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The modelling of the electric field generated by the electrical transport lines

Eleonora Darie[a], Robert Pecsi[a]*

[a]The Faculty of Building Services and Equipment, Technical University of Civil Engineering of Bucharest, Lacul Tei Bvd., no. 122 – 124, RO 020396, sector 2, Bucharest, Romania

Abstract

This paper presents the basic concepts regarding the electrostatic effect of the electrical transport lines on the electrical lines located on the same electrical support pillar. The influence of the electrical transport lines on the neighbouring lines can be: electrostatic, given by the electrostatic field and electromagnetic, given by the electromagnetic field. Depending on the position and the configuration of the electrical lines, the induced voltages and the electric field can be calculated analytically or numerically (by using the Quick Field application).Two configurations are analysed analytically: inductor line – one-wired induced line and one-wired inductor line – two-wired induced line. The graphical results (the electrical potential and the electrical field of the one-wired inductor line and one-wired induced line) of the experimental simulations (inductor line – one-wired induced line and one-wired inductor line) are presented in the Quick Field application.

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Keywords: Electrical line; simulation; electrostatic field; electromagnetic field; numerical analysis

1. Introduction

In the literature [1-6] it is well-known that the electrical transportation lines create electromagnetic fields around themselves, fields that induce voltages in those electrical lines that are located on the same support pillars. The induced voltages are representing a part of the transportation lines voltage ratings and can reach dangerous values [1-2

* Corresponding author
E-mail address: robert.pecsi@gmail.com

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& 4], their effects being able to cause the faulty operation of the telecommunication signalling and electric shocks [1]. The electrical field generated by the electrical transportation lines (hereinafter called inductor lines) is depending on these lines' position and configuration and on the other electrical lines being on the same support pillar (hereinafter called the induced lines) position and configuration. We shall analyse two cases: one-wired inductor and induced lines; one-wired inductor line and two-wired induced lines.

2. One-wired inductor and induced lines

Figure 1 [5] shows a one-wired inductor line together with a one-wired induced line. It is supposed that the inductor line is charged with the *q [Cb/m]* charge and has the potential of *U[V]*. Around it an electric field is generated, field that determines in point P, a point from the induced line's surface the potential U_P. The value of this potential can be calculated with the following equation [1]:

$$U_P = U \frac{\ln \frac{r_{j*P}}{r_{jP}}}{\ln 2 \frac{h_j}{r}} \quad (1)$$

The potential can be calculated with the equation [1], [2], [3]:

$$\left(U - U_P\right) \cdot C_{C-P} = U_P \cdot C_{P-0}, \quad (2)$$

where C_{C-P} and C_{P-0} are the capacities formed between the inductor line's wire and the induced line's wire, respectively netween the induced line's wire and the earth. From this las equation (2) we can calculate the voltage U_P:

$$U_P = U \frac{C_{C-P}}{C_{P-0} + C_{C-P}} \quad (3)$$

2.1. The calculation of the electric field's intensity

The calculation of the E_J electric field's intensity in a point P (figure 1) being in the electrical field of a q_J electrical charge (the specific charge for the length unit of the electrical line) being at the height of h_J over the earth's level can be made with the following equation [4]:

$$\overline{E}_j = \frac{q_j}{2 \cdot \pi \cdot \varepsilon_0} \cdot \left(\frac{\overline{r}_{jP}}{r_{jP}^2} - \frac{\overline{r}_{j*P}}{r_{j*P}^2} \right), \quad (4)$$

where $\overline{r}_{jP}, \overline{r}_{j*P}$ are the distances between the point ,where is located the charge $+q_j$ and the point P and, respectively between the point where is located the charge $-q_j$ and the point P.

The vertical - E_z - and the horizontal - E_x – components of the E electrical field are calculated in a similar way:

$$E_z = \frac{q_j}{2\cdot\pi\cdot\varepsilon_0}\cdot\left[\frac{h_j - h_P}{\left(h_j - h_P\right)^2 + x_P^2} + \frac{h_j + h_P}{\left(h_j + h_P\right)^2 + x_P^2}\right]$$
$$E_x = \frac{q_j}{2\cdot\pi\cdot\varepsilon_0}\cdot\left[\frac{x_P}{\left(h_j - h_P\right)^2 + x_P^2} - \frac{x_P}{\left(h_j + h_P\right)^2 + x_P^2}\right] \quad (5)$$

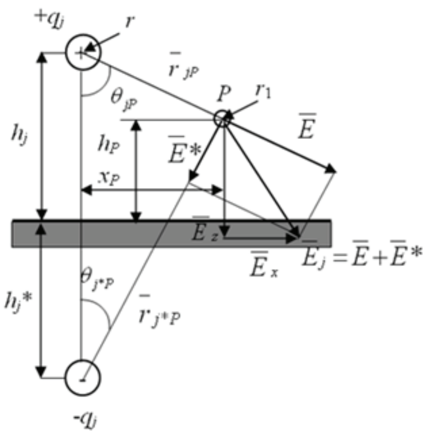

Fig. 1 – One-wired inductor line and one-wired induced line.

