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Live Line Measuring the Parameters of 220 kV Transmission Lines with Mutual Inductance in Hainan Power Grid

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Abstract

A live line measurement method for the zero sequence parameters of transmission lines with mutual inductance is introduced. The mathematical models of the measurement method are given. Global Positioning System (GPS) is used as the synchronous signal for the measurement carried out at different substations simultaneously. The measurement system and digital simulation results are given. Finally, the live line measurement results of two 220 kV transmission lines with mutual inductance in Hainan grid are given. Results from both simulation and on-site measurement show that the live line measurement method is feasible, and its measurement accuracy can satisfactorily meet the requirements of engineering measurement.

Keywords: Transmission lines; Zero sequence parameter; Mutual inductance; Live line measurement; GPS

1. Introduction

Accurate line parameters are the foundation of relay protection setting calculation, fault location, fault analysis, network loss and power flow calculation. With the increasment of transmission lines on the same towers, zero sequence parameters will affect the fault states and zero sequence currents of lines [1]-[4].

The traditional methods have the formulas calculation method [5] and the outage measurement methods [6]-[7]. The zero sequence impedances of lines are affected by many factors, such as line alignment and ground resistance. The calculated values are unable to meet the requirement of relay protection setting calculation. For example, if we use the calculated values in the setting calculation, it will make the protection refusing action or mis-operation. So it is a great threat to the safe and stable operation of power system. According to the regulations, the zero sequence impedances of the overhead lines and cables should be obtained by actual measurement [8].

The traditional measurement methods can only be used under the cases that all lines must be withdrawn from normal operation. Because the transmission lines are distributed components, the line length is over 1000 kilometers and the electromagnetic coupling between lines which cause the measurement of line parameters difficulty. To measure the zero sequence self inductance of a new line, because the new line has electromagnetic coupling with other live lines, the parameters of the new line cannot be measured independently with the traditional methods. We should withdraw all the lines from normal operation before measuring the zero sequence parameters. Obviously, it is not acceptable for power system. So the traditional measurement methods cannot satisfy the requirement of modern power system.

A new live line measurement method based on Global Positioning System (GPS) technology is introduced and has been successfully applied in the live line measurement of two 220 kV transmission lines with mutual inductance in Hainan power grid. The measurement results of the live line measurement method prove that it can meet the requirement of parameter measurement of transmission lines.

2. The Theory of the Live Line Measurement Method

The algebra equation sets of n transmission lines with mutual inductance can be described as follows,

$$\begin{bmatrix} Z_{11}Z_{12}\cdots Z_{1i}\cdots Z_{1n} \\ Z_{21}Z_{22}\cdots Z_{2i}\cdots Z_{2n} \\ \cdots \\ Z_{i1}Z_{i2}\cdots Z_{ii}\cdots Z_{in} \\ \cdots \\ z_{n1}z_{n2}\cdots z_{ni}\cdots z_{nn} \end{bmatrix} \begin{bmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \cdots \\ \dot{I}_i \\ \cdots \\ \dot{I}_n \end{bmatrix} = \begin{bmatrix} \dot{U}_1 \\ \dot{U}_2 \\ \cdots \\ \dot{U}_i \\ \cdots \\ \dot{U}_n \end{bmatrix} \quad (1)$$

or

$$Z\dot{I} = \dot{U} \quad (2)$$

Where $z_{ii} = r_{ii} + jx_{ii}\ (i = 1, 2, \cdots, n)$ are the zero sequence self impedances. $z_{ij} = r_{ij} + jx_{ij}$, $(i, j = 1, 2, \cdots, n, i \neq j)$ are the zero sequence mutual impedances between line i and line j. $\dot{I}$ is the zero sequence current vector. $\dot{U}$ is the zero sequence voltage vector.

