TOWER GROUND IMPEDANCE INFLUENCE ON AC OVERHEAD LINE GROUND FAULT CURRENTS

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Abstract - When a ground fault occurs on an overhead transmission line in a three-phase power network with grounded neutral, the fault current returns to the grounded neutral through the towers, ground return path and ground wires. This paper describes an analytical method in order to determine the ground fault current distribution in power networks, when the fault occurs at the last tower of the line, at a large distance from the other terminal and the tower impedances influence on these currents is studied.

Key words: transmission line, ground fault, tower potential

1. INTRODUCTION

The estimation of the ground current distribution has many major applications in power systems design, especially in grounding systems. Extensive work has been undertaken, especially in the last two decades, to model transmission network for ground fault current analysis. Carson, in his paper [1] has formulated the well known impedance equations of ground return paths. Rudenberg applied difference equations in calculating the fault current distribution in ground return circuits [7]. Since the late 1960's many other authors (Endreny, Edelmann [3], Poter, Finsh, Johnson, Sebo, Fesonen, Dawalibi, Mukhedhar etc.) have presented methods for the solution of ladder circuit. Endreny [4] has provided an equivalent impedance calculation method for a ladder network of infinite length, and Sebo [8] proposed the use of two methods, first an equivalent star method and then a matrix method. The approach generally used by these authors was to represents the lumped parameter ladder circuit by an equivalent distributed parameter ladder circuit and to solve it by differential equations. This process gives satisfactory results only for the line sufficiently long. Recently, by using Kirchoff's theorems, the principle of superposition and the summation of geometric series, other equation were derived and used in paper like [2, 7, 9].

When a ground fault occurs on an overhead transmission line in a power network with grounded neutral, large currents are injected into the soil through the tower's earthing systems thus raising the potential of the surrounding soil. The fault current returns to the grounded neutral through the tower's structure, ground return path and ground wires. Ground fault current due to a fault at any tower, apart from traversing through it, will also get diverted in each portion to the ground wires and other towers. As a consequence, the step and touch voltages near the faulted tower will be smaller then the values obtained in the absence of the ground wires. In previous works was already presented an analytical method in order to determine the ground fault current distribution in effectively grounded power network [10, 11]. Considering that the fault current is known and taking into account that a phase-to-ground fault occurring on a transmission line, it was possible to find the values of the currents in towers, ground wire and the currents who return to the stations. In [11] it was presented the case when the fault appears to the last tower of the transmission line, considering both infinite and finite transmission line, respectively the case when the fault appears at any tower of the transmission line, the two sections of the line are finite and it is assumed that the fault is fed from both directions.

In this paper it will be presented the case when the fault appears at the last terminal, at large distance from the other terminals. Ground fault current distribution is influenced by the ground wire, ground tower impedance, distance between faulted tower and the terminals etc. The impedances of the faulted tower and its adjacent towers, has a significantly influence on the fault current distribution. These impedances should be taken into consideration in overhead ground wire sizing, transmission line relaying and safety analyses. A parametric analysis is done in order to study the effects of ground tower impedance on the ground fault current distribution.

2. GROUND FAULT CURRENT DISTRIBUTION

In figure 1 is presented an overhead transmission line with one ground wire, connected to the ground at every tower of the line. 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 self-impedance of the ground wire connected between two grounded towers, called the self-impedance per span, it is noted with Z_{cp_d}. It is assumed that the distance between two consecutive towers is the same for every span. Z_{cp_m} represents the mutual-impedance between the ground wire and the faulted phase conductor, per span. It is assumed that the fault occurs at the last tower.

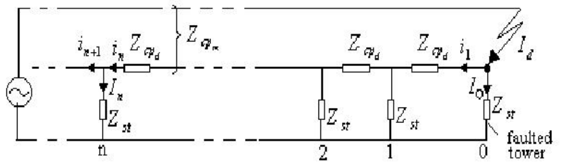

Fig. 1 Fault current distribution

When the fault appears, part of the ground fault current will get to the ground through the faulted tower, and the rest of the fault current will get diverted to the ground wire and other towers.

