GROUND WIRES INFLUENCE ON AC POWER LINES IMPEDANCES

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Abstract - When a ground fault occurs on an overhead transmission line in a power network with grounded neutral, the fault divides the line into two sections, each extending from the fault towards one end of the line. If some certain conditions are met, then these two sections of the line may be considered infinite. In this paper it will be presented the case when the fault appears at large distance from both terminals, and the two sections of the line between the fault and the terminals could be considered infinite. First, it is considering that the transmission line has one ground wire, than the two ground wires case will be treat.

Keywords: transmission line, ground wire, line impedance.

1. INTRODUCTION

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 towers, ground return path and ground wires. The ground fault divides the line into two sections, each extending from the fault towards one end of the line. Depending of the number of towers between the faulted tower and the stations, respectively of the distance between the towers, these two sections of the line may be considered infinite, in which case the ground fault current distribution is independent on the termination of the network, otherwise, they must be regarded as finite, in which case the ground fault current distribution may depend greatly on the termination of the network [2].

In previous work [3, 4, 5], authors presented analytical method for determination the ground fault current distribution between the transmission line towers and ground wire. Ground current due to fault at any tower, apart from traversing through it, will also get diverted in portion to the ground wire and other towers. It was considered an overhead transmission line with one ground wire, connected to the ground at every tower of the line.

But, quite often there are more than one ground wire installed on the transmission line. Additional ground wire reduces the overall series impedance. As a consequence the tower voltages during a ground fault will be lower than in the case of a single ground wire.

In this paper it will be presented the case when the fault appears at large distance from both terminals, and the two sections of the line between the fault and the terminals could be considered infinite. First, it is considering that the transmission line has one ground wire, than the two ground wires case will be treat.

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. TRANSMISSION LINE IMPEDANCE

One ground wire

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} in Ω / km.

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.

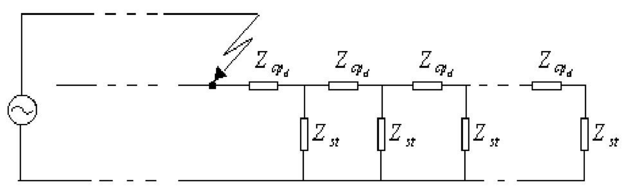

Fig. 1. Equivalent ladder network for an infinite half-line

The impedance of the ladder network, seen from the fault location, can be determined using either the lumped parameters or the distributed parameters.

In order to determine the equivalent impedance of the circuit presented in figure 1 using lumped parameters, it is applied the continuous fractions theory already presented in [3]. For the equivalent impedance seen from the fault location (figure 1), can be written the following expression:

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

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

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

From this expression, results the next equation:

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

The solutions of this equation are:

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

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 [3]:

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

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

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

Taking into account that usually $Z_{cp_d} << Z_{st}$, expression (6) can be written as follows:

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

Expression (6) gives the impedance of an infinite section of a transmission line, extended from the fault towards one end of the line.

For an 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 (figure 2) [5]:

$$\frac{1}{Z_{\infty\infty}} = \frac{1}{Z_{1\infty}} + \frac{1}{Z_{st}} + \frac{1}{Z_{1\infty}} \quad (8)$$

This impedance represents the resultant impedance of the two half-lines and the ground resistance of the tower at the fault in parallel.

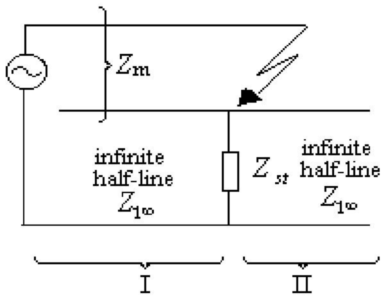

Fig. 2. Full-line, infinite on both directions

The coupling between the faulted phase conductor and the ground conductor is taken into account by Z_m, which represents the mutual impedance between the ground wire and the faulted phase conductor, per span. $\nu = \frac{Z_m}{Z_{cp_d}}$, represents the coupling factor.

The voltage rise of the faulted tower U_0 is given by the next expression [2]:

$$U_0 = (1 - \nu) I_d Z_{\infty\infty} \quad (9)$$

I_d in expresion (8) represents the fault current.