Suppose $\dot{U}_{pi}$ and $\dot{U}_{qi}$ are the zero sequence terminal voltage vectors at the two terminals of line i, and $\dot{I}_{qi}$ are the zero sequence terminal current vectors at the two terminals of line i, Then $\dot{U}_i = \dot{U}_{pi} - \dot{U}_{qi}$ is the zero sequence voltage drop vectors of line i, $\dot{I}_i = (\dot{I}_{pi} + \dot{I}_{qi})/2$ is the average zero sequence current vectors of line i. It is well known that the zero sequence voltages of lines are the difference of the zero sequence voltage of both terminals. The equation of any line i at the k-th measurement can be described as follows,

$$\dot{U}_{ki} = Z_{i1}\dot{I}_{k1} + Z_{i2}\dot{I}_{k2} + \cdots + Z_{ii}\dot{I}_{ki} + \cdots + Z_{in}\dot{I}_{kn} \quad (3)$$

From the p （p≥n(n+1)/2） independence data groups measured on line i $(i = 1, 2, \cdots, n)$, p independence equations will be obtained. For the convenience of calculation, the p measurement equations is rewritten in a matrix, such as $U_i = AZ_i$. The unknown parameters are $Z_i = [Z_{i1}, Z_{i2}, \cdots, Z_{in}]^T$.

$$A = \begin{bmatrix} I_1^{(1)}, I_2^{(1)}, \cdots, I_n^{(1)} \\ I_1^{(2)}, I_2^{(2)}, \cdots, I_n^{(2)} \\ \cdots \\ I_1^{(p)}, I_2^{(p)}, \cdots, I_n^{(p)} \end{bmatrix} \quad (4)$$

Where A is a $p \times n(n+1)/2$ order matrix. The superscripts $1, 2, \cdots, p$ of vectors $\dot{I}$ are the independent measuring cases and the subscripts $1, 2, \cdots, n$ of vectors $\dot{I}$ are the serial number of n lines.

Set

$$U = \left[U_i^{(1)}, U_i^{(2)}, \cdots, U_n^{(p)}\right]^T,$$

Then $U = AZ$ is an overdetermined algebraic equation, the least-square estimation algorithm is used to solve the unknown parameters Z_{LS},

$$Z_{iLS} = \left(A^T A\right)^{-1} A^T U_i \quad \left(i = 1, 2, \cdots, n\right) \quad (5)$$

Equation (5) uses the impedance method to measure the zero sequence impedances of lines. It can calculate both the zero sequence parameters of the new lines and the zero sequence parameters of the original lines.

The zero sequence self impedance Z_{ii} and the zero sequence mutual impedance Z_{ij} can be calculated by the computer.

3. Hardware Structure of the Live Line Measurement System

The hardware structure of a live line measuring system based on GPS technology is shown in Figure 1. The measurement system consists of several sections, such as the GPS receiver, input signal transformation channels, embedded DSP (Digital Signal Processor) card, double-port RAM (DRAM), Embedded PC card, control signal output and other man-machine interfaces. The central computer stores and processes the sampled data, calculates line parameters and outputs measurement results.

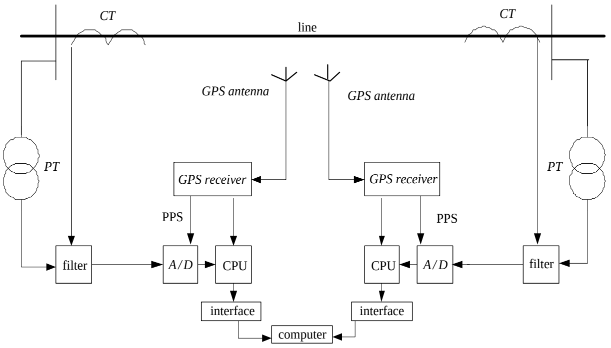

Figure 1. The hardware structure of the live line measurement system

4. Digital Simulation Results

According to the above method, the zero sequence parameters of two transmission lines with mutual inductance are simulated under the measurement cases for single-phase wire break, single-phase grounding, unbalanced load and external power source.

The parameters of two coupled 220 kV lines are shown in table 1. Line I is 100 km and Line II is 50 km. The voltage level of the lines source is 220 kV and the load is 100 MW. Put the measured voltage and current data into the computer, the measurement results are shown in table 2. The simulation results validate the live line measurement method is correct.