By using the Maxwell equations for the electrical charges, we find [5]:

$$[U] = [K]\cdot[q] \quad (6)$$

where [U] is the colon matrix of the voltages formed between the wires and the earth, [K] is the square matrix of the potential coefficients and [q] is the colon matrix of the wires' electrical charges.

3. One-wired inductor lines and two-wired induced line

This is the case of the telecommunication lines with two electric wires (figure 2) [1], [4].

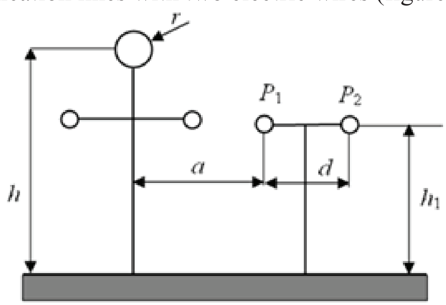

Fig. 2: One-wired inductor line and two-wired induced line

3.1. The calculation of the induced voltages

If the telecommunication line would be on the same support pillar with the induced line, each wire (P1, P2) have had the potential against the earth as calculated with equation (1). Between the two wires there is no potential-difference due to their symmetrical position [1]. In operation there are two limit-situations, depending on the two lines' relative positions: the first one is that when the two lines are on the same support pillar and the second one is that when the two lines have a great distance between them. In the first case, we can write:

$$r_{j*P} = h_j + h_P \tag{7}$$

Thus, equation (1) becomes:

$$U_P = \frac{U \cdot \ln \dfrac{h_j + h_P}{h_j - h_P}}{\ln 2\dfrac{h_j}{r}} \tag{8}$$

where $r_{jP} = h_j - h_P$.

In the second case, we can write for the distances:

$$r_{j*P}^{\;2} = r_{jP}^{\;2} + 4\, h_j \cdot h_P \tag{9}$$

Because the distance between the lines is big, the equation (1) becomes:

$$U_P = U\,\frac{\dfrac{2h_j \cdot h_P}{x_P^{\;2}}}{\ln 2\dfrac{h_j}{r}} \tag{10}$$

By analysing the equation (7), we can notice that the electrostatically induced voltage is proportional with the height of the inductor line and with the height of the induced line (h_j, respectively h_P) and is inverse proportional with the distance between them (x_P).

By equation (10) we can determine the induced voltages U_{P1} and U_{P2} [1]:

$$U_{P1} = U\,\frac{\dfrac{2h \cdot h_1}{a^2}}{\ln 2\dfrac{h}{r}}; \quad U_{P2} = U\,\frac{\dfrac{2h \cdot h_1}{(a+d)^2}}{\ln 2\dfrac{h}{r}} \tag{11}$$

4. The numerical analysis for the determination of the power lines' electrostatic effect

4.1. Generalities

Quick Field [7] is a software aimed for solving electrical field and magnetic field problems, based on the method of the finite elements, which is a numerical (approximation) method for solving the partial derivatives equations.

It is considered a range of field D, where is distributed an electrostatic field, described by a Laplace equation type ($\Delta V = 0$), where V is the electrostatic potential, to be determined. [7]

For solving this equation, we must know the values of the potential V, on the range's border. If the values of the potential on the border's range are known, this means that we have the Dirichlet type conditions [7].

For solving this equation with the finite elements' method, the domain of the field is digitized by using the finite elements network [7].

4.2. Modelling and Simulation

The numerical model for the one-wire inductor line and the one-wired induced line, without considering losses, is shown in Figure 3, analysis that solves an electrostatic question, the model being plane-parallel. Electrostatic analysis is used to analyse a variety of capacitive systems such as transmission lines. Generally, the quantities of interest in electrostatic analysis are voltages and electric fields. The QuickField program is able to perform a linear electrostatic analysis for 2D models and it is based on Poisson's equation. The following options are available for electrostatic analysis: material properties (air, orthotropic materials with constant permittivity); loading sources (Voltages Boundary conditions; Post-processing results: voltages, electric fields.

