TRANSMISSION TOWER POTENTIALS DURING GROUND FAULTS

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Abstract: A phase-to-ground fault occurring on a transmission line divides the line into two sections, each extending from the fault towards one end of the line. In this paper are studied these two sections of the line and then the analysis of full-lines can be accomplished by regarding them as a composite of the two sections. These two sections of the line may be considered infinite if some certain conditions are met; otherwise, they must be regarded as finite. This paper treat the case when those two sections of the line are both long and allows the determination of the transmission tower voltages during ground faults, for long lines.

Key words: overhead transmission lines, ground fault, tower potential.

1. Introduction

A phase-to-ground fault occurring on a transmission line divides the line into two sections, each extending from the fault towards one end of the line. In this paper are studied these two sections of the line and then the analysis of full-lines can be accomplished by regarding them as a composite of the two sections. These two sections of the line may be considered infinite if some certain conditions are met; otherwise, they must be regarded as finite. In this paper is treat the case when both of those sections are infinite.

During ground faults on transmission lines, a number of towers near the fault are likely to acquire high potentials to ground. These tower voltages, if excessive, may present a hazard to humans and animals.

Since during a ground fault the maximum voltage will appear at the tower nearest to the fault, attention in this study will be focused on that tower.

The voltage rise of the faulted tower depends of a number of factors. Some of the most important factors are:

- magnitudes of fault currents on both sides of the fault location;
- fault location with respect to the line terminals, conductor arrangement on the tower and the location of the faulted phase;
- the ground resistance of the faulted tower;
- soil resistivity;
- number, material and size of ground wires.

In exploring the effects of these factors, an important assumption will be that the magnitudes of the fault currents, as supplied by the line on both sides of the fault location, are known from system studies; no attempt will be made, therefore, to determine these quantities.

The calculation method introduced is based on the following assumptions:

- impedances are considered as lumped parameters in each span of the transmission line;
- capacitances of the line are neglected;
- the contact resistance between the tower and the ground wire, and respectively the tower resistance between the ground wire and the faulty phase conductor, are neglected.

2. Faults on overhead lines

When a ground fault occurs on an overhead transmission line in a power network with grounded neutral, the fault current returns to the grounded neutral through the tower structure, ground return path and ground wires. In this case, an infinite half-line can be represented by the ladder network presented in figure 1. It is assumed that all the transmission towers have the same ground impedance Z_{st} and the distance between towers is long enough to avoid the influence between there grounding electrodes. The impedance of the ground wire connected between two grounded towers, called the self impedance per span, it is noted with Z_{cp_d}. Considering the same distance l_d between two consecutive towers and that Z_{cp_d} is the same for every span, then $Z_{cp_d} = Z_{cp} l_d$, where Z_{cp} represents the impedance of the ground wire in Ω / km. Z_{cp_m} represents the mutual impedance between the ground wire and the faulted phase conductor, per span.

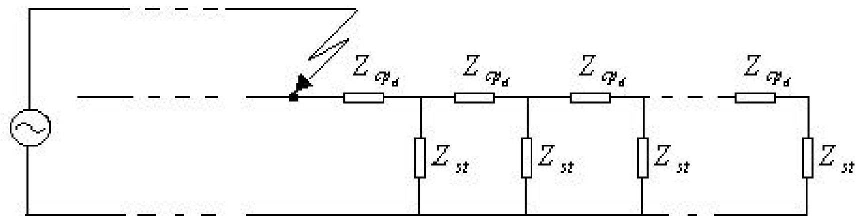

Figure 1. Equivalent ladder network for an infinite half-line

In order to determine the equivalent impedance of the circuit presented in figure 1, it is applied the continuous fractions theory (Edelmann 1966).

