

Characterization of the Electric and Magnetic Field Exposure from a 400 kV Overhead Power Transmission Line in Romania

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Abstract – In the paper, the electric and magnetic fields from a relatively new design of 400 kV overhead transmission line used in the Romanian power system are computed and compared to the exposure limits established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for the general public. The computations are carried out with two dedicated software tools, called PowerMag and PowerELT, which have been written in LabVIEW, based on a 2D quasi-static analytical approach. This approach, as well as the electric and magnetic field distributions obtained for the considered 400 kV transmission line, will be discussed in detail.

Keywords – *electric field, magnetic field, 400 kV transmission line, 2D computation, exposure limits*

I. INTRODUCTION

Over the past 35 years, extensive research has been conducted to determine if the extremely low frequency (ELF) electric and magnetic fields like those from power lines, in-house installations and household appliances can affect the human health. Researchers from different fields conducted numerous epidemiological studies regarding the potential effects of ELF fields, such as cancer in children and in adults, reproductive effects, neurological effects, cardiovascular disorders, immunological modifications, etc. Most notably, a weak statistical association was reported between childhood leukaemia and chronic exposure to average ELF magnetic fields above 0.3 to 0.4 μT [1-3].

The current consensus among various national and international scientific organizations is that there are no known adverse health consequences of exposure to ELF fields at the levels generally found in residential and occupational environments, including proximity to

electric transmission and distribution facilities. Despite this fact, the public frequently expresses concern about ELF fields, often in the context of proposed new transmission lines [4]. This is why the main objective of our study is to compute the typical ELF electric and magnetic field exposure from a relatively new design of overhead transmission line used in the Romanian power system, namely a 400 kV single-circuit line (SCL) with geometry dictated by RODELTA type towers.

Further, the paper is organized as follows: Section II presents related results in the literature, including previous developments of the authors; Section III describes the methods adopted for the computation of the ELF electric and magnetic fields; Section IV investigates the distribution of the ELF fields from the considered 400 kV SCL and check compliance with the ICNIRP guidelines; the conclusions are drawn in Section V.

II. RELATED RESULTS IN THE LITERATURE

The ELF electric and magnetic fields from power lines change very slowly in time, which means that they can be considered as quasi-static. Hence, these fields may be computed separately.

In 2D analysis, the common practice is to assume that the power line conductors are straight horizontal wires of infinite length, parallel to a flat earth and parallel to each other. The electric field is usually computed by finding the linear charge of the conductors [5-10], while the magnetic field is usually computed by applying the Biot-Savart law [10-16]. Such an approach has been adopted in our paper as well.

Although most computer programs for calculating electric and magnetic fields from overhead power lines are developed in MATLAB, e.g. [6, 16-20], the software tools used in this study have been written in LabVIEW, which is a graphical programming environment

commonly used for data acquisition, instrument control and industrial automation [21-23]. The program for computing ELF magnetic fields from overhead power lines is called *PowerMAG* and has already been used in [24] and [25], to investigate the magnetic field exposure from typical 110 kV and 220 kV single- and double-circuit lines of the Romanian power system. The program for computing ELF electric fields from overhead power lines is a completely new tool, called *PowerELT*. These simulation tools are able to generate quite accurate lateral profiles (along y -axis) of the electric and magnetic fields at a specified height above the ground, as well as to directly map the two fields in the cross section (yz -plane) of the power line, between any two sets of user-defined coordinates. As with other simulation programs, the knowledge of the power line geometry, as well as of the voltage and of the current respectively (amplitude and phase), for each line conductor, is a prerequisite.

III. DESCRIPTION OF THE METHODS

This section highlights the solution methodology for determining the 2D distribution of both the electric and magnetic fields.

A. Computation of the electric field strength

Assuming that the earth is perfectly conductive, the electric field in the vicinity of a power line conductor located at (y_i, z_i) above the earth and having a linear charge q_i can be obtained by using the image method, as presented in Fig. 1, where $r_{ci} = \sqrt{(y - y_i)^2 + (z - z_i)^2}$ is the distance between the conductor and the observation point (y, z) and $r_{ii} = \sqrt{(y - y_i)^2 + (z + z_i)^2}$ is the distance between the image conductor and the point (y, z) . The influence of multiple conductors will be taken into account by applying the superposition principle.

