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Induced Voltages in Metallic Pipelines near Power Transmission Lines

Leonid GRCEV, Voislav JANKOV and Velimir FILIPOSKI
Faculty of Electrical Engineering, University "Sv. Kiril i Metodij", Karpos II bb, 1000 Skopje, Macedonia ***leonid.grcev@ieee.org***

Abstract. With the continuous development of the electric power system and the pipeline networks used to convey oil or natural gas, cases of close proximity of high voltage structures and metallic pipelines become more and more frequent. Accordingly there is a growing concern about possible hazards resulting from voltages induced in the metallic pipelines by magnetic coupling with nearby power transmission lines. This paper presents a methodology for computation of the induced voltages in buried isolated metallic pipelines. A practical example of computation is also presented.

1. Introduction

Cases of close proximity of high voltage structures and metallic pipelines become more and more frequent. Therefore there is a growing concern about possible hazards resulting from the harmful influence of electrical systems on the safety of people in contact with the pipeline, or damage to the pipeline and the cathodic protection equipment [1].

The problem of voltages in buried metallic pipelines due to inductive coupling with transmission lines is rapidly rising with the improvement of the isolation pipeline material technology. The high quality isolation has a big electrical resistance, but it results with increasing induced potential of the pipeline [5]. The ways of decreasing the potential of the pipeline often causes conflict with the cathodic protection. Therefore a parametric analysis is required before an optimal technical solution for reduction of the excessive potentials is chosen.

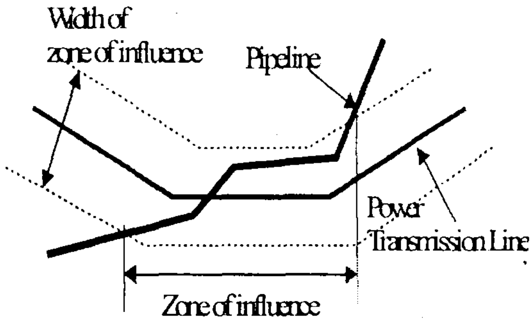
2. Mathematical Model

The way to determine the voltage influence is consisted of the following steps:

- computing the current distribution along the transmission line in case of power system fault,
- computing the induced voltage,
- determining the voltage to ground along pipeline for the worst case of the fault in the power system.

The zone of influence [1] (Fig. 1) is divided into linear sections, Fig. 2. The induced voltage along the pipeline is computed as a superposition of induced voltages in all sections. The influence of the rest of the pipeline is modeled with equivalent

Thevenin's generators (Fig. 4). Every section of the pipeline is modeled with a suitable equivalent circuit as a lossy transmission line (Fig. 3).
The potential distribution on the pipeline for one section is calculated as in [2]:



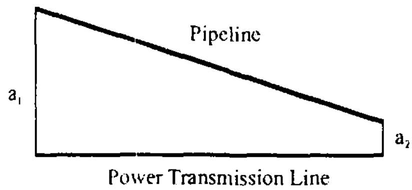
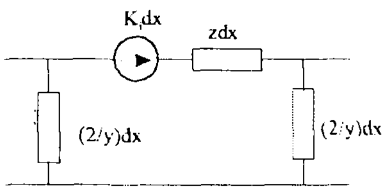


Fig. 1. Zone of influence power transmission zone of line on the pipeline.

Fig. 2. Linear section in the influence



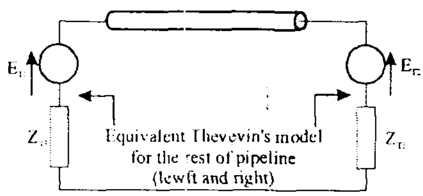


Fig. 3. Equivalent circuit of the part of the section.

