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Design of a one-sided, impedance-based transmission line fault locator using line topology and source impedances

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ABSTRACT

The article discusses an algorithm for a one-sided, impedance-based (transmission) line fault locator using line topology. Standard one-sided impedance-based fault locators, included in the digital protection systems [2–4,8] compute the distance to the fault using the symmetrical components of line impedance. Section 5 demonstrates that this method of determining the distance to the fault exhibits significant inaccuracies in the case of a non-transposed line. The designed algorithm eliminates this inaccuracy, as it computes the distance to the fault with regard to impedance of corresponding phase, or more precisely the faulty loop. Moreover, the algorithm reflects the source impedances on both sides of the line and therefore eliminates or decreases the influence of power from the opposite side to determine the distance to the fault.

1. Introduction

Information is critical to determine the distance to a fault (from a particular substation), with the best possible accuracy (in case of a short circuit on transmission line) as it impacts the time needed to locate the fault and the duration of any overall transmission line outage as well. While the "travelling wave system" (TWS) is currently the most accurate at locating a fault, an impedance-based approach remains fundamental towards determining the distance to the fault. There are economical (TWS is another investment and must be installed on both sides of the line to ensure accurate measurement) and technical considerations at play (TWS needs to have precise time synchronization and it may be knocked out of service in the event of a transmission line fault).

Impedance-based fault locators are implemented in almost every digital protection system. The main weakness of such a fault locator algorithm is the assumption that the transmission line is balanced, i.e. the line is completely transposed. It calculates the distance to the fault using the symmetrical (positive and zero sequence impedance) components of line impedance [2,3] and does not consider transmission line topology, i.e. different (unequal) impedance of each phase, or more precisely each fault loop. Furthermore, the algorithms of certain vendors do not factor in the influence of the power system [3].

The design of the fault locator algorithm described in this article takes transmission line topology into consideration and computes the distance to the fault with appropriate compensation for the individual fault loop impedances. This method of calculation may eliminate errors arising from the replacement of real, non-transposed (unbalanced), transmission line parameters with symmetrical components. The algorithm also factors in source impedances and decreases inaccuracy introduced by resistance faults when power is fed from both sides.

2. Transmission line

2.1. Series impedance of a transmission line

Series impedance of a three-phase transmission line, called ***Line*** (Fig. 1), may be determined using an impedance matrix $\mathbf{Z}_{\mathbf{Line}}$ [1,6]

$$\mathbf{Z}_{\mathbf{Line}} = \begin{bmatrix} \overline{\mathbf{Z}}_{L11} & \overline{\mathbf{Z}}_{L12} & \overline{\mathbf{Z}}_{L13} \\ \overline{\mathbf{Z}}_{L21} & \overline{\mathbf{Z}}_{L22} & \overline{\mathbf{Z}}_{L23} \\ \overline{\mathbf{Z}}_{L31} & \overline{\mathbf{Z}}_{L32} & \overline{\mathbf{Z}}_{L33} \end{bmatrix} \quad (1)$$

where $\overline{\mathbf{Z}}_{Lxx} = \mathbf{R}_{Lxx} + \mathbf{j}\mathbf{X}_{Lxx}$ – self-impedance of phase $\mathbf{x}$; $\overline{\mathbf{Z}}_{Lxy} = \mathbf{R}_{Lxy} + \mathbf{j}\mathbf{X}_{Lxy}$ – mutual impedance between phases $\mathbf{x}$ and $\mathbf{y}$, $\overline{\mathbf{Z}}_{Lxy} = \overline{\mathbf{Z}}_{Lyx}$.

In general, $\overline{\mathbf{Z}}_{L11} \neq \overline{\mathbf{Z}}_{L22} \neq \overline{\mathbf{Z}}_{L33}$, $\overline{\mathbf{Z}}_{L12} \neq \overline{\mathbf{Z}}_{L13} \neq \overline{\mathbf{Z}}_{L23}$.

