INDUCED LOSSES IN LINEAR EQUIPMENT BURIED NEAR AN OVERHEAD POWER LINE

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Abstract

This work focused on the influence of an overhead power line on buried linear equipment (cable, pipeline). Its aim was to analyze the volumetric losses in buried linear equipment as a function of the distance from an overhead power line. The computations were performed numerically by simulation software based on the finite element method.

Keywords

Induced losses, electromagnetic field, numerical analysis, linear equipment, overhead line

1. INTRODUCTION

At present, there is a tendency to build power corridors common for more transmission systems. Lots of aspects, such as difficulties in getting sites, high cost of land, environment protection, etc. force the industry to place transmission lines in parallel, i.e., to install electric lines and buried linear equipment in the same transmission corridors. Overhead power lines usually affect operation of buried equipment. These problems are geometrically incommensurable (diameter of the linear equipment versus the distance between conductors of overhead line and earth surface). This work investigates the influence of such overhead lines on linear equipment. The problem was solved using simulation software COMSOL Multiphysics and Agros2D.

2. THE MODEL AND THE AREA OF COMPUTATION

In fact, buried linear equipment is only seldom arranged in parallel with the overhead line. Often it only crosses the corridor in some angle or even perpendicularly. In such cases, however, the influence of the overhead line on the linear equipment is lower and will not be dealt with here.

The aim of the paper is to determine the induced currents in the buried linear equipment and its resistive heating as a function of several parameters (distance of the linear equipment from the line, arrangement of the overhead line, electric conductivity of soil, etc.).

Fig. 1 depicts a typical arrangement of buried linear equipment in parallel with a power overhead line. The following text will deal with two parallel 400 kV lines suspended from a Donau type tower. With the lines, the following nominal values are considered and used in the computations: $U_1 = U_2 = 400$ kV, $I_1 = I_2 = 790$ A. The boundary value problem is thus set for a magnetic vector potential. The area of air and soil was selected as rectangle 70 x 60 m. In the area of air the relative permeability μ_r equals 1 and the specific conductivity γ is zero.

In practice, there is a change in soil type both vertically and horizontally; therefore, there is also a change in specific electrical conductivity γ. Moreover, the changes in specific conductivity of soil depend not only on soil type, but also on pH of soil, yearly rainfall and the level of ground water. The anticipated values range from 0.0005 S/m (for rock) to 0.5 S/m (for silt a light clay). The assumed relative permeability of soil μ_r is 1.

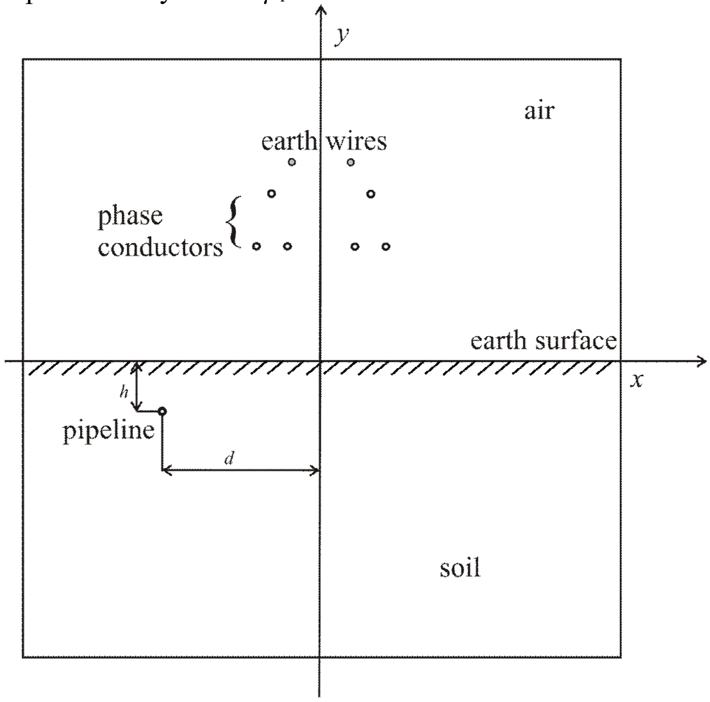


Fig. 1. Example of Buried Linear Equipment Parallel to an Overhead Line

A transposition in double-circuit three-phase overhead lines has a considerable effect on the monitored values in the buried linear equipment. There are thirty-six possible arrangements of phases in the layout, but only six of them being the basic ones. The situation is investigated for six basic transpositions of the overhead line according to Table 1.