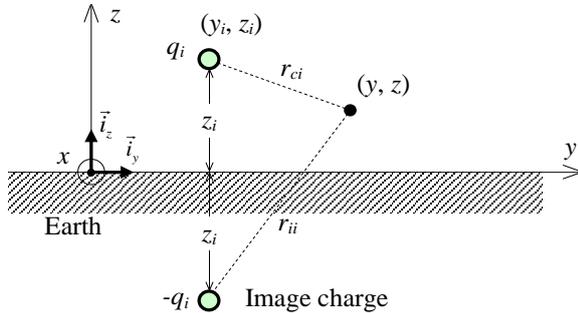


Fig. 1. Single power line conductor model for computing the electric field strength in the yz -plane

In conformity with [8, 26-28], the total electric field strength (from all power line conductors) can be calculated with the formula:

$$\vec{E}(y, z) = \sum_{i=1}^n \frac{q_i}{2\pi\epsilon_0} \left(\frac{y - y_i}{r_{ci}^2} - \frac{y - y_i}{r_{ii}^2} \right) \cdot \vec{i}_y + \sum_{i=1}^n \frac{q_i}{2\pi\epsilon_0} \left(\frac{z - z_i}{r_{ci}^2} - \frac{z + z_i}{r_{ii}^2} \right) \cdot \vec{i}_z, \quad (1)$$

where $\epsilon_0 = 1/(36\pi \cdot 10^9)$ F/m represents the electric permittivity of the free space and n is the total number of conductors.

The charges q_i on conductors are determined from the phase voltages and Maxwell potential coefficients, using the matrix equation:

$$[q] = [p]^{-1} \cdot [V], \quad (2)$$

where $[q]$ is the column vector of the linear charges on each conductor, $[V]$ is the column vector of the potentials of the conductors and $[p]^{-1}$ is the inverted matrix of the Maxwell potential coefficients. These coefficients are calculated on the basis of line geometry and conductor radius, using the expressions:

$$p_{ii} = \frac{1}{2\pi\epsilon_0} \ln \left(\frac{2z_i}{R_i} \right); \quad (3)$$

$$p_{ij} = \frac{1}{2\pi\epsilon_0} \ln \left(\frac{D'_{ij}}{D_{ij}} \right), \quad (4)$$

in which R_i represents the radius of the conductor i , D_{ij} is the distance between the conductor i and the conductor j , and D'_{ij} is the distance between the conductor i and the image of the conductor j .

If the line conductors are bundled (as in the case of a 400 kV transmission line), the conductor radius R will be replaced by an equivalent radius R_{eq} , given by [29]:

$$R_{eq} = \sqrt[N]{R \cdot d^{(N-1)}}, \quad (5)$$

where N is the number of individual conductors in bundle and d is the separation distance between conductors. Eq. (5) is valid for up to three conductors per bundle.

B. Computation of the magnetic flux density

In 2D analysis, the ELF magnetic fields from overhead power lines can easily be computed using the Biot-Savart law, the image method and the superposition principle. According to [10-13, 25], a simple, yet reasonable formula for calculating the total magnetic flux density at any observation point (y, z) in the vicinity of an overhead power line is:

$$\vec{B}(y, z) = -\sum_{i=1}^n \frac{\mu_0 I_i}{2\pi} \left[\frac{z - z_i}{r_{ci}^2} - \frac{z + z_i + \delta(1-j)}{r_{ii}^2} \right] \cdot \vec{i}_y + \sum_{i=1}^n \frac{\mu_0 I_i}{2\pi} \left[\frac{y - y_i}{r_{ci}^2} - \frac{y - y_i}{r_{ii}^2} \right] \cdot \vec{i}_z, \quad (6)$$

where I_i represents the phase current carried by the i -th conductor – located at (y_i, z_i) with respect to the coordinate system in Fig. 2 – in the positive x -direction, $r_{ci} = \sqrt{(y - y_i)^2 + (z - z_i)^2}$ is the distance from the observation point (y, z) to the i -th conductor, $r_{ii} = \sqrt{(y - y_i)^2 + (z + z_i + \delta(1-j))^2}$ is the “complex distance” from the observation point (y, z) to the i -th conductor’s image, $\mu_0 = 4\pi \cdot 10^{-7}$ H/m represents the magnetic permeability of the free space, and n is the total number of conductors.

