COUPLING FACTOR INFLUENCE ON AC OVERHEAD LINE GROUND FAULT CURRENTS

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Abstract: High-voltage systems have an effectively grounded neutral. When phase to earth faults occur at transmission line towers, 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 towers, ground return path and ground wires. This paper presents an analytical method in order to determine the ground fault current distribution between neutral conductors and the earth, via the towers. It will be treat the case when the fault appears at the last tower of the transmission line at a large distance from the other terminal. It will be studied the influence of the coupling factor between the faulted phase and the ground wire on the ground fault current distribution.

Key words: transmission line, ground fault current distribution

1. INTRODUCTION

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

Knowledge of fault current distribution is important for the size selection of an overhead ground wire, respectively for the evaluation of voltage rise of the faulted tower.

Based on Kirchoff's theorems and on methods presented by Rudenberg [6], Verma [7], Endreny [4], Edelmann [3] and Dawalibi [2], an analytical method in order to determine the ground fault current distribution in effectively grounded power network, were already presented in authors previous works [8, 9]. It was possible to find the values of the currents in towers, ground wire and the currents who return to the stations. In [9] 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. The method is applied to three phase systems with mutual coupling between phase conductors and ground wire.

In this paper it will be presented the case when the fault appears at the last tower of the transmission line, at large distance from the other terminal. The calculation method is based on the following assumptions: impedances are considered as lumped parameters in each span of the transmission line, line capacitances are neglected; the contact resistance between the tower and the ground wire, and the tower resistance between the ground wire and the faulted phase are neglected.

It is considered an overhead transmission line with one ground wire, connected to the ground at every tower of the line and the fault appears in the middle of the line. There are obtained the expressions of the currents flowing to ground through the towers and the currents in every span of the ground conductor. The influence of the coupling factor between the faulted phase and the ground wire on the ground fault current distribution is studied.

2. FAULTS ON OVERHEAD LINE

Figure 1 presents the connection of a ground wire to earth through transmission towers. 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 was noted with Z_{cp_d}. It was 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. 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.

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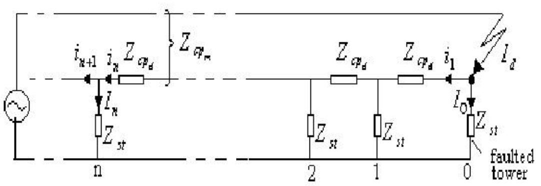

Fig. 1 Fault current distribution

Figures (including diagrams and images) should be inserted in line with text, with a short description caption, using JPEG, JPG format (BMP only with the quality is very important).

As we already presented in [8, 9], the current I_n flowing to ground through the *n*th tower, counted from the terminal tower where the fault is assumed to take place, is equal with the difference between the currents i_n and i_{n+1}:

$$I_n = i_n - i_{n+1} \tag{1}$$

The loop equation for the *n*-th mesh is given by the next relation:

$$I_n Z_{st} - I_{n-1} Z_{st} + i_n Z_{cp_d} - \nu I_d Z_{cp_d} = 0 \tag{2}$$

Where ν represents the coupling factor between the overhead phase and ground conductor ($\nu = \dfrac{Z_{cp_m}}{Z_{cp_d}}$).

The equation (2) could be written in the next form:

$$i_n = \frac{(I_{n-1} - I_n) Z_{st}}{Z_{cp_d}} + \nu I_d \tag{3}$$

Similary:

$$i_{n+1} = \frac{(I_n - I_{n+1}) Z_{st}}{Z_{cp_d}} + \nu I_d \tag{4}$$

Substituting equations (3) and (4) in equation (1), for the current in the faulted tower will be obtained the next equation, which is a second order difference equation:

$$I_n \frac{Z_{cp_d}}{Z_{st}} = I_{n+1} - 2I_n + I_{n-1} \tag{5}$$

According to [6], the sollution of this equation is:

$$I_n = Ae^{\alpha n} + Be^{-\alpha n} \tag{6}$$

According with the solution (6) which contains the arbitrary parameters *A* and *B,* the current flowing to ground through the succesive towers, has an exponentiall variation.