Table 1: Arrangement of the Phases

Phase arrangement	Variant
× × ● ○ ● ○	1
○ × ● × ● ○	2
× × ○ ● ● ○	3
● × ○ × ● ○	4
○ × × ● ● ○	5
● × × ○ ● ○	6

3. MATHEMATICAL MODEL AND ITS NUMERICAL SOLUTION

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 the steady state, the electromagnetic field generated by the overhead line is then harmonic and may be described by the Helmholtz equation for the z-th component of phasor of magnetic vector potential $\boldsymbol{A}$

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

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 of heat generated by resistive heating of the steel part of the linear equipment is then given by the expression

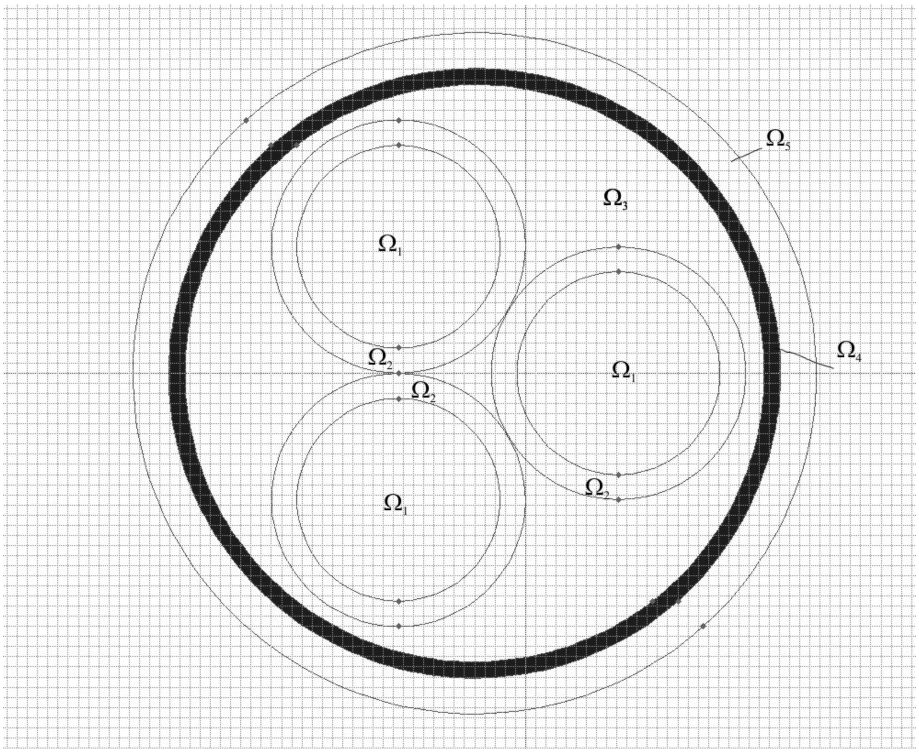
$$Q_{\mathrm{av}} = \frac{1}{2}\mathrm{Re}\left\{\frac{\underline{J}_z \cdot \underline{J}_z}{\gamma}\right\} \tag{2}$$

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

4. ILLUSTRATIVE EXAMPLE – BURIED CABLE

Fig. 2 depicts an underground three-phase power cable. In order to make a comparison, there is also considered another cable which is under the outer insulation equipped with copper concentric wire functioning as a shielding. There are given geometric dimensions of the cable, 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 γ = 5.8·10^7 S/m, μ_r = 1; the specific electrical conductivity of steel γ = 60000 S/m and the relative permeability μ_r = 8000. In insulation materials, the considered values are γ = 0 S/m, μ_r = 1.

The definition area Ω consists of five subareas (see Fig. 2). The steel covering, which is the subject of this study, is marked bold.



Ω_1 – copper conductors,
Ω_2 – PVC insulation,
Ω_3 – rubber,
Ω_4 – steel covering (flat steel bands),
Ω_5 – outer PVC housing

Fig. 2. Cable – Definition Area

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 in the cable covering without the influence of the overhead power lines. The volumetric heat losses are $9.766 \cdot 10^{-3}$ W/m^3.

