Transferred Potential from Substation HV/MV by MV Cable Line

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Abstract – **This paper deals with potential transferring, performed by medium – voltage cable line. For this matter, we have analyzed power lines formed of three–core cables with non–insulated metal sheath (IPO 13, NPO 13), as well as three–phase lines formed of three single–core cables with isolated electric screen (XHE 48, XHE 49 type). When non - insulated metal sheath cables are considered, the effects which the cable length and the HV/MV substation grounding system resistivity have on transferred potential value were analyzed. In the case of power line formed of single – core cables, the effects of the number of HV/MV substations powered by that particular power line, as well as the effects of HV/MV substation grounding system resistivity on transferred potential value, were analyzed.**

Keywords – **potential, cable, metallic screen, impedance**

I. INTRODUCTION

Metal sheath or electric protection of medium - voltage cables are grounded on both of their ends, by connecting to the substation grounding system. When a certain electric potential occurs on the substation grounding system earth electrode (during the earth fault in HV power network), it is transferred to the MV/LV substation, through grounded metal sheath or electric screen of MV cables. If the MV/LV substation functional and protective groundings are connected, transferred potential may occur in low voltage power network and consumers installations. This means when TN protection system is applied metal parts of electric equipment, devices and appliances, which may be reached by the consumer, may have a certain electric potential. This potential may be greater then permitted, which may lead to undesired consequences.

Since the transferred potential value depends on the construction of the cable, here is going to be analyzed cables with impregnated paper insulation (IPO 13, IPZO 13, NPO 13 and NPZO 13 type) and cables with cross - linked polyethylene insulation (XHE 48 and XHE 49 type).

II. CABLES WITH NON – INSULATED METAL SHEATH

The cables with metal sheath and armature protected from corrosion by impregnated jute, textile, paper etc. several months after they are laid, come into a good contact with soil. These are the cables of IPO 13, IPZO 13, NPO 13 and NPZO 13 type, with impregnated paper insulation and lead sheath. They are commonly used in 10 kV to 35 kV power networks. Considering the metallic screen and cable armature are in the close contact with the soil they are buried in, and, looking from the point of potential transferring, therefore they can be treated as a line with distributed parameters. Having this in mind, the equivalent electrical scheme for the purpose of calculation of the currents and potential on screen, is shown in Fig. 1. The impedance per unit length of the screen and armature in parallel is marked with z; the y stands for parallel admittance which directs the current to the ground, while the propagation resistance of the MV substation grounding system is marked with Z_2.

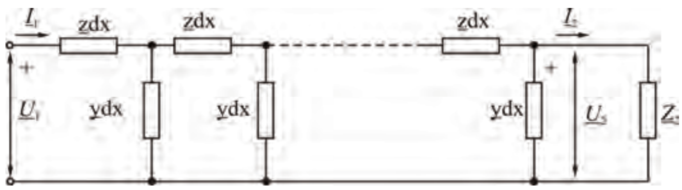

Fig. 1 Equivalent electrical scheme

Equivalent electrical scheme analysis shows [1]:

$$U_1 = U_2 ch(\gamma_c l) + Z_c I_2 sh(\gamma_c l) \ , \tag{1}$$

$$I_1 = \frac{U_2}{Z_c} sh(\gamma_c l) + I_2 ch(\gamma_c l) \ , \tag{2}$$

where:

$\gamma_c = \sqrt{z\,y}$ - propagation coefficient,

$Z_c = \sqrt{\frac{z}{y}}$ - characteristic impedance.

Since there is:

$$U_2 = Z_2 I_2 \ , \tag{3}$$

the potential at the beginning of the cable, i.e. on the grounding system of the HV/MV substation, becomes:

$$U_1 = U_2 \left[ch(\gamma_c l) + \frac{Z_c}{Z_2} sh(\gamma_c l) \right] \ . \tag{4}$$

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U_1 is metal sheath potential at the beginning of the cable, i.e. at HV/MV substation grounding system. U_2 is metal sheath potential at the end of the cable, i.e. at MV/LV substation grounding system. Their ratio is equal to transferred potential coefficient K_i :

$$K_i = \frac{U_2}{U_1} = \frac{1}{ch(\gamma_c l) + \dfrac{Z_c}{Z_2} sh(\gamma_c l)} , \tag{5}$$

with module:

$$K_i = \frac{1}{\left| ch(\gamma_c l) + \dfrac{Z_c}{Z_2} sh(\gamma_c l) \right|} . \tag{6}$$