Two ground wires

So far it has been assumed that the transmission line has only one ground wire. When there are two ground wires, the expressions presented for single ground wire can still be used, if Z_{cpe} and Z_{cpme} values will represents the group of ground wires and if those conductors are identical and disposed in a mutually symmetrical position. Considering figure 3, the following equations could be written:

$$\begin{aligned} U_1 &= Z_{cp11} I_{cp1} + Z_{cp12} I_{cp2} \\ U_2 &= Z_{cp21} I_{cp1} + Z_{cp22} I_{cp2} \end{aligned} \quad (10)$$

Those two ground wires, being interconnected at both ends, $U_1 = U_2$, and the self impedance of the group can be defines as:

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$$Z_{cpe} = \frac{U}{I_{cp1} + I_{cp2}} \quad (11)$$

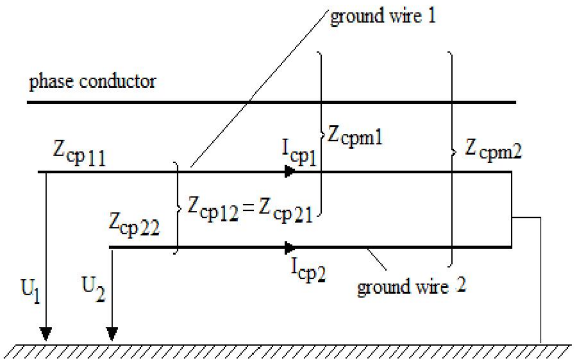

Fig. 3. Two ground wires

The mutual impedance between the equivalent ground wire and the faulted phase conductor will be:

$$Z_{cpme} = \frac{I_{cp1}Z_{cpm1} + I_{cp2}Z_{cpm2}}{I_{cp1} + I_{cp2}} \quad (12)$$

From these three expressions, it will be determined the expressions for the self impedance of the equivalent ground wire, respectively for the mutual impedance between equivalent ground wire and the faulted phase:

$$Z_{cpe} = \frac{Z_{cp11}Z_{cp22} - Z_{cp12}^2}{Z_{cp11} + Z_{cp22} - 2Z_{cp12}} \quad (13)$$

$$Z_{cpme} = \frac{Z_{cpm1}(Z_{cp22} - Z_{cp12}) + Z_{cpm2}(Z_{cp11} - Z_{cp12})}{Z_{cp11} + Z_{cp22} - 2Z_{cp12}} \quad (14)$$

4. RESULTS

In order to illustrate the theoretical approach outlined in section above, we are considering that the line who connects two stations is a $220kV$ transmission line. The line has two aluminium-steel ground wire $160/95mm^2$ (figure 4).

Line impedances per one span are determined on the bases of the following assumption: average length of the span is $250m$. Ground wire impedance per one span Z_{cp_d} and the mutual impedance Z_m between the ground wire and the faulted phase are calculated for different values of the soil resistivity ρ with formulas based on Carson's theory of the ground return path [1].

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.

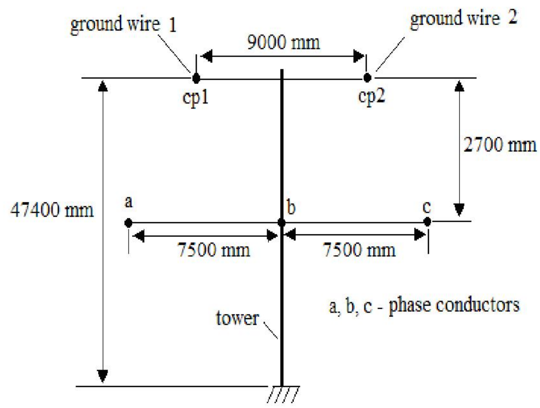

Fig. 4. Disposition of line conductors

The fault was assumed to occur on the phase which is the furthest from the ground conductors, because the lowest coupling between the phase and ground wire will produce the highest tower voltage [2].

Impedance Z_m is calculated only in relation to the faulted phase conductor, because it could not be assumed that a line section of a few spans is transposed.

Figure 5 presents the values of the equivalent impedance of the line, composed by two infinite half-line as a function of the towers impedances, for different values of the ground wire impedance.