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

The dependences of volumetric losses Q_{AV} in the cable covering on distance d for the arrangements in Tab. 1 are shown in Fig. 3.

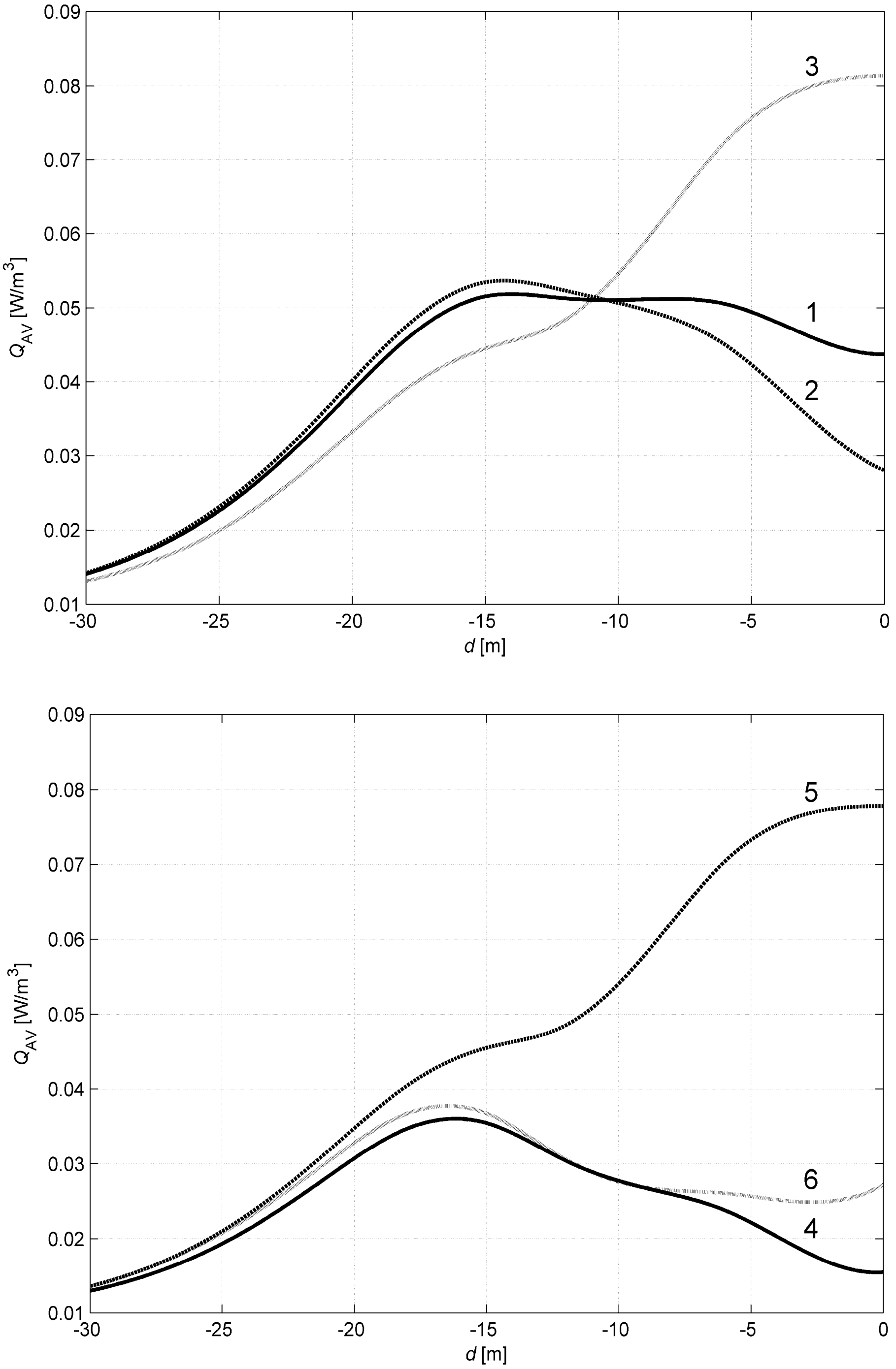


Fig. 3. Dependences of Volumetric Losses in the Cable Covering on the Distance for the Cases in Tab. 1.