III. Cables with Insulated Electric Screen

Now days medium voltage single – core cables with cross – linked polyethylene insulation (XHE 48, XHE 49U type) are frequently used [7]. The reason for this lays in the fact that these cables may hold on to greater current load then cables with impregnated paper insulation (IPO 13, NPO 13 type), with same cross section [4]. Single – core cables have the polyethylene sheath which prevents the contact between the cable electric screen and the soil it is buried in. This is totally different situation from the one with cables of IPO 13 (NPO 13) type.

A three phase power line, composed of three single – core cables, is supplies several MV/LV substations in which the grounding systems are connected to electric protections of cables. This way the grounding systems of all of MV/LV substations are connected, therefore it can be said that power line composed of three single – core cables possess certain grounding qualities [2,3]. Having in mind that electric screen of cables are also connected to HV/MV substation grounding system, it is clear that when an earth fault occurs in HV/MV substation, the potential is transferred to MV/LV substation.

The mathematical model used for the analysis of grounding effects and potential transferring is formed under following assumptions:

- Distances between neighboring substations are equal (they are to be calculated using average length, which is attained when the total line length is divided by the number of MV/LV substations supplied by the line in question),
- grounding impedances of MV/LV substations are equal.

Taking these assumptions, the equivalent scheme, shown in Fig. 2, is formed. Z_1 is an electric screen impedance of single–core cables connecting two neighboring MV/LV substations. Z_2 is MV/LV substation grounding impedance.

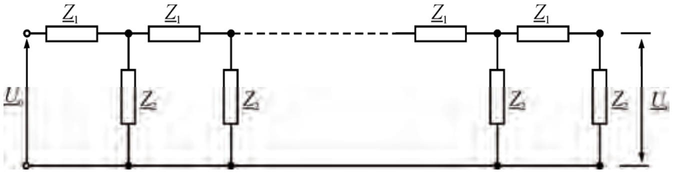

Fig. 2. Equivalent scheme for grounding effects analysis

Scheme in Fig. 2 represents a cascade of n reversed Γ – networks [6]. In order to make mathematical analysis simpler, it is suitable to transform the scheme given in Fig. 2 to a scheme in Fig. 3, which represents a cascade of symmetrical T -networks.

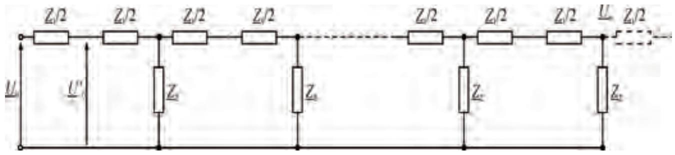

Fig. 3. Modified scheme from Fig. 2

Having in mind labeling in Fig. 3 and taking into account the real fact that the current at the end of modified scheme is $I_n = 0$, we have:

$$\begin{aligned} U_0' &= U_n\, ch(n\gamma_c) , \\ I_0' &= U_n \frac{sh(n\gamma_c)}{Z_c} , \end{aligned} \tag{7}$$

as to:

$$\begin{aligned} U_0 &= U_0' + \frac{Z_1}{2} I_0 = U_n\, ch(n\gamma_c) + \frac{Z_1}{2} I_0 , \\ I_0 &= I_0' . \end{aligned} \tag{8}$$

where:

$$\begin{aligned} Z_C &= \sqrt{Z_1 Z_2 \left(1 + \frac{Z_1}{4Z_2}\right)} , \\ \gamma_c &= \ln\left[1 + \frac{Z_1}{2Z_2} + \sqrt{\frac{Z_1}{Z_2} + \left(\frac{Z_1}{2Z_2}\right)^2}\,\right] . \end{aligned} \tag{9}$$

Expression 8 gives the relation between the potential at the beginning of the cable electric screen (HV/MV substation grounding system potential) and the potential at the end of the cable electric screen (n-th MV/LV substation grounding system potential):

$$U_0 = U_n \left(ch(n\gamma_c) + \frac{Z_1}{2\,Z_c} sh(n\gamma_c) \right) . \tag{10}$$