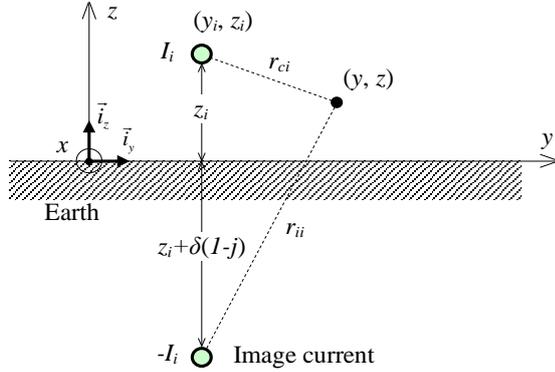


Fig. 2. Single power line conductor model for computing the magnetic flux density in the yz -plane

As it can be seen in the simplified power line model in Fig. 2, the image current for each conductor – equal in amplitude and opposite in direction to the conductor current – is buried in the earth at the “complex depth” $z_i + \delta(1-j)$, where $\delta = 503\sqrt{\rho_g / f}$ represents the skin depth of the earth, ρ_g is the earth resistivity and f is the frequency. Since the earth resistivity typically ranges from 10 Ωm to 1000 Ωm , the image currents are normally located at hundreds of meters below the ground.

IV. RESULTS AND DISCUSSIONS

As already stated, for the purpose of this study, a 400 kV single-circuit overhead transmission line with geometry dictated by RODELTA type (suspension) towers has been considered. Each of three phases (R, S and T) consists of three standard ACSR 300/69 mm^2 conductors, separated by a distance of 0.4 m. The radius of an individual conductor is 12.57 mm, leading to an equivalent conductor radius of 126.22 mm.

The input data, including the geometrical parameters of the line, as well as the voltage and current information

(RMS value and phase), are given in Table 1. Note that the specified z_i values correspond to an “average height” of the conductors above the ground, calculated as $z_i = z_{max} - (2/3) \cdot s$ [30, 31], where z_{max} is the maximum conductor height (at the tower) and s is the conductor sag.

Table 1. Input data for the 400 kV overhead transmission line.

	y_i (m)	z_i (m)	\underline{U}_i (kV)	\underline{I}_i (A)
R	-7.5	12.6	231 $\angle 0^\circ$	1000 $\angle -30^\circ$
S	0.0	23.6	231 $\angle -120^\circ$	1000 $\angle -150^\circ$
T	7.5	12.6	231 $\angle 120^\circ$	1000 $\angle 90^\circ$

A. The distribution of the electric field

Fig. 3 shows the lateral profiles of the total RMS electric field strength and of its transversal components, at the height of 1 m above the ground. The maximum electric field strength – 4903.2 V/m – is registered at a distance of 9 m from the centerline, accounting for 98.06% of the exposure limit established by ICNIRP for the general public, 5000 V/m [32]. At 37.5 m distance from the centerline, which represents the semi-width of the safety / protection zone for 400 kV overhead transmission lines [33], the electric field strength decreases to 562.9 V/m, accounting for 11.26% of the ICNIRP exposure limit. At the centerline, a field strength value of 2467.1 V/m is registered.

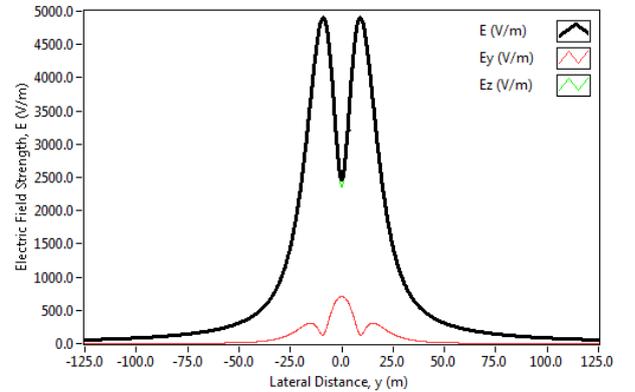


Fig. 3. Lateral profiles of the total RMS electric field strength and of its transversal components at 1 m above the ground

Fig. 4 shows the distribution of the electric field from the ground level up to 10 m above the ground. At 50 m to 100 m distance from the centerline, no significant differences can be observed between the electric field strength values calculated at various heights.

B. Distribution of the magnetic field

Generally, the magnetic field from a power line varies widely with time because the current in the conductors depends on the power consumption. In this study, we assumed a current of 1000 A, considerably higher than the average loading for the selected 400 kV line.