As we already presented in [11], the current I_n flowing to ground through the nth tower, counted from the terminal tower where the fault is assumed to take place, has an exponentially variation, and is given by the next solution:

$$I_n = Ae^{\alpha n} + Be^{-\alpha n} \quad (1)$$

A and B in equation (1) are arbitrary parameters which could be obtained from the boundary conditions, and parameter α is given by the next expression:

$$\alpha \approx \sqrt{\frac{Z_{cp_d}}{Z_{st}}} \quad (2)$$

The curent in the ground conductor is given by the next solution :

$$i_n = A\frac{e^{\alpha n}}{1-e^{\alpha}} + B\frac{e^{-\alpha n}}{1-e^{-\alpha}} + \nu I_d \quad (3)$$

ν in expression (3) represents the coupling factor between the overhead phase and ground conductor ($\nu = \frac{Z_{cp_m}}{Z_{cp_d}}$). The boundary condition (condition for $n = 0$) at the terminal tower of figure 1 is:

$$I_d = I_0 + i_1 \quad (4)$$

That means that the fault current is given by the sum between the current in the faulted tower and the current in the first span of the ground wire.

In case that it is considered that the line is sufficiently long so that, after some distance, the varying portion of the current exponentially decays to zero, then the parameter $A \to 0$. In this case only the parameter B must be found from the boundary conditions [7].

According to (1) and (3), results:

$$I_n = Be^{-\alpha n} \quad (5)$$

$$i_n = B(e^{-\alpha n}/1-e^{-\alpha}) + \nu I_d \quad (6)$$

Substituting these expressions in (4), with $n = 0$ for I_n and $n = 1$ for i_n, it will be obtained:

$$I_d = B\frac{1}{1-e^{-\alpha}} + \nu I_d \quad (7)$$

For B it will be obtained the next expression:

$$B = (1-\nu)(1-e^{-\alpha})I_d \quad (8)$$

The current in the faulted tower will get the expression:

$$I_0 = B = (1-\nu)(1-e^{-\alpha})I_d \quad (9)$$

The current in the first span, counted from the faulted tower, will be:

$$i_1 = I_d - I_0 = I_d[e^{-\alpha} + \nu(1-e^{-\alpha})] \quad (10)$$

The voltage rise at the terminal tower is:

$$U_0 = Z_{st}I_0 = (1-\nu)ZI_d \quad (11)$$

where with Z was noted the equivalent impedance of the network looking back from the fault. Usually, the terminal tower is connected, through an extra span Z'_{cp_d}, to the station grounding grid (Figure 2). Consequently, the ladder network representing such a line must be closed by a resistance representing the grounding system of the station resistance. In this case, a part of the total ground fault current will flow through the station ground resistance R'_p. In order to use the previous results, it is enough to replace the current I_d with $I'_d = I_d - I'_p$, and thus the value of the current in the faulted tower will be [12]:

$$I_0 = (1-\nu)(1-e^{-\alpha})I'_d \quad (12)$$

The sum between Z'_{cp_d} and R'_p is noted with $Z'_p = R'_p + Z'_{cp_d}$ and the current I'_p through the station grounding grid resistance will be given by the next expression:

$$I'_p = I_d Z/(Z'_p + Z) \quad (13)$$

In case the values of Z'_p and Z are known, I'_p can be found out from expression (13). I'_d is given by the next expression:

$$I'_d = I_d - I'_p = I_0 + i_1 \quad (14)$$

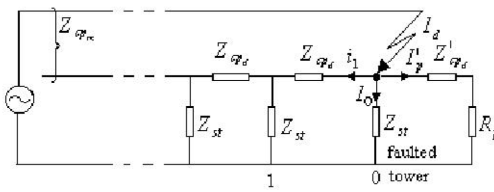

Fig. 2 Fault current distribution

3. RESULTS

In order to illustrate the theoretical approach outlined in section above, we are considering that the line who connects two stations is a 110kV transmission line with aluminium-steel 185/32mm^2 and one aluminium-steel ground wire 95/55mm^2 (figure 3) [5].

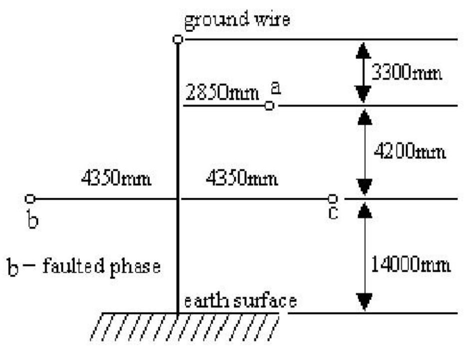

Fig. 3 Disposition of line conductors

Line impedances per one span are determined on the bases of the following assumptions: average length of the span is 250m; the resistances per unit length of ground wire is 0,3 Ω / km and it's diametere is 16 mm.