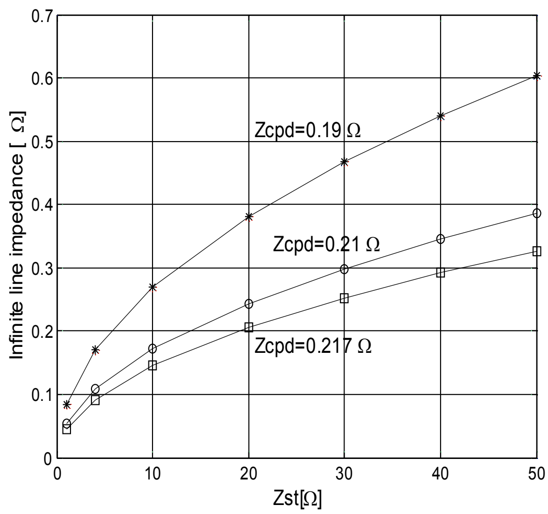

Fig. 5. Equivalent impedance of the infinite line as a function of the tower ground impedance

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. Figure 6 presents the voltage rise of the faulted tower as a function of the tower impedance, for different values of the ground wire impedance. The highest voltage rise of the faulted 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 [2, 3, 4].

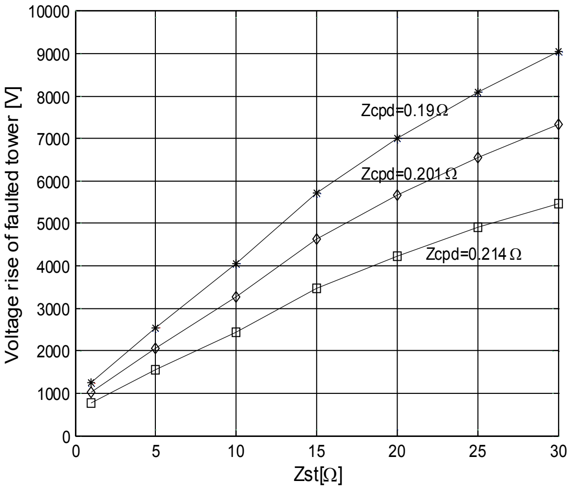

Fig. 6. Voltage rise of the faulted tower as a function of the tower impedance

Figure 7 illustrates the dependence of the mutual reactance between the two ground wires with ground return, calculated using Carson's expressions, as a function of the horizontal distance between the two ground wires, for different values of the ground soil resistivity.

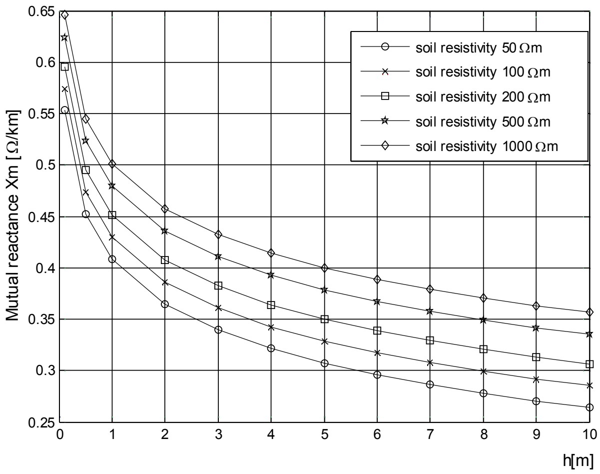

Fig. 7. The mutual reactance between the two ground wires with ground return as a function of horizontal distance

4. CONCLUSION

A parametric analysis is done in order to study the effects of the ground wires on the line impedances during a ground fault. At first was considered an overhead transmission line with one ground wire, connected to the ground at every tower of the line. However, quite often there are more than one ground wire installed on the transmission line. Considering two ground wires, the method and equations presented for single ground wire can be still applied, but in equations for the self and mutual impedances of the two ground wires, the mutual coupling between the two ground wires must be taken into consideration.

Additional ground wire reduces the overall series impedance. As a consequence the tower voltages during a ground fault will be lower than in the case of a single ground wire. The presence of the ground wires also influence the step and touch voltages near the faulted tower, which will be smaller then the values obtained in the absence of the ground wires.

ACKNOWLEDGMENTS

This work was supported by the Romanian National Council of Academic Research CNCSIS – UEFISCU, through the research Grant PNII – IDEI code 485/2008.

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