The arbitrary parameters *A* and *B* could be obtained from the boundary conditions. Parameter α in the solution (6) could be obtained by substituting the solution (6) in equation (5). Because $Z_{cp_d} << Z_{st}$, it can be written:

$$\alpha \approx \sqrt{\frac{Z_{cp_d}}{Z_{st}}} \tag{7}$$

By applaying equation (1) to the (*n*-1) tower, it will be obtained the following expression:

$$I_{n-1} = i_{n-1} - i_n \tag{8}$$

By substituting the equations (1) and (8) in equation (2), it will be obtained the next equation with a constant term:

$$i_n \frac{Z_{cp_d}}{Z_{st}} = i_{n+1} - 2i_n + i_{n-1} + \nu I_d \frac{Z_{cp_d}}{Z_{st}} \tag{9}$$

Similar with equation (5), the current in the ground conductor is given by the next solution:

$$i_n = ae^{\alpha n} + be^{-\alpha n} + \nu I_d \tag{10}$$

a, b represents the arbitrary parameters.

Because of the link between currents i_n and I_n , the arbitrary parameters *A*, *B* and *a, b* are not independent. By substituting the solutions (6) and (10) in equation (1), it will be obtained:

$$Ae^{\alpha n} + Be^{-\alpha n} = ae^{\alpha n}(1 - e^{\alpha}) + be^{-\alpha n}(1 - e^{-\alpha}) \tag{11}$$

Because these relations are the same for every value of *n*, it will be obtained the next expressions:

$$A = a(1 - e^{\alpha}) \tag{12}$$

$$B = b(1 - e^{-\alpha}) \tag{13}$$

The current in the ground wire will be then given by the following expression:

$$i_n = A\frac{e^{\alpha n}}{1 - e^{\alpha}} + B\frac{e^{-\alpha n}}{1 - e^{-\alpha}} + \nu I_d \tag{14}$$

The boundary condition (condition for $n = 0$) at the terminal tower of figure 1 is:

$$I_d = I_0 + i_1 \tag{15}$$

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 [6]. According to (6) and (14), results:

$$I_n = Be^{-\alpha n} \tag{16}$$

$$i_n = B(e^{-\alpha n} / 1 - e^{-\alpha}) + \nu I_d \tag{17}$$

Substituting these expressions in (15), with $n = 0$ for I_n and $n = 1$ for i_n , it will be obtained:

$$I_d = B + B(e^{-\alpha} / 1 - e^{-\alpha}) + \nu I_d \tag{18}$$

For *B* it will be obtained the next expression:

$$B = (1 - \nu)(1 - e^{-\alpha}) I_d \tag{19}$$

The current in the faulted tower will get the expression:

$$I_0 = B = (1 - \nu)(1 - e^{-\alpha}) I_d \tag{20}$$

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

$$i_1 = I_d - I_0 = I_d [e^{-\alpha} + \nu(1 - e^{-\alpha})] \tag{21}$$

The voltage rise at the terminal tower is:

$$U_0 = Z_{st} I_0 = Z_{st}(1 - \nu)(1 - e^{-\alpha}) I_d \tag{22}$$

3. RESULTS

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 2) [5].

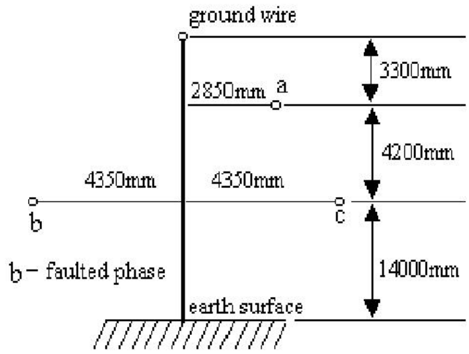

Fig. 2 Disposition of line conductors

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 $0{,}3\,\Omega/km$ 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 from both stations was assumed to be I_d =15000A. Those values are valid for a soil resistivity of 100 Ω m. It was assumed that the fault appears at the middle tower of the line, so there are N=20 towers between the faulted tower and each of the terminals.