Table 1. The Parameters of Two Lines with Mutual Inductances

lines	Zero sequence resistance (Ω/km)	Zero sequence inductance (mH/km)	Zero sequence capacitance (μF/km)	Zero sequence mutual resistance (Ω/km)	Zero sequence mutual inductance (mH/km)
Line I	0.3864	4.1264	0.007751	0.1	1.0
Line II	0.3864	4.1264	0.007751		

Table 2. The Digital Simulation Results

Measurement cases	Zero sequence self impedance of line I		Zero sequence self impedance of line II		Zero sequence mutual impedance	
	Measuring values(Ω)	Relative error%	Measuring values (Ω)	Relative error (%)	Measuring values (Ω)	Relative error (%)
Unbalanced load	39.2030 +j128.5394	0.66	19.2531 +j64.1589	0.97	4.9365 +j15.8589	0.76
Single-phase grounding	39.1287 +j130.5960	0.78	19.6459 +j65.0125	0.41	4.8998 +j15.9016	0.94
Single-phase wire break	38.3977 +j130.2778	0.56	19.7547 +j64.3568	0.47	4.7587 +j15.6541	0.75
Two-phase grounding	38.4139 +j129.0645	0.45	19.6545 +j65.0113	0.41	5.1210 +j15.8146	0.81

5. An Example of Live Line Measurement

The schematic diagram of the two 220 kV transmission lines with mutual inductance in Hainan power grid is shown in Figure 2.

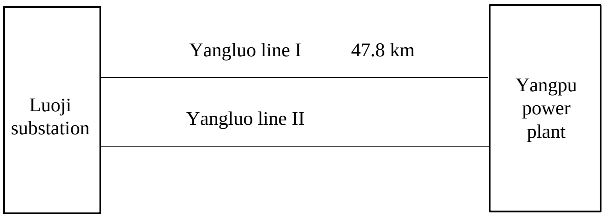

Figure 2. The diagram of two lines with mutual inductance in Hainan grid

The length of two coupled 220 kV Yangluo I and Yangluo II lines is 47.8 km.

According to practical situation, the external voltage source is applied at 220 kV Luoji substation. Live line measurement equipments are put at Luoji substation and Yangpu power plant. The extern voltage source is applied to the outage line when 220 kV Yangluo I and II lines rolling blackouts. The zero sequence currents are taken from CT of lines. The zero sequence voltages are taken from the open delta winding of PT of lines or buses.

The measurement wire diagram with an extern voltage source is shown in Figure 3.

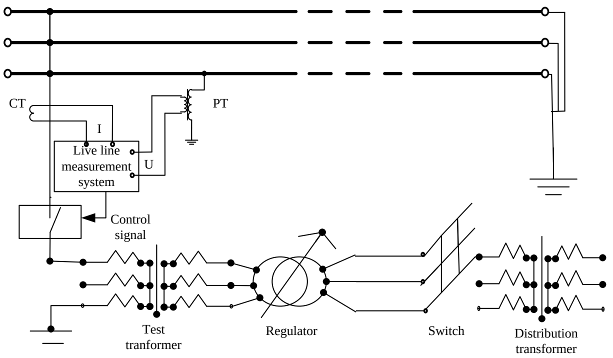

Figure 3. The measurement wire diagram with an extern voltage source

The control signal is generated by the measurement equipments, and it controls the air switch to supply zero sequence voltage. The measurement wire of two coupled lines is shown in Figure 4.

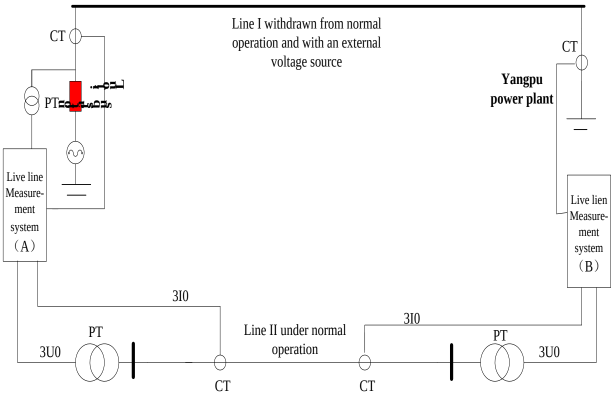

Figure 4. The wire diagram of live line measurement

The measurement cases of the lines are given in table 3.