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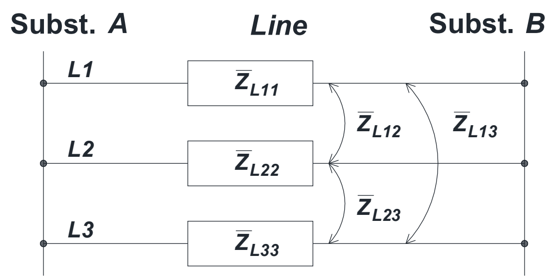

Fig. 1. Series impedance of the transmission line.

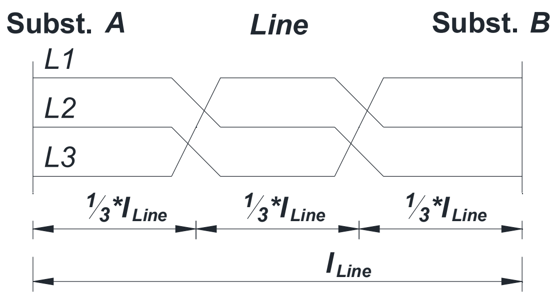

Fig. 2. Completely transposed line.

This is due to the non-symmetric position of any phase (phase wire) to the remaining phases and ground wire (or wires). Particular examples are shown in Section 5.

Transmission line symmetrical components (positive and zero sequence impedance – $\bar{Z}_{1Line}$, $\bar{Z}_{0Line}$) are as follows: [1]

$$\bar{Z}_{1Line} = \frac{\left(\bar{Z}_{L11} + \bar{Z}_{L22} + \bar{Z}_{L33}\right) - \left(\bar{Z}_{L23} + \bar{Z}_{L13} + \bar{Z}_{L12}\right)}{3} = R_{1Line} + jX_{1Line}$$
$$\bar{Z}_{0Line} = \frac{\left(\bar{Z}_{L11} + \bar{Z}_{L22} + \bar{Z}_{L33}\right) + 2 \times \left(\bar{Z}_{L23} + \bar{Z}_{L13} + \bar{Z}_{L12}\right)}{3} = R_{0Line} + jX_{0Line} \quad (2)$$

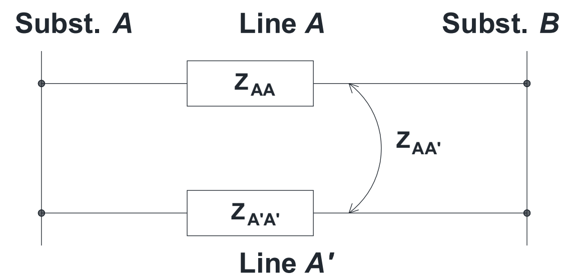

Fig. 3. Series impedance of a double-circuit line.

In case of a completely transposed line (Fig. 2), the series impedance matrix is as follows [1]:

$$\mathbf{Z}_{\mathbf{LineT}} = \begin{bmatrix} \bar{Z}_{self} & \bar{Z}_{mut} & \bar{Z}_{mut} \\ \bar{Z}_{mut} & \bar{Z}_{self} & \bar{Z}_{mut} \\ \bar{Z}_{mut} & \bar{Z}_{mut} & \bar{Z}_{self} \end{bmatrix} \quad (3)$$

where

$$\bar{Z}_{self} = \frac{\bar{Z}_{L11} + \bar{Z}_{L22} + \bar{Z}_{L33}}{3} = \frac{2 \times \bar{Z}_{1Line} + \bar{Z}_{0Line}}{3}$$
$$\bar{Z}_{mut} = \frac{\bar{Z}_{L12} + \bar{Z}_{L13} + \bar{Z}_{L23}}{3} = \frac{\bar{Z}_{0Line} - \bar{Z}_{1Line}}{3}$$

l_{Line} – line length.

In the rest of the calculation, as in the case of the completely transposed transmission line, we will consider every part of the line transposed, i.e. the impedance of any part p is $\mathbf{Z_p} = p \times \mathbf{Z_{LineT}}$.