For the equivalent impedance seen from the fault location (figure 1), can be written the following expression:

$$Z_{1\infty} = Z_{cp_d} + \cfrac{1}{\cfrac{1}{Z_{st}} + \cfrac{1}{Z_{cp_d} + \cfrac{1}{\cfrac{1}{Z_{st}} + \cfrac{1}{Z_{cp_d} + \ldots + Z_{cp_d} + \cfrac{1}{\cfrac{1}{Z_{st}} + \cfrac{1}{Z_{cp_d} + Z_{st}}}}}}} \quad (1)$$

Expression (1) could be written in a recurrent manner using the following equation:

$$Z_{1\infty} = Z_{cp_d} + \cfrac{1}{\cfrac{1}{Z_{st}} + \cfrac{1}{Z_{1\infty}}} \quad (2)$$

From this expression, results the next two-degree equation:

$$Z_{1\infty}^2 - Z_{cp_d} Z_{1\infty} - Z_{cp_d} Z_{st} = 0 \quad (3)$$

The solutions of this equation are:

$$Z_{1\infty} = \frac{Z_{cp_d}}{2} \pm \sqrt{Z_{cp_d} Z_{st} + \frac{Z_{cp_d}^2}{4}} \quad (4)$$

The continuous fraction belonging to equation (1) converges to a limit value that represents the first solution (corresponding to the "+" sign) of the equation (4) if there are fulfilled the following van Vleck and Jensen theorem's conditions (Edelmann 1966):

$$\begin{aligned} &\mathrm{Re}(Z_{cp_d}) > 0, \quad \mathrm{Re}(Z_{st}) > 0, \\ &\mathrm{Im}(Z_{cp_d}) < \infty, \quad \mathrm{Im}(Z_{st}) < \infty \end{aligned} \quad (5)$$

Therefore, the solution of equation (3) is the following:

$$Z_{1\infty} = \frac{Z_{cp_d}}{2} + \sqrt{Z_{cp_d} Z_{st} + \frac{Z_{cp_d}^2}{4}} \quad (6)$$

The impedance of the ladder network, seen from the fault location, can be determined using either the lumped parameters or the distributed parameters.
Using lumped parameters, the impedance of the infinite half-line, according with (Endreny 1967), is:

$$Z_{\infty} = \frac{Z_{cp_d}}{2} + \sqrt{Z_{cp_d} Z_{st} + \frac{Z_{cp_d}^2}{4}} \quad (7)$$

As it can be observed, expression (7) is identical with expression (6).
Taking into account that usually $Z_{cp_d} << Z_{st}$, expression (6) can be written as follows:

$$Z_{1\infty} \approx \frac{Z_{cp_d}}{2} + \sqrt{Z_{cp_d} Z_{st}} \quad (8)$$

Expression (6) gives the impedance of an infinite section of a transmission line, extended from the fault towards one end of the line.
For a infinite line in both directions (the two sections of the line between the fault and the terminals could be considered long), the equivalent impedance is given by the next expression:

$$\frac{1}{Z_{\infty\infty}} = \frac{1}{Z_{1\infty}} + \frac{1}{Z_{st}} + \frac{1}{Z_{1\infty}}$$

$$\Rightarrow Z_{\infty\infty} = \frac{1}{\frac{2}{Z_{1\infty}} + \frac{1}{Z_{st}}} \quad (9)$$

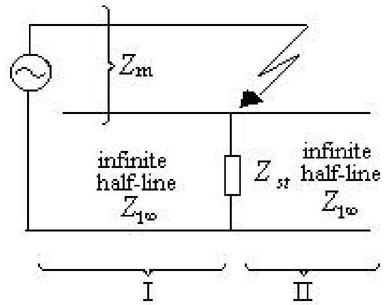

Figure 2 Full-line, infinite on both directions

The voltage rise of the faulted tower U_0 is given by the next expression (Vintan 2003, Endreny 1967):

$$U_0 = (1-n) I_d Z_{\infty\infty} \quad (10)$$

In expression (10), the coupling between the faulted phase conductor and the ground conductor is taken into account by Z_{cp_m}, the mutual impedance per unit length of line and $n = \frac{Z_{cp_m}}{Z_{cp_d}}$ represents the coupling factor. I_d belonging to expression (10) represents the fault current.

3. Results and Conclusions

For numerical results it was considered that the arrangement of phases on the towers of the line is that presented in figure 3 (Normativ PE 134/1984). It was considered only one ground wire.

