CURRENT REDUCTION FACTOR OF A COMPOUND CABLE LINE

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ABSTRACT

A compound cable line is analysed in this paper. A general mathematical model for determining the current reduction factor of compound cable line consisting of one three-core and three single-core cables is presented. The presented mathematical model can be applied in practice when cables are laid into the ground sections with different electrical resistivities.

I. INTRODUCTION

A compound cable line is analysed in this article. This cable line consists of a three-core cable and three single-core cables. Its sheaths are connected at the junction point, but the cables are not grounded there. Compound cable sheaths are grounded only at sending and receiving ends. They participate in the grounding system of the neighbouring power plants. During a single-pole short circuit, short-circuit current flows through the grounding system. Current repartition depends on electromagnetic conditions and on grounding potentials. In order to determine short-circuit current caused by electromagnetic conditions, current reduction factor, $\overline{k}$ is used. The current reduction factor of the analysed cable line is defined as follows:

$$\overline{k} = 1 - \frac{\overline{I}_p}{3\,\overline{I}_o} \qquad (1)$$

where

$\overline{I}_p$ - sheath current (passive part) of the compound cable line

$3\,\overline{I}_o$ - triple zero sequence of phase current (active part) of the compound cable line

II. THEORETICAL BASIS

Figure 1 shows the scheme of the compound cable line whose current reduction factor is calculated. Let's suppose that single-core cables are laid in trefoil formation, touching each other. Figure 1 also shows the grounding type of the compound cable line. The current through the ground is designated as: I_e. That current is defined as follows:

$$\overline{I}_e = 3\,\overline{I}_o - \overline{I}_p \qquad (2)$$

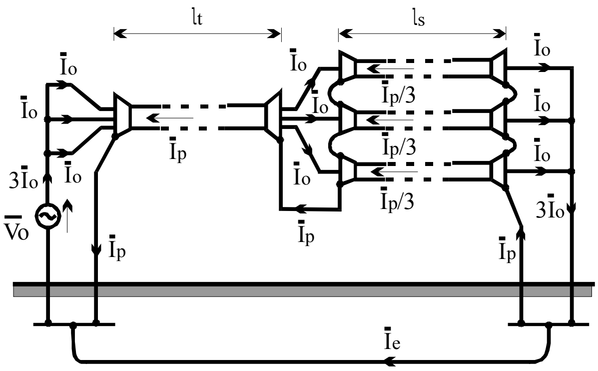

Figure 1 Compound cable line

In the passive part of the compound cable line the current can be defined as follows:

$$\overline{I}_p \cdot (\overline{Z}_t + \frac{\overline{Z}_s + 2\,\overline{Z}''_{sm}}{3}) = 3\,\overline{I}_o \cdot (\overline{Z}_{tm} + \frac{\overline{Z}'_{sm} + 2\,\overline{Z}''_{sm}}{3}) \qquad (3)$$

where

$\overline{Z}_t$ - self impedance of the three-core cable sheath with earth return,

$\overline{Z}_s$ - self impedance of the single-core cable sheath with earth return,
$\overline{Z}_{tm}$ - mutual impedance between sheath and phase conductors of three-core cable line with earth return,
$\overline{Z}'_{sm}$ - mutual impedance between sheath and phase conductors of single-core cable line with earth return,
$\overline{Z}''_{sm}$ - mutual impedance between phase conductors of single-core cable line with earth return

The following relations are used to calculate those impedances [2,3]:

$$\overline{Z}_t = (R_{t1} + \frac{\omega\mu_0}{8})\ell_t + j\frac{\omega\mu_0 \ell_t}{2\pi}\ln\frac{D_{et}}{r_t} \quad (4)$$

$$\overline{Z}_s = (R_{s1} + \frac{\omega\mu_0}{8})\ell_s + j\frac{\omega\mu_0 \ell_s}{2\pi}\ln\frac{D_{es}}{r_s} \quad (5)$$

$$\overline{Z}_{tm} = \frac{\omega\mu_0}{8}\ell_t + j\frac{\omega\mu_0 \ell_t}{2\pi}\ln\frac{D_{et}}{r_t} \quad (6)$$

$$\overline{Z}'_{sm} = \frac{\omega\mu_0}{8}\ell_s + j\frac{\omega\mu_0 \ell_s}{2\pi}\ln\frac{D_{es}}{r_s} \quad (7)$$

$$\overline{Z}''_{sm} = \frac{\omega\mu_0}{8}\ell_s + j\frac{\omega\mu_0 \ell_s}{2\pi}\ln\frac{D_{es}}{d_c} \quad (8)$$

where

R_{t1}, R_{s1} - resistance per unit length of three-core and single-core cables, respectively, Ω/m,
r_t, r_s - radius of three-core and single-core cable sheaths, respectively, m,
D_{et}, D_{es} - effective depth of penetration of the alternating current into the earth along the routes of three-core and single-core cables, respectively, m. Those routes can have different geophysical characteristics. Effective depths of penetration are calculated as follows:

$$D_{et} = 658\sqrt{\frac{\rho_t}{f}} \quad (9)$$

$$D_{es} = 658\sqrt{\frac{\rho_s}{f}} \quad (10)$$

where

ρ_t, ρ_s - earth electrical resistivity along the route of three-core and single-core cables , respectively, Ωm.,
f - system frequency, Hz, (f=50 Hz),
d_c - outer radius of single-core cable, m,
ω - angular frequency, $\omega = 2\pi f$,
μ_0 - vacuum permeability, $\mu_o = 4\pi 10^{-7}$, Vs/Am,
j - imaginary unit ($j = \sqrt{-1}$).

From relation (3) the following equation is obtained:

$$\frac{\overline{I}_p}{3\overline{I}_0} = \frac{3\overline{Z}_{tm} + \overline{Z}'_{sm} + 2\overline{Z}''_{sm}}{3\overline{Z}_t + \overline{Z}_s + 2\overline{Z}''_{sm}} \quad (11)$$

Substituting from equation (11) the equation (1) becomes:

$$\overline{k} = \frac{3(\overline{Z}_t - \overline{Z}_{tm}) + \overline{Z}_s - \overline{Z}'_{sm}}{3\overline{Z}_t + \overline{Z}_s + 2\overline{Z}''_{sm}} \quad (12)$$

According to equations (4-8) and using substitution

$$R_p = R_{t1}\ell_t + \frac{R_{s1}}{3}\ell_s \quad (13)$$

the equation (12) becomes:

$$\overline{k} = \frac{R_p}{AN}$$

$$AN = R_p + \frac{\omega\mu_0}{8}(\ell_t + \ell_s) + j\frac{\omega\mu_0}{2\pi}(\ell_t \ln\frac{D_{et}}{r_t} + \ell_s \ln\frac{D_{es}}{\sqrt[3]{r_s d_c^2}}) \quad (14)$$

Equation (14) is a general relation for determining the current reduction factor of a compound cable line.
From (14, 13) and l_s=0 the current reduction factor of three-core cable line is:

$$\overline{k}_t = \frac{R_{t1}}{R_{t1} + \frac{\omega\mu_0}{8} + j\frac{\omega\mu_0}{2\pi}\ln\frac{D_{et}}{r_t}} \quad (15)$$

By analogy, from equations (14, 13) and l_t=0 the current reduction factor of single-core cable line is:

$$\overline{k}_s = \frac{\frac{R_{s1}}{3}}{\frac{R_{s1}}{3} + \frac{\omega\mu_0}{8} + j\frac{\omega\mu_0}{2\pi}\ln\frac{D_{es}}{\sqrt[3]{r_s d_c^2}}} \quad (16)$$

From (15, 16) it is obvious that the current reduction factor of only a three-core cable or of only three single-core cables laid in trefoil formation, does not depend on the cable length.

III. NUMERICAL EXAMPLE

The model presented is applied in a compound cable line. Cross-sectional area of the copper stranding conductor is 185 mm^2. Rated voltage is 20 kV.
The presented compound cable line consists of:

- three-core cable line, l_t=3 km, and
- three single-core cable line laid in trefoil formation , l_s=1 km.

The sheath of the three-core cable was made of lead pipe, 2.4 mm thick with outer radius of 58 mm. The resistance is R_{t1}=0.58 Ω/km. The cable is laid in the conductive ground with $\rho_t = 50\ \Omega m$.

The cross-sectional area of the sheath of single-core cable is 25 mm^2. It consists of copper helical wires, which were wound around the upper semi-conductive layer. The radius of the semi-conductive layer is 38 mm. The sheath resistance is R_{s1}=0.78 Ω/km. The outer radius of single-core cable is d_c=49 mm [4]. Cables are laid into the non-conductive ground with $\rho_t = 2000\ \Omega m$.

In case the cable sheaths are not grounded at the junction point (sheaths are grounded only at sending and receiving cable line ends, Figure 1), the current reduction factor is:

$$\overline{k} = 0.583\angle -50.1^o \quad (17)$$

In case the cable sheaths are grounded at the junction point and at sending and receiving cable line ends, the current reduction factor of the three-core cable and three single-core cables laid in trefoil formation are as follows:

$$\overline{k}_t = 0.650\angle -45.2^o \quad (18)$$

$$\overline{k}_s = 0.327\angle -67.1^o \quad (19)$$

IV. CONCLUSION

A general mathematical model for determining the current reduction factor of compound cable line consisting of one three-core cable and three single-core cables is presented in this paper. Three single-core cables are laid in trefoil formation. The presented mathematical model can be applied in practice when cables are laid into the ground sections with different electrical resistivities

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