K-th MV/LV substation grounding system potential, looking from the end of the supplying cable, can be obtained from the Eq. (7). The total number of MV/LV substations between *k*-th and *n*-th substation is $(n-k)$. Therefore the voltage and the current on exiting ends of the *k*-th T -network are:

$$U'_k = U_n \, ch((n-k)\gamma_c) \; , \qquad I'_k = U_n \frac{sh((n-k)\gamma_c)}{Z_c} \; . \tag{11}$$

The voltage on the grounding system of the *k*-th MV/LV substation is now:

$$U_k = U'_k + \frac{Z_1}{2} I'_k \; , \tag{12}$$

as to:

$$U_k = U_n \left(ch((n-k)\gamma_c) + \frac{Z_1}{2Z_c} sh((n-k)\gamma_c) \right) \; . \tag{13}$$

Dividing U_k by U_0 (the potential at the beginning of the line), the transferred potential coefficient $K_i(k)$, for the observed MV/LV substation, is obtained:

$$K_i(k) = \frac{U_k}{U_0} \; , \quad k = 1, 2, \cdots, n \; . \tag{14}$$

Considering Eqs. (10) and (11), the transferred potential coefficient is gained:

$$K_i(k) = \left| \frac{ch((n-k)\gamma_c) + \frac{Z_1}{2Z_c} sh((n-k)\gamma_c)}{ch(n\gamma_c) + \frac{Z_1}{2Z_c} sh(n\gamma_c)} \right| \tag{15}$$

$k = 1, 2, \cdots, n.$

IV. Results of Calculation

In order to see out the effects of IPO 13 (NPO 13) type cables on potential transferring, we have analyzed the dependence of K_i coefficient on cable length and MV/LV substation grounding resistivity. Fig. 4 show the dependence of the transferred potential coefficient module on the cable length (distances between HV/MV and MV/LV substations), for different values of MV/LV substation grounding active impedance. Supposed depth of burring is 0.7m. Besides the value of impedance per unit length is $z = 0.7 + j2 \, \Omega/\mathrm{km}$, which corresponds to the case of transferring moderate current values which do not bring cable steel armature into magnetic saturation.

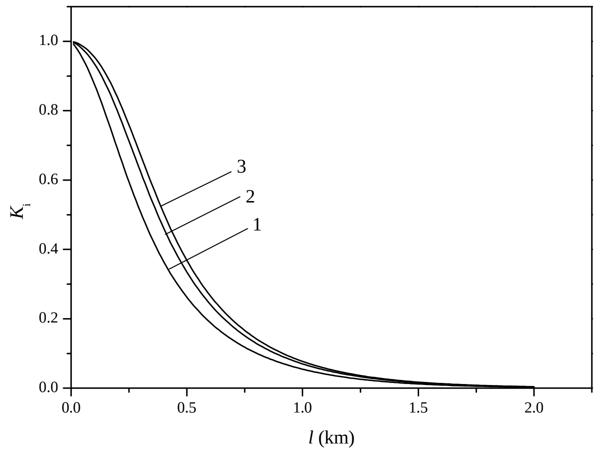

Fig. 4. Dependence of the transferred potential coefficient module on the cable length

Curve l in Fig. 4 is obtained for R_2 = 1 Ω, while curves 2 and 3 are obtained for R_2 = 3 Ω and R_2 = 10 Ω. Fig. 3 shows a intensive decrease of transferred potential value, starting from the 0.5 km cable length.

When cables with insulated metallic screen are considered, we have analyzed the potential transferring, occurred when the three – phase 10 kV line, composed of three single – core XHE 49 cables, with cross section of 120 mm^2, was used. These cables, with 29 mm in cross section diameter, have the electric screen of with a cross section of 16 mm^2. Cables are buried in a trefoil formation. The electric resistivity of the soil is $\rho = 50 \, \Omega\mathrm{m}$ value of impedance Z_1 per unit length is $z_1 = 0.38 + j0.65 \, \Omega/\mathrm{km}$. Different values for distances between neighboring MV/LV substations are used, as well as for MV/LV substation grounding system resistivity. The number of MV/LV substations varied from 1 to 8. Following figures display only one part of results obtained from calculation, made by authors.