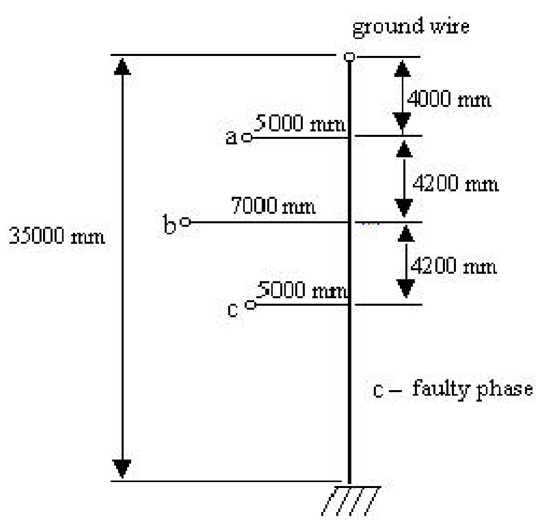

Figure 3 Phases arrangements on the tower

If it is considered that the ground wire is an aluminium-steel wire, having the section *160/95mm²*, and the diameter *d=18,13mm*, then $Z_{cp_d} = 0{,}193\Omega$.

In figure 4 is represented the equivalent impedance $Z_{\infty\infty}$ of the line for different values of $K = \frac{Z_{cp_d}}{Z_{st}}$. The values considered were $Z_{cp_d} = 0{,}193\Omega$ and respectively $Z_{st} = 19{,}3\Omega$, $Z_{st} = 3{,}86\Omega$, $Z_{st} = 0{,}193\Omega$, $Z_{st} = 0{,}0386\Omega$.

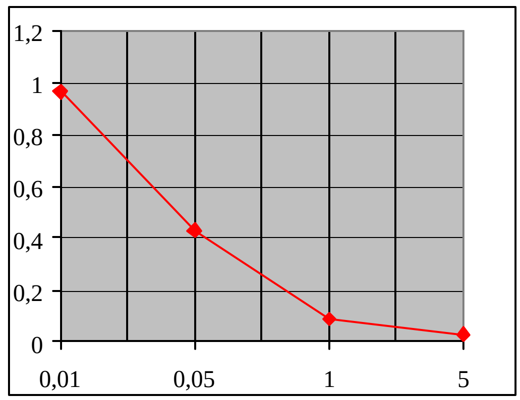

Figure 4 Curve for impedance of infinite line

If it is considered that the ground wire is from steel, having the section *70 mm²*, and the diameter *d=10,5mm*, then $Z_{cp_d} = 2{,}8825\Omega$.

In figure 5 is represented the equivalent impedance $Z_{\infty\infty}$ of the line in this case for different values of $K = \frac{Z_{cp_d}}{Z_{st}}$. The values considered were $Z_{cp_d} = 2{,}8825\Omega$ and respectively $Z_{st} = 28{,}825\Omega$, $Z_{st} = 5{,}765\Omega$, $Z_{st} = 2{,}8825\Omega$, $Z_{st} = 1{,}9\Omega$, $Z_{st} = 0{,}5765\Omega$, $Z_{st} = 0{,}28825\Omega$.

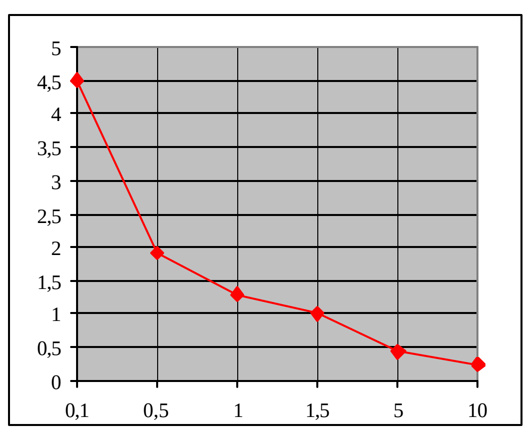

Figure 5 Curve for impedance of infinite line

It can be shown that between the fault and the source, at a great distance from both, the portion of the fault current flowing in the ground conductor is nI_d while $(1-n)I_d$ is returning in the ground, and there is no interchange of currents through the towers. In the absence of coupling between the phase and ground conductors, the total of I_d will gradually flow into the ground through the towers, and, if the line is long enough, no current remains in the ground wire. The voltage rise at the fault location is, according to (10), the product of this latter current portion and $Z_{\infty\infty}$. This impedance represents the resultant impedance of the two half-lines and the ground resistance of the tower at the fault in parallel, and is given by the expression (9) (Endreny 1967).

Taking into account the above considerations, it can be said that in the both directions infinite line case, the highest voltage rise of a given tower is obtained when the fault appear on the phase which is the furthest from the ground conductors. For example, in a vertical arrangement of phases, the lowest phase should be assumed faulty.

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