We consider an inductor line (voltage rating of 20 kV, frequency of 50 Hz), in air, located at the height of 8 meters above the ground and an induced line (voltage rating of 250 V), located at the height of 5 meters above the ground. The two lines are mounted on electricity support pillars (the distance between them being of 20 meters). The voltage electrostatically induced by the inductor line into the induced line is determined numerically (figure 4).

Analytically, the electrostatic voltage induced by the inductor line in the induced one, from a distance of 20 meters has the value of UP = 0,5 kV (equation (10)).

Is both the lines have been on the same electricity support pillar, the electrostatic voltage induced by the inductor line in the induced one would be UP = 3,72 kV (equation (8)). The resulting induced voltage is very high and is able to impair the insulation of the induced line.

The electric potential corresponding to the numerical model illustrated in figure 3 is shown in figure 4.

The electrostatic potential variation, between the one-wired inductor line and induced line is shown in figure 5.

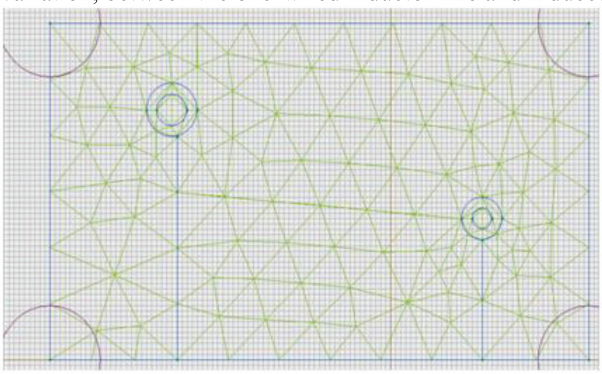

Fig. 3 – Numerical Model for the one-wired inductor line and one-wired induced line (the induced line is situated at a certain distance from the inductor line).

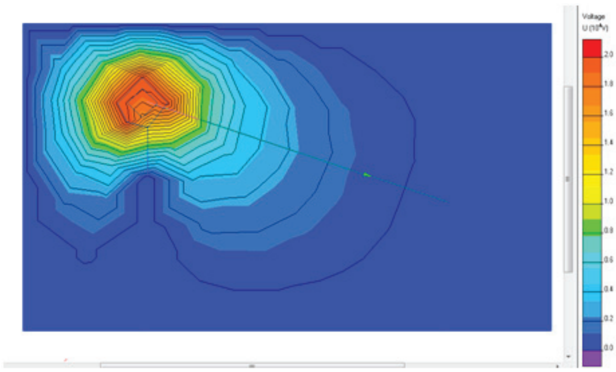

Fig. 4 – Colour map for electrical potential of the one-wired inductor line and one-wired induced line.

For the distant lines, we can consider that the distance measured along the arrows is equal to the distance between the lines' axes (as shown in figure 1).

Figures 5 and 6 show the variation of the induced voltage and of the electric field's intensity between the inductor line the induced one, for the analysed model.

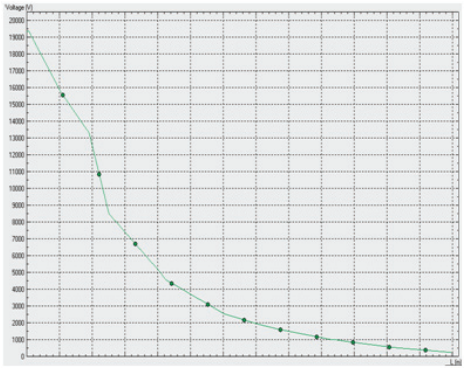

Fig. 5 - Electrostatic potential variation, between the one-wired inductor line and one-wired induced line.

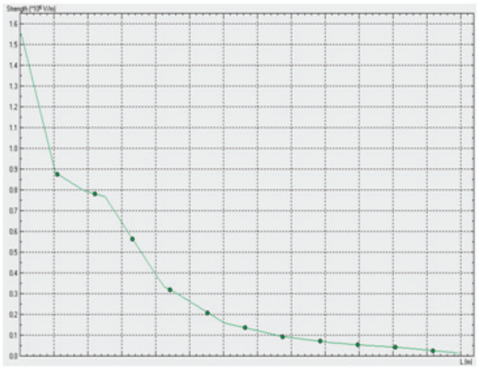

Fig. 6 - Electric field variation, between the one-wired inductor line and one-wired induced line.

The considered inductor line creates around itself an intense electromagnetic field (1,55 x106 [V/m]), which induces voltages with effects that could be disturbing for the induced line.