The highest volumetric losses in the cable covering during the normal operation occur in the variants when the phases are placed symmetrically with respect to the axis of the tower (variant 3 in Tab. 1). This configuration is also the least favorable from the viewpoint of magnetic flux density penetrating to the cable covering.

The next study shows a single-phase short circuit. A short-circuit current of 10 kA is supposed in the phase conductor closest to the cable, other conductors of the line with fault are without current.

The Donau tower has two earth wires. The backward short-circuit current is distributed between the earth wire and earth. The percentage distribution of the short-circuit current between earth wires and the earth depends on impedances of earth wires and earth.

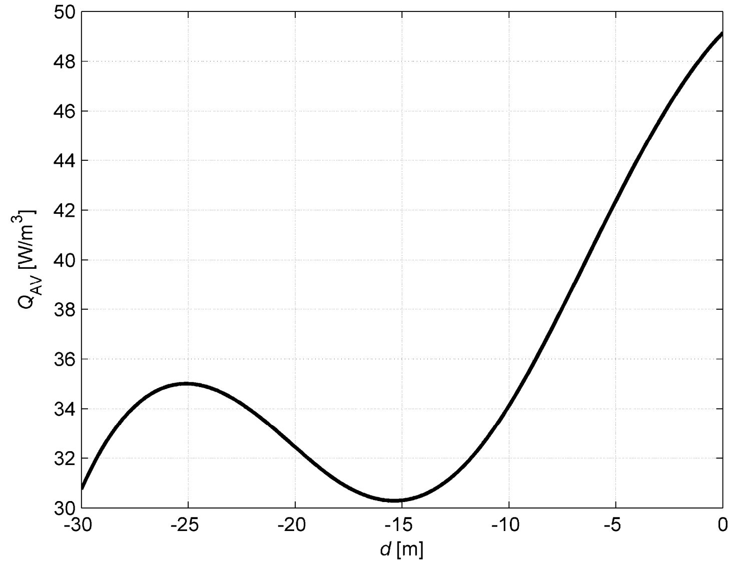


Fig. 4. Volumetric Losses in the Cable Covering as a Function of the Distance (in the middle of the route)

Fig. 4 depicts the volumetric losses Q_{AV} in the cable covering 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 in half (50 % earth wire, 50 % earth). Now the volumetric losses Q_{AV} are much higher than in the first investigated case.

5. ILLUSTRATIVE EXAMPLE – BURIED PIPELINE

The 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, $\gamma = 60000$ S/m is considered. Its relative permeability $\mu_r = 8000$. The gas in the pipeline is characterized by parameters $\gamma = 0$ S/m and $\mu_r = 1$.

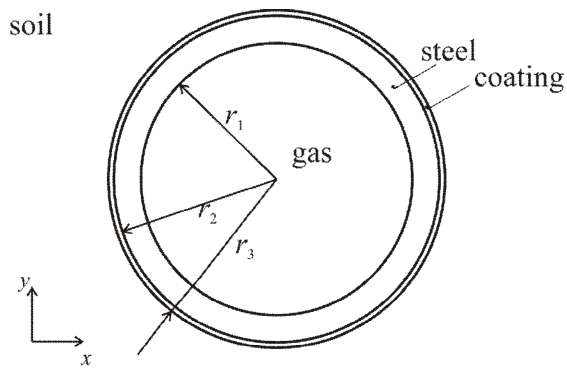


Fig. 5. Buried Pipeline

The inner diameter of the pipeline is 0.5 m and its thickness is 0.02 m, see Fig. 5 (r_1 = 0.25m, r_2 = 0.27 m). The insulating coating is used for covering the steel pipeline. 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 also advanced polymer coatings (polyethylene, polypropylene, etc.). The thickness of asphalt coatings range from several mm to cm, but the thicknesses of the polymer coatings are measured in μm. The insulation coating is characterized by parameters γ = 0 S/m and μ_r = 1. Some cases have also been solved for uncoated, non-defective coating, which does not affect the field distribution.

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 γ = 0.01 S/m, its relative permeability μ_r = 1.

