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The Effect of Short-Circuit Currents in Overhead Transmission Line on near Buried Parallel Equipment

Abstract. *This work is focused on the effect of short-circuit currents on linear equipment (cable, pipeline) buried near an overhead transmission line. Its aim was to analyze the volumetric losses in the steel part of the buried linear equipment as a function of the distance from an overhead transmission line. The numerical analysis was performed by simulation software based on the finite element method.*

Streszczenie. *Praca dotyczy efektów generowanych w obiektach liniowych (kablach, rurach) zakopanych w pobliżu linii przesyłowych, w których występują prądy zwarciowe. Celem była ilościowa analiza nagrzewania stalowych części obiektów w funkcji odległości od linii przesyłowej. Symulacje wykonano przy pomocy metody elementów skończonych.* ***(Oddziaływani prądów zwarciowe w liniach napowietrznych na podziemne liniowe obiekty w pobliżu linii)***

Keywords: short-circuit currents, overhead transmission line, volumetric losses, electromagnetic field, numerical analysis
Słowa kluczowe: prądy zwarciowe, linie napowietrzne, pole elektromagnetyczne, analiza numeryczna, straty cieplne

Introduction

At present, there is a tendency towards building power corridors common for more transmission systems. Lots of aspects, such as difficulties in getting sites, high cost of land, or environment protection force industry to place transmission lines in parallel. This work investigates the effect of short-circuit currents on parallel equipment (cable, pipeline) buried near overhead transmission lines. From the magnetic viewpoint this equipment is considered linear.

Formulation of the problem

Fig. 1 depicts a typical arrangement of buried linear equipment in parallel with two parallel 400 kV lines suspended from a Donau type tower. The Donau tower has two earth wires. The study shows a single-phase short circuit. A short-circuit current of 10 kA is supposed in the phase conductor closest to the linear equipment, other conductors of the line with fault are without current. The backward short-circuit current is distributed between the earth wire and earth. The percentage distribution of the short-circuit current between the earth wires and earth depends on impedances of earth wires and earth.

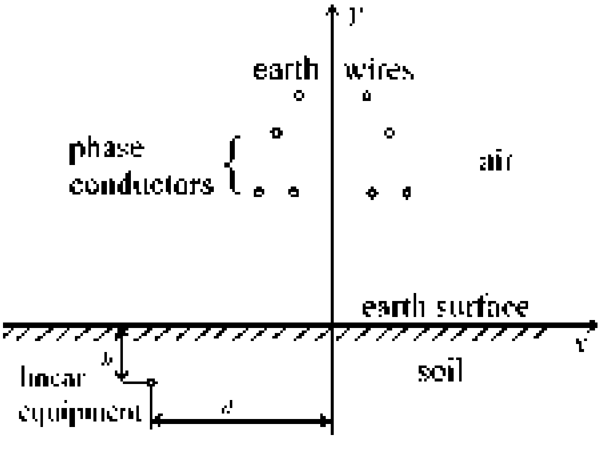

Fig.1. Buried linear equipment parallel to overhead line

Mathematical model

The problem is solved two-dimensionally in the Cartesian coordinate system *x*, *y*, as the model does not change in the direction of the *z*-axis. The concerned values of magnetic field are also influenced by the conductor sags. For the same reason, computations are performed for the given height of conductors above the ground.

The investigated domain is considered linear (i.e., even the steel part of the linear equipment is supposed to exhibit a constant permeability, which is possible due to its rather low saturation). In a steady state, the electromagnetic field generated by the overhead line is harmonic and may be described by the Helmholtz equation for the *z*-th component of phasor of magnetic vector potential $\boldsymbol{A}$ in the form

$$\Delta \underline{A}_{\mathrm{z}} - \mathrm{j}\omega\gamma\mu \underline{A}_{\mathrm{z}} = \mu \underline{J}_{\mathrm{ext,z}} \tag{1}$$

where $\underline{J}_{\mathrm{ext,z}}$ is the *z*-th component of the phasor of external current density in the conductors of the overhead line, μ denotes the magnetic permeability, γ stands for the electric conductivity, and ω is the angular frequency. The time-average volumetric value Q_{AV} of heat generated by resistive heating of the steel part of the linear equipment is then given by the expression

$$Q_{\mathrm{av}} = \frac{1}{2}\mathrm{Re}\left\{\frac{\underline{J}_z \cdot \underline{J}_z}{\gamma}\right\} \tag{2}$$

where $\underline{J}_z$ is the phasor of the current density induced in the linear equipment. The computations are performed by COMSOL Multiphysics [3] and Agros2D [4] supplemented with a number of special procedures coded for this purpose.