Figure 7 presents the equilines of Potential, the vectors of Strength (E), the colour Map of Strength (E) and the discretization network.

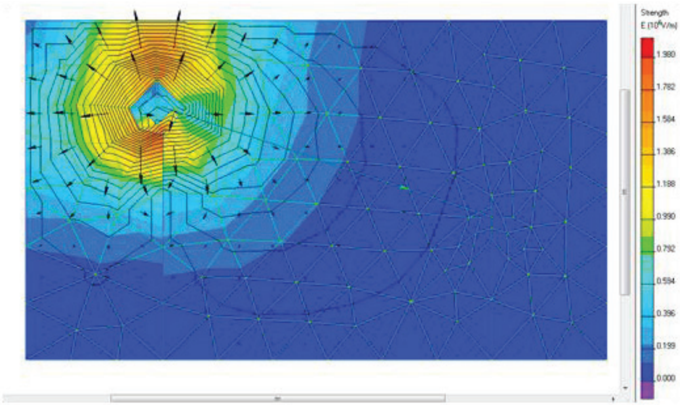

Fig. 7.- Equilines of Potential, vectors of Strength (E), colour Map for strength and the discretization network for the considered numerical model.

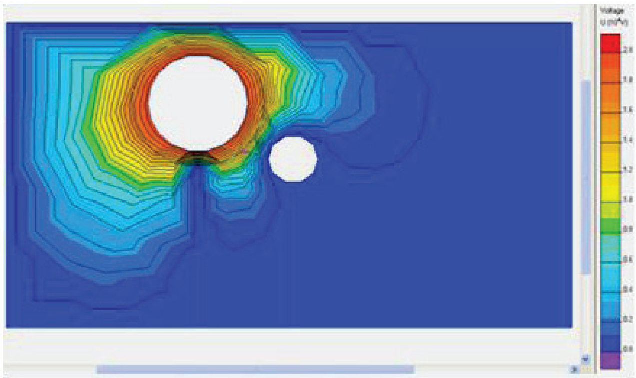

Fig. 8.- Colour map for electrical potential of the one-wired inductor line and one-wired induced line, decreasing the distance between them.

In Figure 8, there is shown the electrostatic potential for the one-wired inductor line and one-wired induced line, decreasing the distance between them.

Analytically we can notice that the electrostatic induced voltage (U_P=0,9 kV) is higher as the distance between the two lines decreases (to 15 meters) (equation (10)).

So, the induced electrostatic voltage is higher when the distance between the two lines is lower.

5. Conclusions

The electrostatic influence of the electrical transportation lines is determined by the electric field generated by the charges of the electric wires. This influence is present both at the creep operation and at the load operation. Depending on the configuration of the two lines (inductor and induced, one-wired and two-wired) there are more cases which can be differentiated and differently analysed analytically (equations (7-11)) and numerically (figures (3-8)).

The induced voltage is proportional with the distance between the wires of the inductor lines (equations (7-11)). If the induced line is located on the same electricity support pillar with the inductor line (figure 2), each wire P_1, P_2 have a voltage to the ground that can be calculated with the equation (8). Between the two wires there is no potential-difference, due to the symmetrical relative position.

For the decrease of the electrostatically induced voltages, there are measures like: the avoidance of the one-wired telecommunication lines; the different positions of the electrical transportation lines and the telecommunication lines; the strengthening of the telecommunication lines' insulation, when they are in the transportation lines' neighbourhood; the screening of the telecommunication lines of those sections, where there are parallel intersection with the transportation lines.

References

[1] I. Vulcu, Instalaţii de transport şi distribuţie a energiei electrice, Ed. Matrix Rom, Bucureşti, 2006.
[2] A. Buta, Transportul şi distribuţia energiei electrice, Ed. I.P. Timişoara, 1990.
[3] O. Crişan, Sisteme electroenergetice, Ed. Didactică şi Pedagogică, Bucureşti, 1979.
[4] H. Albert, Calitatea energiei electrice la consumator – o problemă prioritară, Măsurări şi Automatizări, Nr.1, 2005.
[5] G. Drăgan, Tehnica Tensiunilor Înalte, vol. III, Ed. Academiei Române, Bucureşti, 2003.
[6] A. Marincu, M. Greconici, Câmpul electric şi magnetic în vecinătatea unei linii electrice de înaltă tensiune şi posibilele efecte asupra sistemelor biologice, The 5th International Power Systems Conference, Timişoara, România, 2003, pp. 357-362.
[7] QuickField 5.9.