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Short-circuit current calculation method for partial coupling transmission lines under different voltage levels

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ABSTRACT

In power system, there are partial coupling lines under different voltage level because of the development of power system. When faults occur on these lines, zero-sequence mutual impedances bring difficulty to short-circuit calculation. To solve the problem, a new method is proposed in this paper. First, the three phase components are transformed to independent positive-sequence, negative-sequence and coupling zero-sequence components. Then the coupling zero-sequence is decoupled using the idea of six-sequence component method, namely recirculating current method. Finally, the system impedances and impedance of the non-coupling part are modified by comparing the relationship between sequence voltages and sequence currents of the newly defined decoupling method and symmetrical component method. According to the boundary condition, the composite sequence networks are obtained and the short-circuit current can be calculated easily. The PSCAD simulation result of short circuit analysis and calculation indicate that the proposed decoupling method for partial coupling line is appropriate. The short circuit calculation based on the decoupling method is easy to implement. The calculation method is practical and the calculation accuracy is not affected by fault type, different voltage grade and fault resistance.

Introduction

Due to the limitation of the transmission line corridor, side erected transmission lines of different voltage levels becomes more and more popular, which brings both economic benefit and technical difficulties. Because of different voltage levels, the transmission line parameters are different and the zero mutual impedance between lines cannot be ignored [1,2]. Traditional symmetrical component method [3] can only be used to analyze single line fault and the zero mutual impedance between two lines cannot be decoupled. For the mutual problems of double-circuit line on same voltage level, six-sequence component method is proposed and it is widely used in fault analysis, fault location and fault phase selection [4–11]. For the mutual problems of four-circuit line on same voltage level, twelve-sequence component method achieves good results on fault line selection and fault location [12–15]. Analogously, several other sequence component methods are proposed references [16–23]. The method of decoupling zero sequence mutual impedance is usually used to study partial coupling lines under different voltage levels, but the composite sequence networks cannot be obtained and fault analysis is not easy to be implemented. So it is of great significance to study partial coupling transmission lines(PCTL) under different voltage levels. In this paper, the fault analysis of PCTL under different voltage levels is studied in detail. Firstly, the zero mutual impedance between coupling lines is decoupled according to the recirculating current method. Then the zero sequence impedance of non-coupling lines is corrected according to the circuit structure. Lastly, the composite sequence networks of single-line fault are obtained according to the relationship of the sequence components of the faulted point.

The organization of this paper is shown as follows: Section “The characteristics of partial coupling lines under different voltage levels” introduces the characteristics of partial coupling transmission lines under different voltage levels. Section “Analysis of zero-sequence mutual impedance between the partial decoupling lines” analyzes the zero-sequence mutual impedances between the two lines under different voltage levels. Sequence network is introduced based on the modifying of the system impedance. Section “Positive sequence network and negative sequence network” presents the positive sequence network and negative sequence network. Section “Calculation of short-circuit current for partial coupling lines under different voltage levels” shows the short circuit current calculation for PCTL under different voltage levels.

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Simulation results are presented in Section "Simulation and results", followed by conclusions in Section "Conclusion".

The characteristics of partial coupling lines under different voltage levels

In this paper, partial coupling line under 220 kV/500 kV is studied. The system structure discussed in this paper is shown in Fig. 1, and the fault occurs in the coupling portion of the two lines.

The transmission line MN is composed by two lines, one is under 220 kV voltage level, and the other is under 500 kV voltage level, with partial coupling shown as PQ in Fig. 1. In Fig. 1, $Z_{s1\cdot M}$ and $Z_{s2\cdot M}$ are the system impedances of two system sources at Side M; $Z_{s1\cdot N}$ and $Z_{s2\cdot N}$ are the system impedances of two system sources at Side N. Z_{1M_non} and Z_{2M_non} are the impedances of the two lines with no decoupling. Z_{1M_dec} and Z_{1M_dec} are the impedances of the two line with partial decoupling between faulted point and the point P. The parameters related with Side N are shown in Fig. 1. For the coupling part PQ, the parameters of two lines are different because of different voltage levels. However, the parameters of every line are symmetrical. The partial coupling transmission lines with asymmetrical element parameters can be described as Fig. 2. Where, Z_{l1} is the self-impedance of Line I; Z_{m1} is the mutual impedance between phases of Line I; Z_{l2} is the self-impedance of Line II; Z_{m2} is the mutual impedance between phases of Line II; Z_p is the mutual impedance between the two lines. Considering the characteristic of the lines, Line I and Line II have the same model and wire transposition, the self- impedance and the mutual impedance between phases of one line is different from the other.