Obtained results

The first subject of this study is a steel pipeline. The conductivity of steel roughly ranges from 10^4 S/m to 10^6 S/m; in this case, the value is $\gamma = 60000$ S/m. Its relative permeability is $\mu_{\mathrm{r}} = 8000$. The gas in the pipeline is characterized by parameters $\gamma = 0$ S/m and $\mu_{\mathrm{r}} = 1$.

The inner diameter of the pipeline is 0.5 m and its thickness is 0.02 m, see Fig. 2 ($r_1 = 0.25$ m, $r_2 = 0.27$ m). The steel pipeline is covered with insulating coating. This coating is mainly intended as a corrosion protection, preventing the pipeline from direct contact with soil. In practice, the insulation is made of tar, asphalt, pitch, cement or advanced polymer coatings (such as polyethylene or polypropylene). The thickness of asphalt coatings ranges from several mm to cm, but the thicknesses of the polymer coatings are measured in μm. The insulation coating is characterized by parameters $\gamma = 0$ S/m and $\mu_{\mathrm{r}} = 1$.

The distance between the outmost conductor and the axis of the tower is 14.5 m. The distance *d* (Fig.1) between the center of the pipeline and the axis of the tower ranges between 0 to 30 m. The pipeline is buried in the depth of 1 m. The conductivity of soil is $\gamma = 0.01$ S/m and its relative permeability is $\mu_r = 1$.

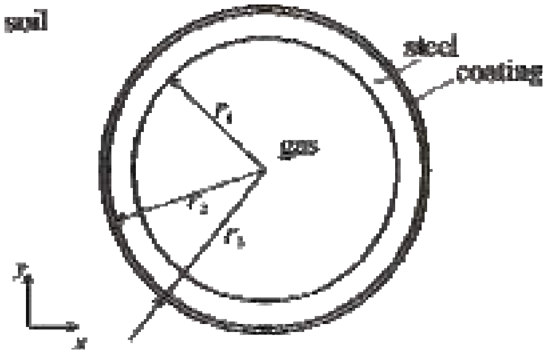

Fig.2. Buried pipeline

Fig. 3 depicts the volumetric losses Q_{AV} in the pipeline as a function of distance *d* during the single-phase short circuit. The distribution of the backward short-circuit current in the middle of the route is usually into halves (50 % earth wires, 50 % earth).

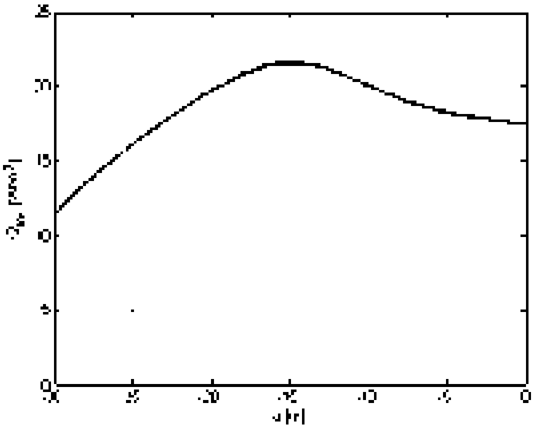

Fig.3. Dependence of volumetric losses Q_{AV} in the pipeline on the distance *d* from the axis of the tower (backward short circuit current: 50 % earth wires, 50 % earth)

