11}$, $\dot{I}_{22}$ and $\dot{I}_{33}$ are the positive-sequence current vectors of three branches; Subscripts 11, 22 and 33 mean that the first number represents one of the three branches and the second number represents one of the measurement modes.

Then, the positive-sequence capacitance of three branches can be written as follows,

$$\begin{cases} C_1 = \dfrac{1}{wl_1}\operatorname{Im}(\dfrac{1}{Y_1}) \\ C_2 = \dfrac{1}{wl_2}\operatorname{Im}(\dfrac{1}{Y_2}) \\ C_3 = \dfrac{1}{wl_3}\operatorname{Im}(\dfrac{1}{Y_3}) \end{cases} \tag{5}$$

where l_1, l_2 and l_3 are the length of three branches; w= $2\pi f$ and f is power frequency.

3. Digital Simulation Results

According to the above method, the positive-sequence capacitance of T-connection transmission lines is simulated under the three cases. Each branch is applied with an external positive-sequence voltage source in turn and the other two branches are opening circuit.

The simulation results of three different cases are shown in **Tables 2-4** respectively.

Table 2. The Simulation Results of Three Branches with the Same Length.

The length of three branches (km)	Capacitance Setting Values (Unit: nF/km)	Capacitance Measurement Values (Unit: nF/km)	Relative Error (%)
30	9.15	9.1501	0.0011
50	12.74	12.734	0.0471

Table 3. The Simulation Results of Three Branches with Different Length.

Length (km)	Capacitance Setting Values (Unit: nF/km)	Capacitance Measurement Values (Unit: nF/km)	Relative Error (%)
Branch 1: 10	12.74	12.830	0.71
Branch 2: 20	9.15	9.3793	2.51
Branch 3: 30	14.00	13.816	-1.31

Table 4. The Simulation Results of Three Branches with Different Length.

Length (km)	Capacitance Setting values (Unit: nF/km)	Capacitance Measurement values (Unit: nF/km)	Relative Error (%)
Branch 1: 50	12.74	12.739	0.0078493
Branch 2: 30	9.15	9.1438	0.067760
Branch 3: 40	14.00	13.992	0.057143

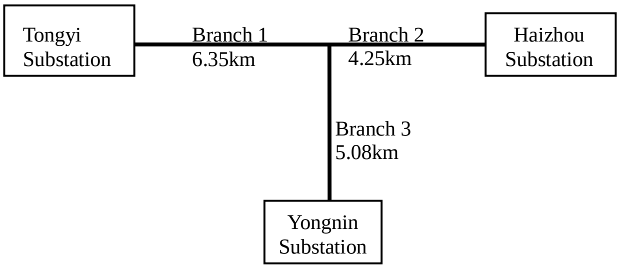

Figure 3. Diagram of the T-connection transmission lines.

Table 5. The Positive-Sequence Capacitance Measurement Results of Three Branches.

Length (km)	Capacitance Calculation Values (Unit: nF)	Capacitance Measurement Values (Unit: nF)	Relative Error (%)
Branch 1: 6.35 km	58.075		
Branch 2: 4.25 km	38.869		
Branch 3: 5.08 km	46.459		

4. An Example of Field Test

The new measurement method has been successfully used in measuring the positive-sequence capacitance parameters of 110kV T-connection transmission lines in a power grid as shown in **Figure 3**.

The independent measuring cases of the T-connection line are shown in **Table 1**.

The positive-sequence capacitance measurement results with the new method are shown in **Table 5**.

5. Conclusions

The new measurement method of the positive-sequence capacitance parameters of T-connection transmission lines is introduced. The theoretical analysis, digital simulation results and the field measurement results have proven that the new measurement method is correct and can be used for measuring the positive-sequence capacitance parameters of T-connection transmission lines.

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