Fig. 4. Equivalent circuit of whole pipeline section with length dx.

$$U(x)=\frac{E_{T1}}{D}\left[Z_0Z_{T2}\cosh\gamma(\ell-x)+Z_0^2\sinh\gamma(\ell-x)\right]+\frac{E_{T2}}{D}\left[Z_0Z_{T1}\cosh\gamma x+Z_0^2\sinh\gamma x\right]$$
$$+\frac{Z_0\sinh\gamma(\ell-x)+Z_{T2}\cosh\gamma(l-x)}{D}\times K\cdot\int_0^x\left[Z_0\sinh\gamma x'+Z_{T1}\cosh\gamma x'\right]dx'$$
$$+\frac{Z_0\sinh\gamma x+Z_{T2}\cosh\gamma x}{D}\times K\cdot\int_x^\ell\left[Z_0\sinh\gamma(\ell-x')+Z_{T2}\cosh\gamma(\ell-x')\right]dx' \quad (1)$$

$$D=(Z_0Z_{T1}+Z_0Z_{T2})\cosh\gamma\ell+(Z_0^2+Z_{T1}Z_{T2})\sinh\gamma\ell$$

where:

E_{T1}, Z_{T1}, E_{T2}, Z_{T2} – EMFs (V) and impedances (Ω), respectively, of the Thévenin's model for the part of the pipeline, left and right of the observed section,

x – coordinate of a point at the pipeline (m) ,

ℓ – total length of the section (m),

K – induced voltage per meter (V/m),

γ – propagation constant of the pipeline (1/m) and

Z_0 – characteristic impedance of the pipeline (Ω).

The propagation constant is evaluated from the modal equation [4]:

$$\gamma^2 y^{-1} = z \tag{2}$$

where

$$y = \left[y_i^{-1} + \frac{1}{\pi(1/\rho_z + j\omega\varepsilon_z)} \ln\frac{1.12}{\gamma a'} \right]^{-1},$$

$$z = z_i + \frac{j\omega\mu_0}{2\pi} \ln\frac{1.85}{a'(\gamma^2 + \Gamma^2)^{1/2}}$$

$$\Gamma^2 = j\omega\mu_0(1/\rho_z + j\omega\varepsilon_z), \qquad a' = \sqrt{a^2 + 4h^2}$$

$$z_i = \frac{\sqrt{\rho_c\mu_c\omega}}{\pi D\sqrt{2}}(1+j), \qquad y_i = \frac{\pi D}{\rho_{iz}\delta_{iz}} + j\omega\frac{\varepsilon_{iz}\pi D}{\delta_{iz}}$$

Here:

z – serial impedance per meter of the pipeline (Ω/m),
y – parallel admittance per meter of the pipeline (S/m),
$\omega = 2\pi f$ (rad/s), (f – frequency (Hz)),
μ_0 – permeability of the vacuum (H/m),
μ_c – permeability of the pipeline material (H/m),
ρ_z – resistance of soil (Ωm),
ρ_c – resistance of pipeline (Ωm),
ρ_{iz} – pipeline coating resistance (Ωm),
ε_0 – permittivity of free space (F/m),
ε_z – soil permittivity (F/m),
ε_{iz} – pipeline coating permittivity (F/m),
D – pipeline diameter (m),
a = D/2,
h – depth of the pipeline (m),
δ_{iz} – width of coating (m).

The characteristic impedance is computed from:

$$Z_0 = \sqrt{z / y} \tag{3}$$

The factor with the strongest influence is the resistance of the coating

$$R_c = \rho_{iz} \cdot \delta_{iz} \, (\Omega \text{m}^2). \tag{4}$$

3. Application

As an illustration of the application of the developed method, results from the proximity effects study of 400 kV power line Skopje 4 – Kosovo B and natural gas buried metallic pipeline (Fig. 5) are presented.