Table 3. Live Line Measurement Cases

Case	Line I	Line II
1	Withdraw from normal operation, with an external voltage source	Under normal operation
2	Under normal operation	Withdraw from normal operation, with an external voltage source

The zero sequence voltages and currents recorded by the measurement system are shown in Figure 5 to Figure 8.

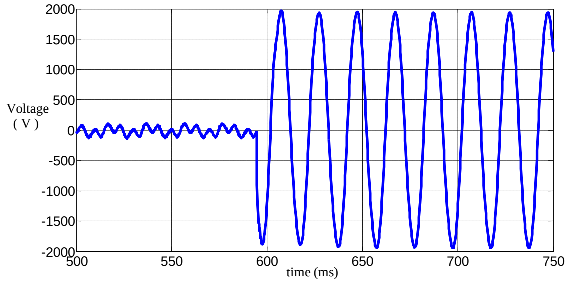

Figure 5. The voltage wave recorded in Yangluo I line

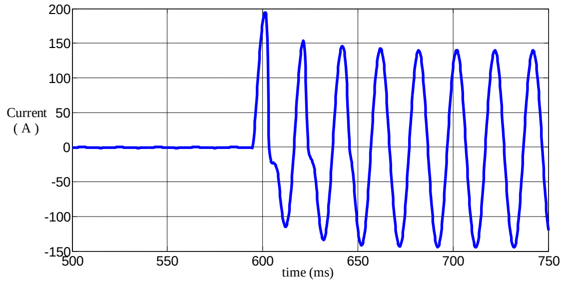

Figure 6. The current wave recorded in Yangluo I line

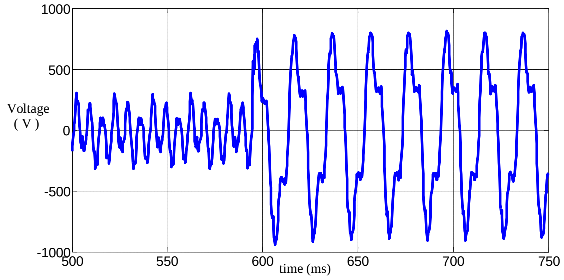

Figure 7. The voltage wave recorded in Yangluo II line

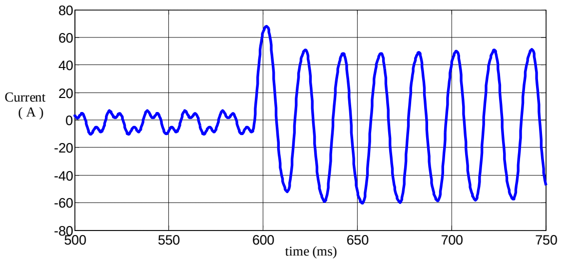

Figure 8. The current wave recorded in Yangluo II line

The measurement results of the zero sequence parameters of the two lines are given in table 4.

Table 4. The Measurement Results of Zero Sequence Parameters

Cases	Zero sequence self impedance of line I (Ω)	Zero sequence self impedance of line II (Ω)	Zero sequence mutual impedance (Ω)
1	8.891 +j56.614	8.591 +j57.634	6.624 +j35.420
2	7.921 +j56.732	7.289 +j57.720	5.630 +j35.512
3	8.008 +j56.305	7.082 +j57.545	5.627 +j35.196
Average measurement values	8.274 +j56.551	7.654 +j57.633	5.961 +j35.376
Traditional method measurement values	13.384 +j57.408	13.384 +j57.408	10.038 +j36.615
Average measurement error	3.05%	1.37%	5.51%

6. The Analysis of Measurement Results

The traditional measurement method calculating Z_0 can be described by (6),

$$Z_0 = \frac{\dot{U}_0}{\dot{I}_0} \tag{6}$$

Where $\dot{I}_0$ is the zero sequence current vector. $\dot{U}_0$ is the zero sequence voltage vector. The method can only be used under outage condition. Mutual inductance must be taken into account if there are electromagnetic coupling between lines.

The results of traditional method are shown in table 5 and table 6.