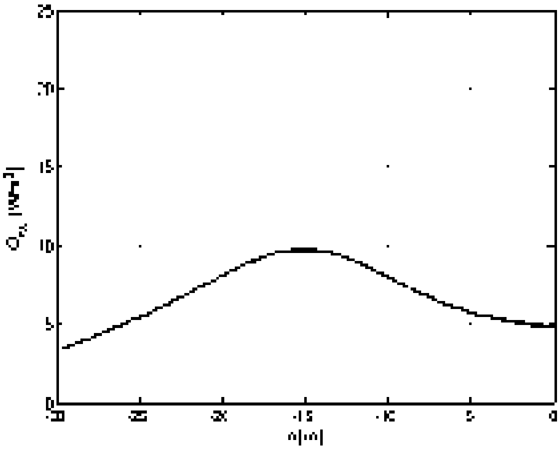

Fig.4. Dependence of volumetric losses Q_{AV} in the pipeline on the distance *d* from the axis of the tower (backward short circuit current: 75 % earth wires, 25 % earth)

Fig. 4 depicts the volumetric losses Q_{AV} in the pipeline as a function of distance *d* during distribution of backward short circuit current, which is as follows: 75 % earth wires and 25 % earth. The short-circuit current in the earth wire is significantly higher in the first miles from the substation.

The eddy currents are induced in the pipeline due to magnetic fields produced by the overhead lines. The magnetic field is unevenly distributed due to a skin effect. Fig. 5 depicts magnetic flux density in one part of the pipeline in the worst case, i.e. during distribution of the backward short-circuit current into halves (50% earth wires, 50% earth); distance *d* from the axis of the tower is 15 m.

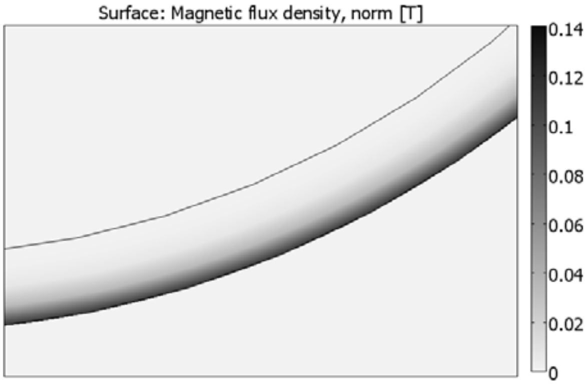

Fig.5. The magnetic flux density in the lower right part of the pipeline (backward short circuit current: 50 % earth wires, 50 % earth, *d* = 15 m)

In order to make a comparison, there is also considered an underground three-phase power cable (see Fig. 6) which is under the outer insulation equipped with steel concentric wire functioning as a shielding. There are given geometric dimensions of the cable (r_1 = 0.055 m, r_2 = 0.06 m, r_3 = 0.07 m), material properties of individual areas of the cable, effective value of the nominal current 100 A and nominal voltage 10 kV with frequency f = 50 Hz. The anticipated physical properties of copper are $\gamma = 5.8 \cdot 10^7$ S/m, $\mu_r = 1$, the specific electrical conductivity of steel is $\gamma = 60000$ S/m and the relative permeability is $\mu_r = 8000$. In insulation materials, the considered values are $\gamma = 0$ S/m and $\mu_r = 1$.

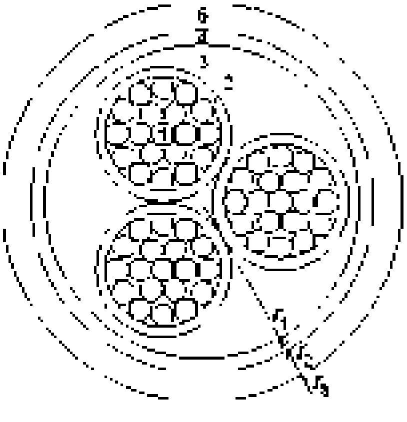

Fig.6. Three-phase power cable: 1 – copper conductors, 2 – PVC insulation, 3 – rubber, 4 – steel covering (flat steel bands), 5 outer PVC housing

The definition area of the cable consists of five subareas (see Fig. 6). The steel covering, which is the subject of this study, is marked by number 4.

The conditions in the steel covering of the cable are significantly influenced by the magnetic field of the cable. That is why the situation is first solved for the cable covering without the influence of the overhead power lines. The volumetric heat losses are $9.766 \cdot 10^{-3}$ W/m^3.