Figure 3 shows the currents flowing in the transmission line towers for different values of the tower impedances.

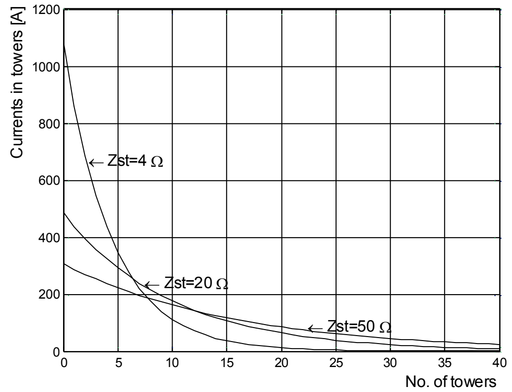

Fig. 3 Currents flowing through the transmission line towers

In order to see the efect of the mutual coupling between the faulted phase and the ground wire, figure 4 presents the currents flowing in the transmission line towers, first considering the mutual coupling between the faulted phase and the ground conductor, than neglecting that mutual coupling.

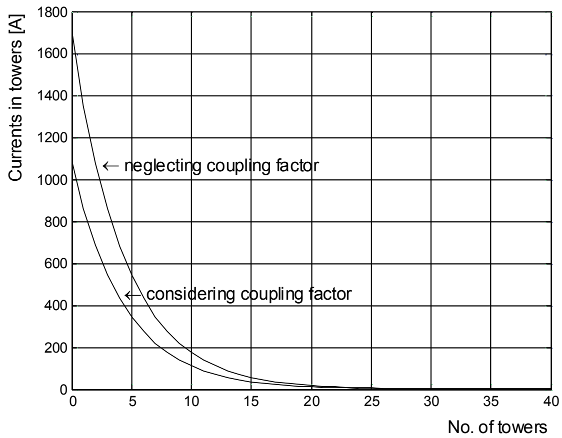

Fig. 4 Mutual coupling influence on the currents flowing through the transmission line towers

Figure 5 shows the currents flowing in the ground wire for different values of the tower impedances.

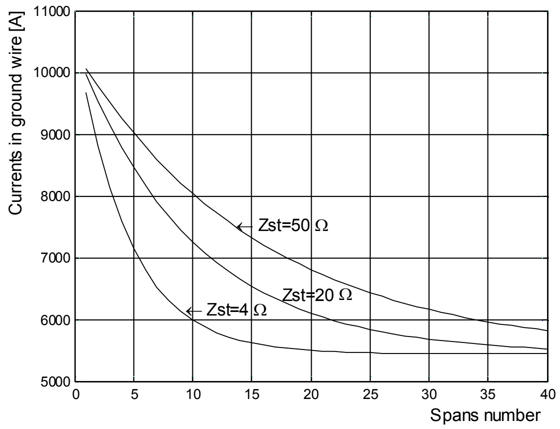

Fig. 5 Currents flowing in the ground wire

4. CONCLUSIONS

The influence of the coupling factor between the faulted phase and the ground wire on the ground fault current distribution in power networks, when the fault appears at the last tower of the transmission line was studied. It was considered an overhead transmission line with one ground wire, connected to the ground at every tower of the line. There were presented the expressions of the currents flowing to ground through the towers and the currents in every span of the ground conductor.

It can be seen that, due to the mutual coupling, the fault current is reduced with $(1-\nu)$. It also can be seen that in the absence of mutual coupling, the fault current will flow through the ground through a smaller number of towers then in the mutual coupling presence.

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