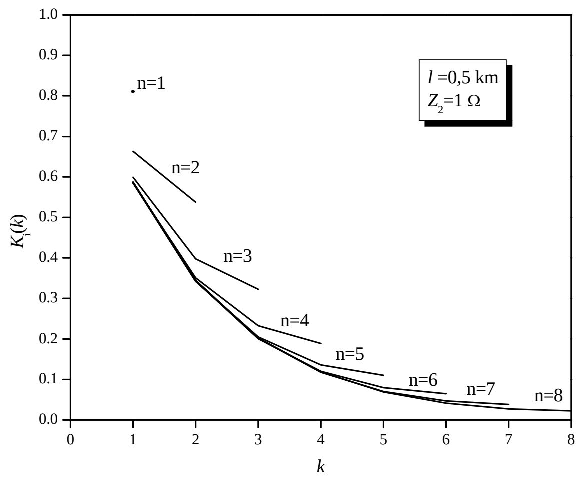

Fig. 5. Dependence of the transferred potential coefficient module when $\ell = 0.5\ \mathrm{km}$ *and* $Z_2 = 1\,\Omega$

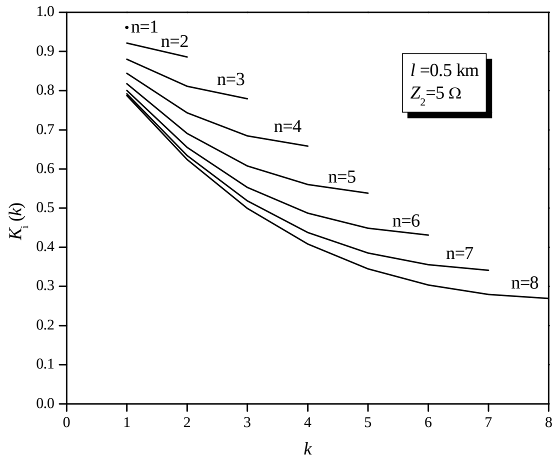

Fig.6. Dependence of the transferred potential coefficient module when $\ell = 0.5\ \mathrm{km}$ *and* $Z_2 = 5\,\Omega$

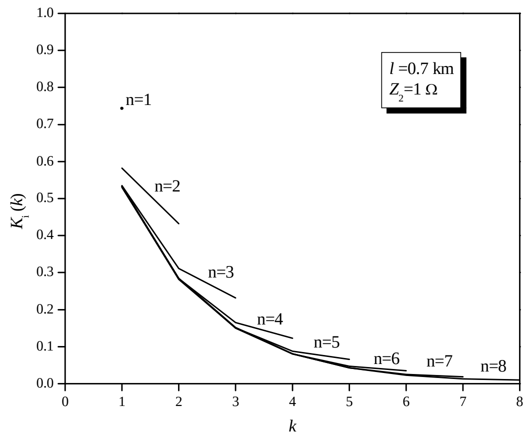

Fig.7. Dependence of the transferred potential coefficient module when $\ell = 0.7\ \mathrm{km}$ *and* $\underline{Z}_2 = 1\,\Omega$

Analysis shows that the ground system potential value of *k*-th MV/LV substation be TS SN/NN decreases with increase of number of MV/LV substations supplied by the line in question. The first MV/LV substation, which is the nearest to the feeding HV/MV substation, has the greatest value of transferred potential. The increase in the distance between two neighboring MV/LV substations leads to decrease in value of coefficient K_i, i.e. leads to decrease of transferred potential value. When the distance between neighboring substations is small, and when there are only a few substations powered up with the same cable, transferred potential value may be significant.

V. Conclusion

When IPO 13 (NPO 13) type cables are considered, the value of transferred potential decreases rapidly, with the increase of cable length. When cable lengths are greater then 0.5 km, it may be easily concluded that problems related to potential transferring practically do not exist.

In case of cable line composed of three single core XHE 49 type cables, the greatest value has the transferred potential of grounding system of the first substation, i.e. MV/LV substation nearest to the feeding HV/MV substation. Looking from the aspect of transferred potential, the most unfavorable is the case of a single MV/LV substation, the only one powered up by a cable line. This statement has more theoretical significance, because this case is rarely seen in real life. When the number of MV/LV substation powered up by cable line increases, the value of the potential transferred to the grounding system of the first MV/LV substation decreases significantly. This value depends on the number of substations powered up by cable line, as well as on $|Z_1/Z_2|$. If $|Z_1/Z_2|$ ratio value is greater, the transferred potential value becomes lower.

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