The dependences of volumetric losses Q_{AV} in the pipeline on distance d for the arrangements in Tab. 1 are shown in Fig. 6. Variant 3 is one of the negative variants. Variants 3 and 5 have the same phase closest to the axis of the tower.

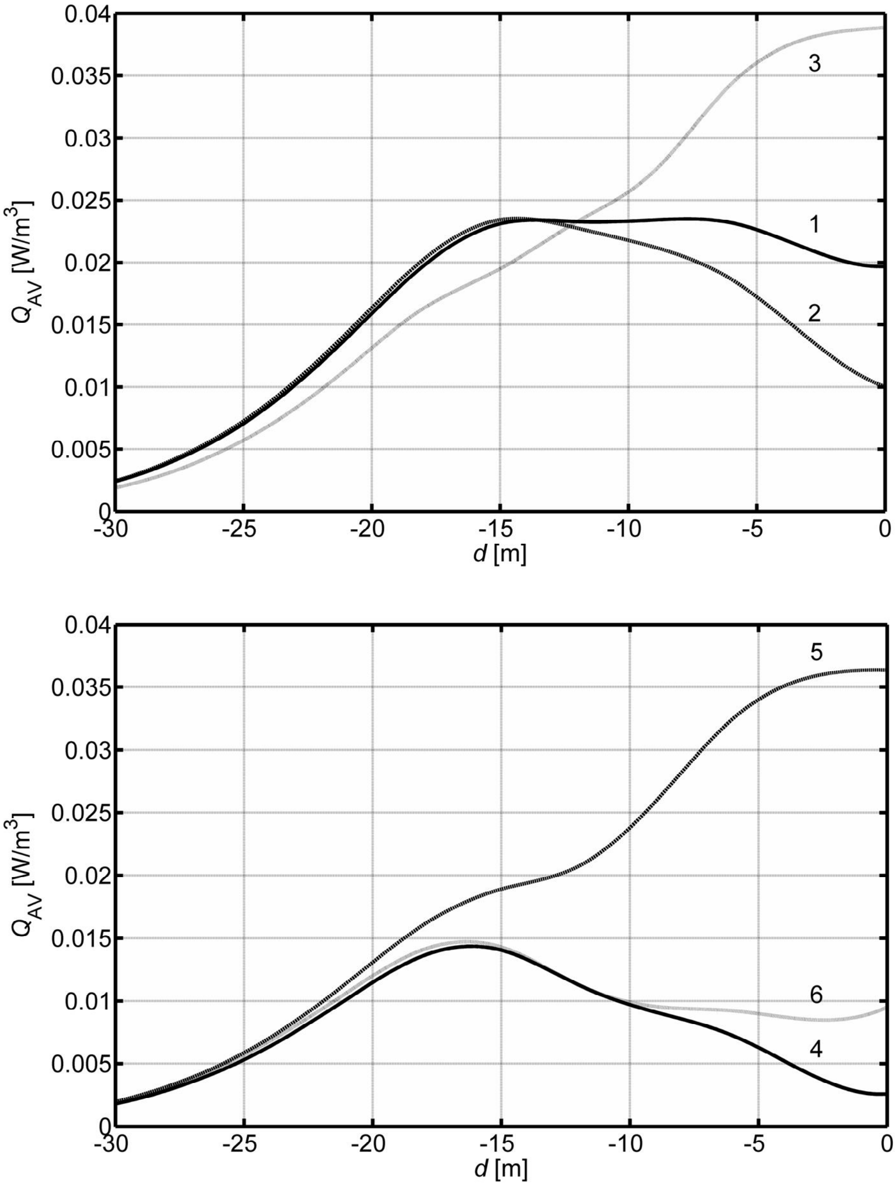


Fig. 6. Dependences of Volumetric Losses in the Pipeline on the Distance for the Cases in Tab. 1.

Fig. 7 depicts the volumetric losses Q_{AV} in the pipeline as a function of distance *d* during the single-phase short circuit.