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]. 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. 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. The total fault current was assumed to be I_d =15000A. Those values are valid for a soil resistivity of 100 Ω m. Figure 4 shows the currents flowing in the transmission line towers for different values of the towers impedances, using expression (5).

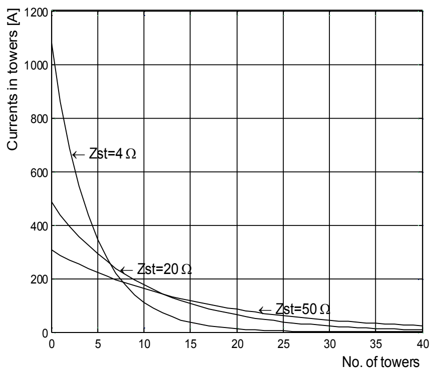

Fig. 4 Currents flowing through the transmission line towers

Figure 5 shows the currents flowing in the ground wire for different values of the towers impedances, using expression (6).

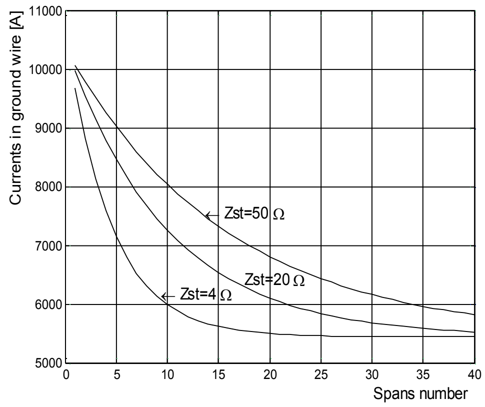

Fig. 5 Currents flowing in the ground wire in case of different values of towers impedances

Figure 6 presents the values of the impedance of the infinite line computed from expression (11), as a function of the tower impedances, for different values of the ground wire.

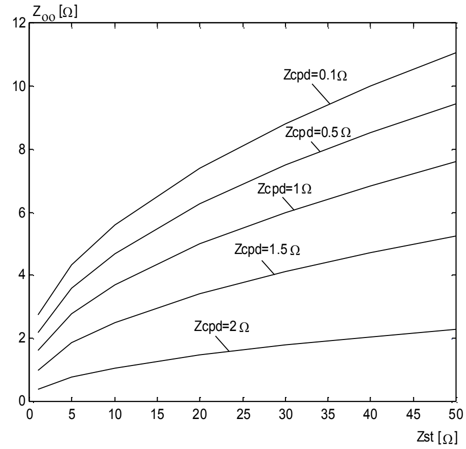

Fig. 6 The impedance of the infinite line

Figure 7 shows the voltage rise of faulted tower as a function of the tower ground impedance, for different values of ground wire impedance.

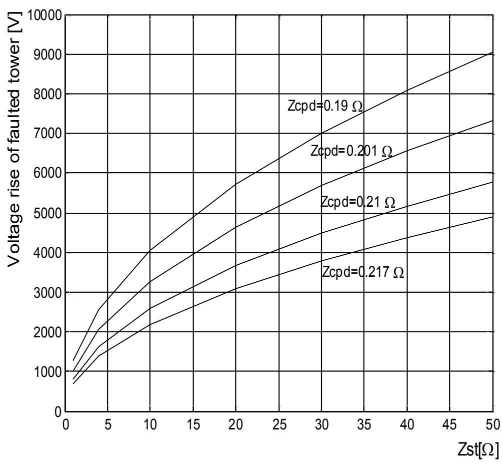

Fig. 7 The voltage rise of the faulted tower as a function of the tower ground impedance

4. CONCLUSIONS

This paper presented an analytical method in order to determine the ground fault current distribution in power networks, when the fault occurs at the last tower of the line. It was considered an overhead transmission line with one ground wire, connected to the ground at every tower of the line. The effect of the ground tower impedance on the magnitude of return currents has been examined.

Taking into account the above considerations, it can be said that 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 [4].

Acknowledgments

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