In case of the parallel lines, called ***LineA*** and ***LineA′*** (Fig. 3), it is also necessary to take into consideration the mutual coupling between the lines. Series impedance or more precisely the series impedance matrix of a double-circuit line is as follows [7]:

$$\mathbf{Z}_{\mathbf{Line\_AA'}} = \left[\begin{array}{ccc|ccc} \bar{Z}_{L11} & \bar{Z}_{L12} & \bar{Z}_{L13} & \bar{Z}_{L11'} & \bar{Z}_{L12'} & \bar{Z}_{L13'} \\ \bar{Z}_{L21} & \bar{Z}_{L22} & \bar{Z}_{L23} & \bar{Z}_{L21'} & \bar{Z}_{L22'} & \bar{Z}_{L23'} \\ \bar{Z}_{L31} & \bar{Z}_{L32} & \bar{Z}_{L33} & \bar{Z}_{L31'} & \bar{Z}_{L32'} & \bar{Z}_{L33'} \\ \hline \bar{Z}_{L1'1} & \bar{Z}_{L1'2} & \bar{Z}_{L1'3} & \bar{Z}_{L1'1'} & \bar{Z}_{L1'2'} & \bar{Z}_{L1'3'} \\ \bar{Z}_{L2'2} & \bar{Z}_{L2'2} & \bar{Z}_{L2'3} & \bar{Z}_{L2'1'} & \bar{Z}_{L2'2'} & \bar{Z}_{L2'3'} \\ \bar{Z}_{L3'2} & \bar{Z}_{L3'3} & \bar{Z}_{L3'3} & \bar{Z}_{L3'1'} & \bar{Z}_{L3'2'} & \bar{Z}_{L3'3'} \end{array}\right] = \left[\begin{array}{c|c} \mathbf{Z_{AA}} & \mathbf{Z_{AA'}} \\ \hline \mathbf{Z_{A'A}} & \mathbf{Z_{A'A'}} \end{array}\right] \quad (4)$$

where $\mathbf{Z_{AA}}$ – self-impedance **LineA**, matrix 3 × 3; $\mathbf{Z_{A'A'}}$ – self-impedance, **LineA′**, matrix 3 × 3; $\mathbf{Z_{AA'}}$ – mutual impedance between **LineA** and **LineA′**, matrix 3 × 3; $\mathbf{Z_{A'A}}$ – mutual impedance between **LineA′** and **LineA**, matrix 3 × 3, $\mathbf{Z_{A'A}} = \mathbf{Z_{AA'}^T}$.

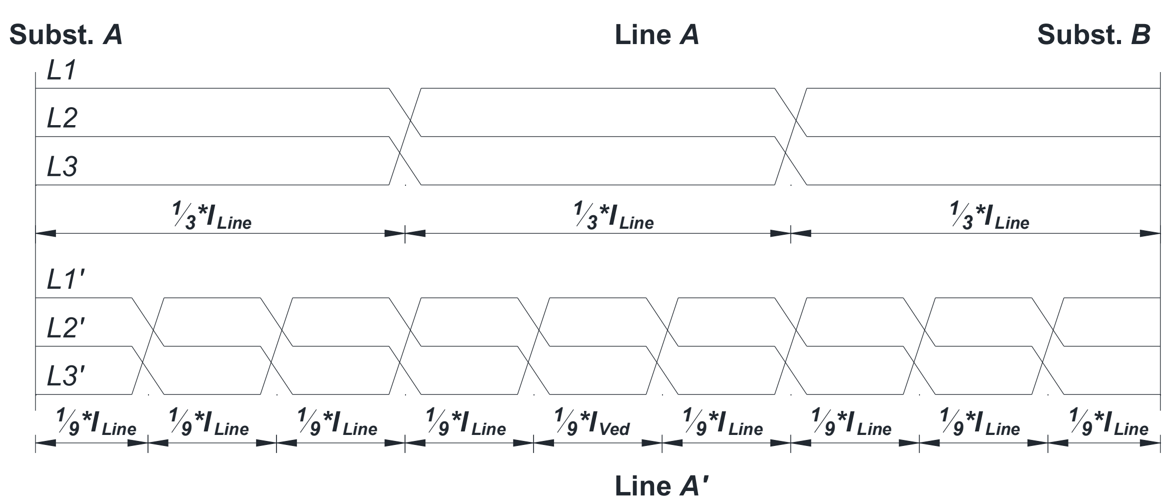

Fig. 4. Completely transposed double-circuit line.