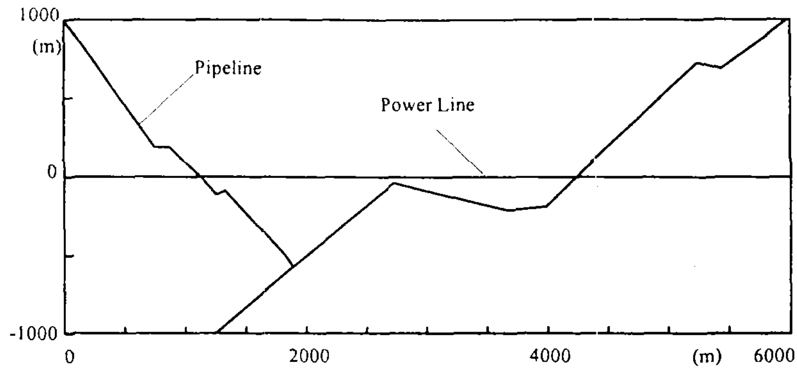


Fig. 5. Situation of 400 kV transmission power line Skopje 4 - Kosovo B and the pipeline

Table 1 and Table 2 show parameters of the transmission power line and pipe line. An average value of 100 Ωm for the soil resistance is adopted based on measurements.

Table 1. Parameters of the 400 kV transmission power line Skopje 4 - Kosovo B

Length	103.9 km
Number of towers	96
Number of conductors per phase	2
Phase conductor	Al-Fe 3x2x 490/65 mm^2
Average height	20 m
Number of ground wires	2
Ground wire conductor	Al-Mg 2 x 126 mm^2

Table 2. Parameters of the pipeline

Diameter	0.265 m
Thickness of pipeline	7 mm
Depth	1 m
Pipeline material	Still
Relative permeability	300
Coating	polyethylene
Resistance of the coating	50000 Ω.mm^2
Thickness of coating layer	2.6 mm
Relative permittivity of coating	5

The distribution of the short circuit current for a fault along the power transmission line 400 kV Skopje 4 – Kosovo B is shown in Fig. 6. The location of the zone of influence of the power line and the location of the worst-case fault resulting in maximal intensity of the induced voltages are also shown.
Table 3 shows calculated values of the electrical characteristics of propagation of the pipeline.

Table 3. Propagation parameters of the pipeline

Characteristic impedance (Ω)	5.03 + j 2.38
Propagation constant (km^{-1})	0.07293 + j 0.06186

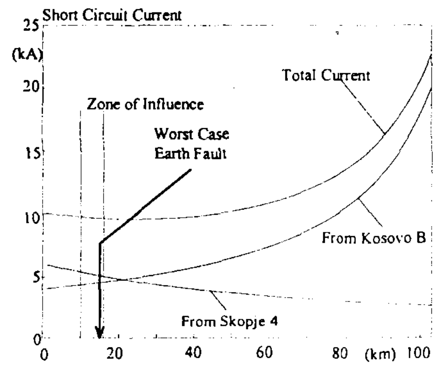


Fig. 6. The distribution of the short circuit current along 400 kV line

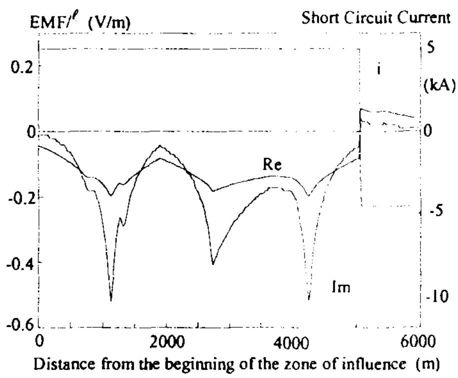


Fig 7. Short circuit current and induced EMF along the pipe line for the worst case fault

Induced EMF per length along the pipeline is shown in Fig. 7. In Fig. 8 and Fig. 9 the calculated induced potentials of the pipeline is shown. Fig. 8 shows the potential distribution along the pipeline for the worst-case fault. Fig. 9 shows the maximal potential in all points of pipeline for any location of the fault.
The results point to a conclusion that potentials of the pipeline are not higher than the allowed limit of 1000 V [1], thus no protection is necessary. However, before the final conclusion for the necessary protection is brought, the influence of the parameters, which are not fully known and are changing in time, should be determined.