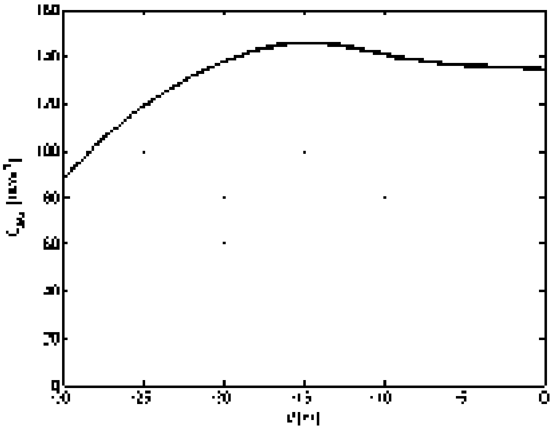

Fig. 7. Dependence of volumetric losses Q_{AV} in the cable covering on the distance *d* from the axis of the tower (backward short circuit current: 50 % earth wires, 50 % earth)

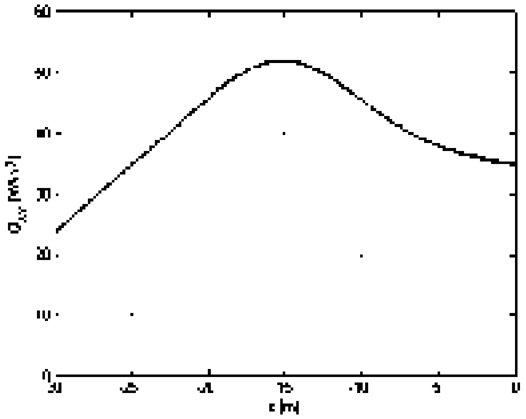

Fig. 8. Dependence of volumetric losses Q_{AV} in the cable covering on the distance *d* from the axis of the tower (backward short circuit current: 75 % earth wires, 25 % earth)

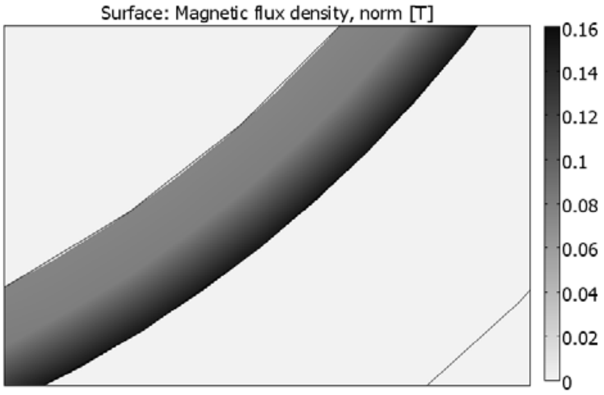

Fig.9. The magnetic flux density in the steel covering of the cable (backward short circuit current: 50 % earth wires, 50 % earth, *d* = 15 m)

The three-phase power cable is buried in the depth of 1 m. The conductivity of soil is $\gamma = 0.01$ S/m and its relative permeability is $\mu_r = 1$. The distance *d* (Fig.1) between the center of the cable and the axis of the tower lies between 0 to 30 m.

Fig. 7 and Fig. 8 depict the volumetric losses Q_{AV} in the cable covering as a function of distance *d* during distribution of backward short circuit current.

Fig. 9 depicts magnetic flux density in the steel covering of the cable in the worst case, i.e. during distribution of the backward short-circuit current into halves (50% earth wires, 50% earth); distance *d* from the axis of the tower is 15 m.

Conclusion

The value of the volumetric losses in buried linear equipment is influenced by the distance of the linear equipment from the overhead transmission line, and by the conductivity of soil, which is variable both vertically and horizontally, depending on the soil composition. The concerned value is also non-negligibly influenced by conductor sags. The volumetric losses in buried linear equipment also depend on the distribution of the currents between earth wires and earth.

Buried linear equipment and overhead lines can induce a field which may influence technical installations placed in the same corridor. The risks arise from the influence of high, very high and especially high voltage on metal pipes, especially the risk of damage to pipelines, the risk of damage to equipment associated with the pipeline, safety of people working with this equipment and protection of living organisms.

Acknowledgment

This work has been supported from the grant project of the University of West Bohemia "Staff and Mobility Development Fund".

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[4] http://agros2d.org
[5] http://hpfem.org/hermes

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