As shown in Fig. 2, the relation between the voltages and currents of the partial coupling lines are shown as follows in Eq. (1):

Where, $U_{\mathrm{I}A}, U_{\mathrm{I}B}, U_{\mathrm{I}C}, U_{\mathrm{II}A}, U_{\mathrm{II}B}, U_{\mathrm{II}C}$ represent the voltage of all the phases respectively, $I_{\mathrm{I}A}, I_{\mathrm{I}B}, I_{\mathrm{I}C}, I_{\mathrm{II}A}, I_{\mathrm{II}B}, I_{\mathrm{II}C}$ represent the currents of all the phases respectively. The voltages and currents can be obtained by the sensors installed at the ends of the lines. They are all originally vectors in the deduction. The phase angle is included in the vectors and and the synchronization will not affect the deduction. Eq. (1) indicates that there are mutual impedances in all the phases. Eq. (1) can be simplified as Eq. (2):

$$\begin{bmatrix}\Delta U_{\mathrm{I}A}\\ \Delta U_{\mathrm{I}B}\\ \Delta U_{\mathrm{I}C}\\ \Delta U_{\mathrm{II}A}\\ \Delta U_{\mathrm{II}B}\\ \Delta U_{\mathrm{II}C}\end{bmatrix} = \underset{\text{the mutual impedance between lines}\qquad\qquad \text{Line II}}{\overset{\text{Line I}\qquad\qquad \text{the mutual impedance between lines}}{\left[\begin{array}{ccc:ccc} z_{l1} & z_{m1} & z_{m1} & z_p & z_p & z_p\\ z_{m1} & z_{l1} & z_{m1} & z_p & z_p & z_p\\ z_{m1} & z_{m1} & z_{l1} & z_p & z_p & z_p\\ \hdashline z_p & z_p & z_p & z_{l2} & z_{m2} & z_{m2}\\ z_p & z_p & z_p & z_{m2} & z_{l2} & z_{m2}\\ z_p & z_p & z_p & z_{m2} & z_{m2} & z_{l2}\end{array}\right]}} \begin{bmatrix}I_{\mathrm{I}A}\\ I_{\mathrm{I}B}\\ I_{\mathrm{I}C}\\ I_{\mathrm{II}A}\\ I_{\mathrm{II}B}\\ I_{\mathrm{II}C}\end{bmatrix} \tag{1}$$

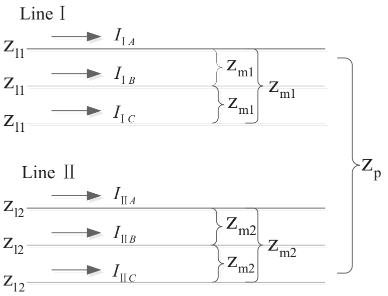

Fig. 2. Coupling lines of different voltage levels.

$$[U_{ABC}] = [Z][I_{ABC}] \tag{2}$$

When the parameters of two lines are symmetrical, according to six-sequence components method, the decoupling is done step by step. Firstly, the mutual impedances of line-to-line are eliminated, and then the mutual impedances between phases are eliminated [6]. Since the parameters of two lines are not symmetrical any more, it cannot decouple the line-to-line mutual impedances completely. The mutual impedances between phases of one line are eliminated firstly, and then the line-to-line mutual impedances are decoupled in this paper. The mutual impedances between phases can be eliminated by symmetrical components as follows.

The transforming matrix for symmetrical method for partial coupling lines is Matrix Q, and

$$[Q] = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0\\ 1 & a^2 & a & 0 & 0 & 0\\ 1 & a & a^2 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 1 & 1\\ 0 & 0 & 0 & 1 & a^2 & a\\ 0 & 0 & 0 & 1 & a & a^2 \end{bmatrix} \tag{3}$$

where, $a = e^{j120^\circ} = -1/2 + j(\sqrt{3}/2)$.

Matrix $[U_{ABC}]$ and $[I_{ABC}]$ in Eq. (2) must be transformed by Matrix [Q], which decomposes the three-phase voltages and currents into sequence components, namely, positive-sequence voltage and current, negative-sequence voltage and current, zero-sequence voltage and current, which is shown in Eq. (4).

$$\begin{cases} [U_{ABC}] = [Q][U_{012}] \\ [I_{ABC}] = [Q][I_{012}] \end{cases} \tag{4}$$

Then Eq. (5) can be obtained from Eq. (4).

$$[U_{012}] = [Q]^{-1}[Z][Q][I_{012}] \tag{5}$$

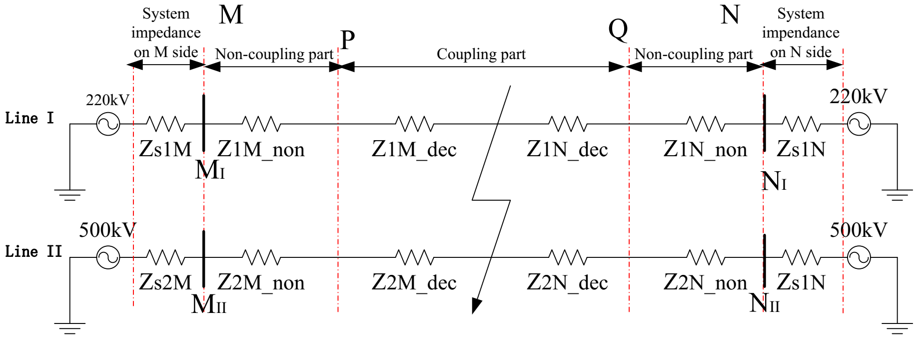

Fig. 1. System structure.