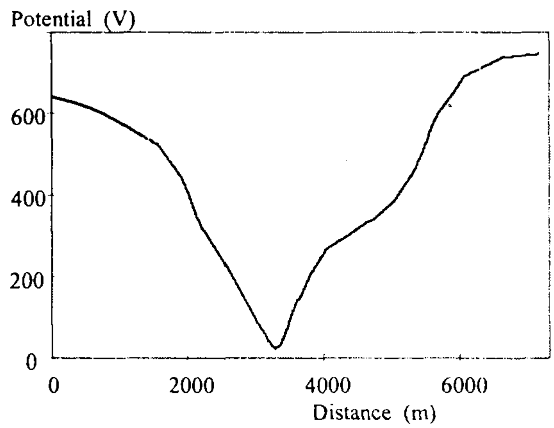


Fig. 8. Potential distribution along the pipeline for the worst case earth fault

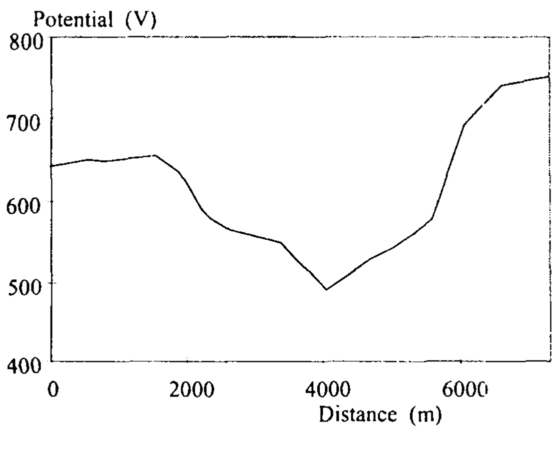


Fig. 9. The maximal potential at the pipe line for all locations of the earth fault along the power line.

As it is well known, the value of the induced voltage in the buried metal pipelines is dependent on the state and quality of the isolation. The electrical quantity, which is usually used to express the state of the isolation, is resistance of the isolation (4). In Figure 10 the maximal voltage is shown as a function of the resistance of the isolation of the pipe. It is important to know this dependence because the resistance of the isolation is a value, which is changing in time (it's value is maximal during installation and it is dropping in time).
Next factor, which has dominant influence on the induced voltages, is the soil resistance. The influence of this factor should also be examined because the electrical characteristics of the soil are changing in time, especially since it depends on the amount of moisture, which is changing with the weather. On Figure 11 the maximal potential dependence on the soil resistance is presented.

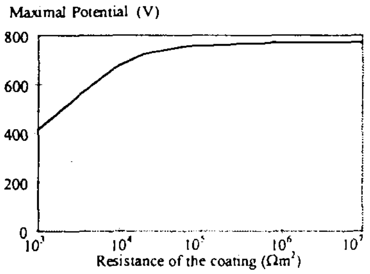


Fig. 10. Maximal pipeline potential vs. coating resistance

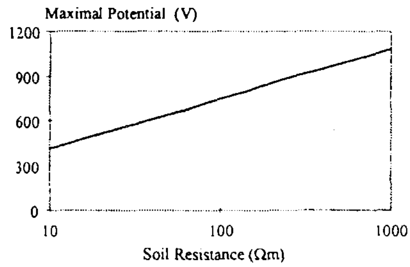


Fig. 11. Maximal pipeline potential vs. soil resistance

Results in Figure 10 point to conclusion that the maximal potential will never be larger than the allowed limit no matter of the pipeline isolation condition. From Figure 11 it can be also concluded that the change of the soil resistance in regard to the measured value 100 Ωm, due to the weather, will not exceed the allowed level for the maximal voltage. According to this it can be concluded that no special protection for the analyzed pipeline is necessary.

4. Conclusion

The methodology for computation of the induced voltages in buried isolated metallic pipelines due to inductive coupling with nearby power transmission line is presented. This methodology enables precise modeling of complex practical cases taking into account parameters with dominant influence. The computer model enables parameter analysis for optimization of protection measures, based upon safety and minimal expenses.

References

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INVERSE PROBLEMS & OPTIMIZATIONS