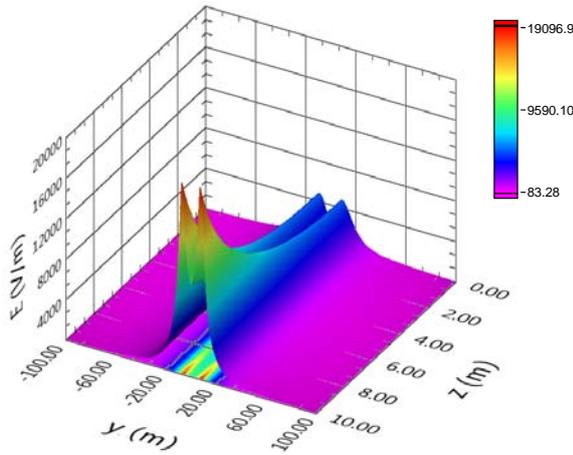


Fig. 4. The distribution of the total electric field strength from the considered 400 kV single-circuit line, from the ground level up to 10 m above the ground

Fig. 5 shows the lateral profiles of the total RMS magnetic flux density and of its transversal components, at the height of 1 m above the ground. The maximum magnetic flux density – 14.01 μT – is registered at the centerline, accounting for only 14.01% of the exposure limit established by ICNIRP for the general public, 100 μT [32]. At 37.5 m distance from the centerline (the semi-width of the safety / protection zone), the magnetic flux density decreases to 2.16 μT , accounting for 2.16% of the ICNIRP exposure limit. A value of 0.3 μT is registered at about 108 m distance from the centerline.

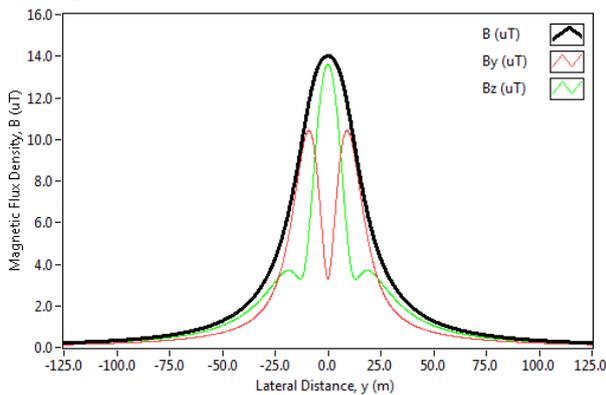


Fig. 5. Lateral profiles of the total RMS magnetic flux density and of its transversal components at 1 m above the ground

Fig. 6 shows the distribution of the magnetic field from the ground level up to 10 m above the ground. At 50 m to 100 m distance from the centerline, no significant differences can be observed between the magnetic flux density values calculated at various heights.

Computations performed at mid span (where the conductors are the lowest) revealed that the magnetic field at 1 m above the ground cannot exceed 50% of the ICNIRP limit. As for the electric field, towards the mid span, it may reach two times the ICNIRP limit.

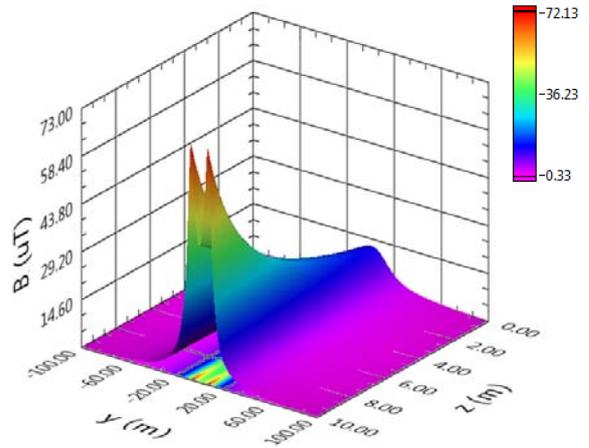


Fig. 6. The distribution of the total magnetic flux density from the considered 400 kV single-circuit line, from the ground level up to 10 m above the ground

V. CONCLUSIONS

The 400 kV overhead transmission lines can be considered as one of the major sources of ELF electric and magnetic fields, which can induce electrical currents within the human body. According to the computations performed in this study, the typical ELF electric and magnetic fields under the considered 400 kV single-circuit transmission line do not exceed 4903.2 V/m (98.06% of the ICNIRP limit for 50 Hz electric fields) and 14.01 μT (14.01% of the ICNIRP limit for 50 Hz magnetic fields) respectively. At 37.5 m distance from the centerline, which represents the semi-width of the safety / protection zone, the electric field decreases to 562.9 V/m (11.26% of the ICNIRP limit), while the magnetic field decreases to 2.16 μT (2.16% of the ICNIRP limit). At mid span, the electric field may reach two times the ICNIRP limit, but the magnetic field cannot exceed 50% of the ICNIRP limit.

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