Table 5. The measurement results of Yanluo I line

cases	Current input (A)	Zero sequence voltage (V)	Zero sequence current (A)	Zero sequence impedance (Ω)
1	40	359.56-j419.732	-27.236-j31.404	5.883+j39.451
2	60	801.35-j100.84	0.749-j59.872	5.554+j40.084
3	80	-912.39-j568.36	-50.168+j61.135	5.289+j40.432
4	100	-1348.8-j199.18	-26.909+j96.174	5.156+j40.630
average values				5.544+j39.998

Table 6. The measurement results of Yanluo II line

cases	Current input (A)	Zero sequence voltage (V)	Zero sequence current (A)	Zero sequence impedance (Ω)
1	40	-298.62+j463.74	31.278+j27.311	5.785+j39.428
2	60	-33.479+j806.83	58.947+j10.635	5.525+j40.065
3	80	-1063.2+j152.39	0.942+j79.041	5.302+j40.417
4	100	-887.65+j1034.2	67.073+j74.004	5.112+j40.617

average values				5.431+j40.132

The model of two lines with mutual inductance is shown in Figure 9.

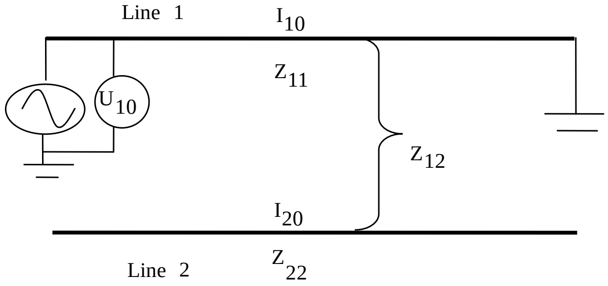

Figure 9. The model of two lines with mutual inductance

The voltammetry characteristic can be written as follows,

$$\dot{U}_{10} = \dot{I}_{10}Z_{10} + \dot{I}_{20}Z_{120} \qquad （7）$$

So when we measure the zero sequence self impedance of the line I, the zero sequence current of line II which influences the zero sequence voltage of line I should be taken into account. The traditional method ignores the influence of line II, so there are theoretical mistakes in (9).

$$\dot{U}_{10} = \dot{I}_{10}Z_{10} \qquad （8）$$

Then,

$$Z_{10} = \frac{\dot{U}_{10}}{\dot{I}_{10}} \qquad （9）$$

From （7）, we can get,

$$Z_{10} = \frac{\dot{U}_{10}}{\dot{I}_{10}} \neq \frac{\dot{U}_{10} - Z_{12}\dot{I}_{20}}{\dot{I}_{10}} \qquad （10）$$

In fact, it indicates that when the current of line I reaches 100 A and the current of line II reaches 47 A, $Z_{12}\dot{I}_{20}$ can't be ignored. So the error of zero sequence self impedance measured by traditional method is great. In this measurement, the error has reached above 30%.

Measure the zero sequence voltages and zero sequence currents of all transmission lines, then calculate (1) and obtain zero sequence self impedance and zero sequence mutual impedance. The live line measurement method not only has high precision, but also is accurate and reliable. The measurement results of zero sequence parameters are shown in table III, it shows that the average measurement error of zero sequence mutual impedance is about 5.5% and zero sequence self impedance is about 2%.

It shows that there are still certain difference between theoretical values and measurement values. It is well known that the computation formulate for zero sequence parameters are derived from Carson formula. The traditional method needs the resistance of earth, the equivalent depth of wires, the length of lines and the arrangement of wires. But it is difficult to get the resistance of earth and the equivalent depth of wires. So the theoretical values are only used as reference, they cannot be used as accurate parameters.

In the case of disturbing, in order to obtain the accurate parameters of zero sequence self impedance, the zero sequence self impedance and the zero sequence mutual impedance should be measured at the same time.

7. Conclusion

The field live line measuring results have proven that the live line measurement method is correct and the measurement system can meet the requirement of measurement. In addition, in order to eliminate the interference of lines, using the live line measurement method to calculate the zero sequence self impedance parameters and the zero sequence mutual impedance parameters simultaneously can improve the accuracy of the measurement results.

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