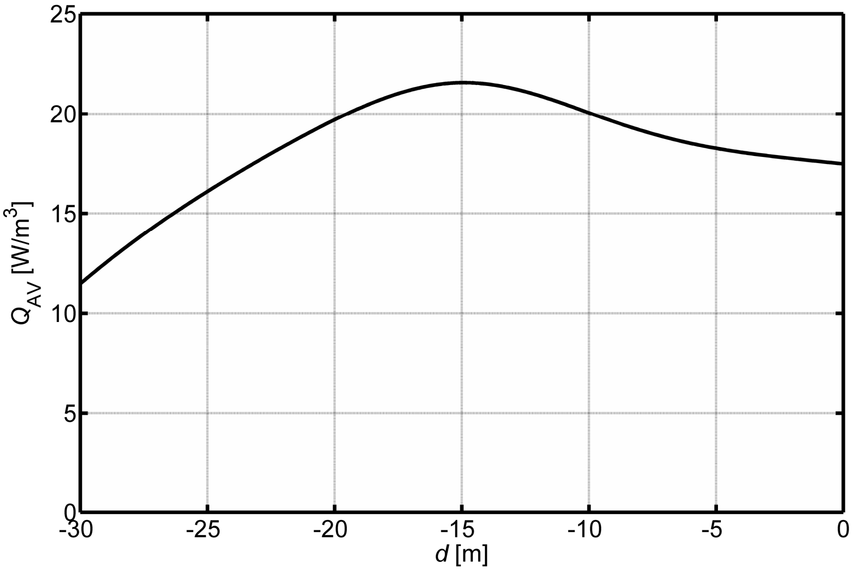


Fig. 7. Volumetric Losses in the Pipeline as a Function of the Distance (in the middle of the route)

The volumetric losses Q_{AV} during a single-phase short circuit are much higher than in the first investigated case without a fault. The volumetric losses in the pipeline depend on the distribution of the currents between the earth wires and earth.

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. 8 depicts magnetic flux density in one part of pipeline in the worst case; during distribution of the backward short-circuit current into halves (50 % earth wires, 50 % earth).

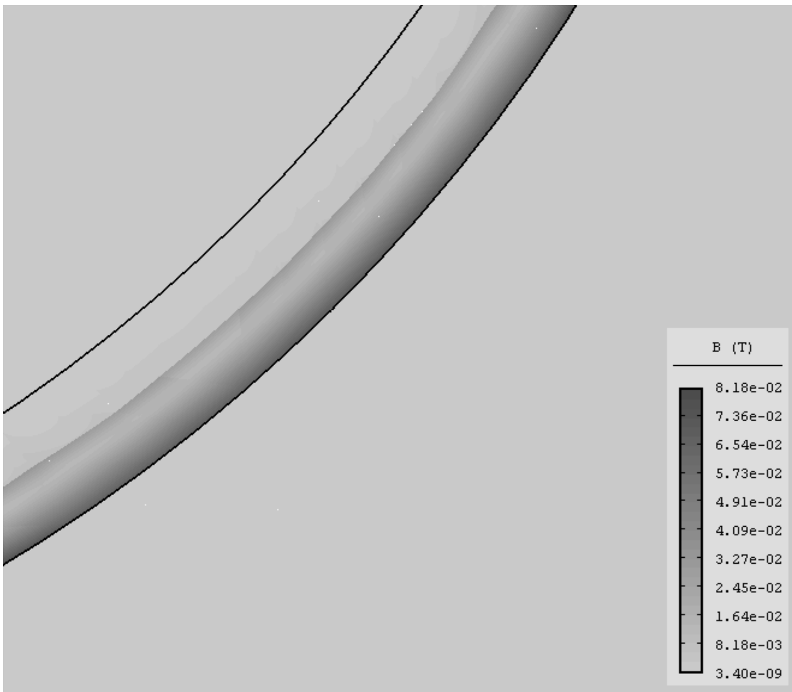


Fig. 8. The Magnetic Flux Density in the Lower Right Part of the Pipeline

6. CONCLUSION

The value of the volumetric losses in buried linear equipment is influenced by the distance of the linear equipment from the overhead line, and by the conductivity of soil, which is variable both vertically and horizontally, depending on the soil composition. The value of the investigated volumetric losses is significantly influenced by the arrangement of phases in two parallel lines. The research shows that it is possible to find an optimal transposition of phase conductors, so that the value of the volumetric losses in linear equipment is minimized. The concerned value is also non-negligibly influenced by the conductor sags.

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 all people working with this equipment and protection of living organisms.

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