ELECTROMAGNETIC POLLUTION LEVELS DUE TO ELECTRIC POWER INSTALLATIONS AND SUITABLE MITIGATION METHODS

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Abstract: *Electric power installations produce, even in normal operation conditions, conducted and radiated electromagnetic disturbances. The radiated disturbances can affect the proper operation of some weak currents equipment located in the vicinity of such an installations and also constitute a threat for the health of living beings. Radiated disturbances constitute anyways an environmental particular pollution factor and, in order to reduce it, many standards impose limit values for the electromagnetic emissions of electric power installations. This paper analyses the features of power frequency electromagnetic fields produced by three-phase overhead lines, and particularly of some high-voltage double-circuit lines in operation in Romania, based on calculations and experimental data. The requirements for accurate evaluation of low frequency electromagnetic fields by measurements and the methods to reduce the emissions of power lines are also discussed.*

Keywords: electric power installation, low frequency electromagnetic field, human exposure.

1. Introduction

All electric installations produce, in normal operating conditions, power frequency electric and magnetic fields in theirs vicinity. The level of the field strengths is a concerning factor regarding both operation of another electromagnetic systems and human exposure.

Regarding human exposure, by mean of standards or recommendations, different limit values were adopted for professionals and general public. For power frequency fields produced by electric power installations, the limits stipulated in [1] for professional exposure are, for electric field strength, 10 kV/m, and for magnetic flux density 500 μT (which correspond of 400 A/m field strength). The exposure corresponding limits for large public [2], are, respectively 5 kV/m and 100 μT (80 A/m field strength).

In order to obtain reproducible values, the standardized measuring procedures for the power frequency field strengths must be known. Such a standard, with regard to human exposure is [3].

This paper reviews the main properties of power frequency fields

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produced by overhead lines and tries to emphasize the necessary precautions to be adopted concerning the proper evaluation of these fields. Based on the computations and measurements, it concludes about the behavior of some overhead lines in operation in Romania regarding the fields in their neighborhood.

A large majority of electric power installations (power lines, substations etc.) in operation in Romania was designed without taking into account a criterion regarding the limitation of power frequency fields in the accessible areas for the personnel or large public. But at this moment a real concern exist regarding the electromagnetic fields produced by existing installations and the field strength is a design criterion for new or refurbished installations.

2. Features of power frequency fields produced by AC three-phase installations

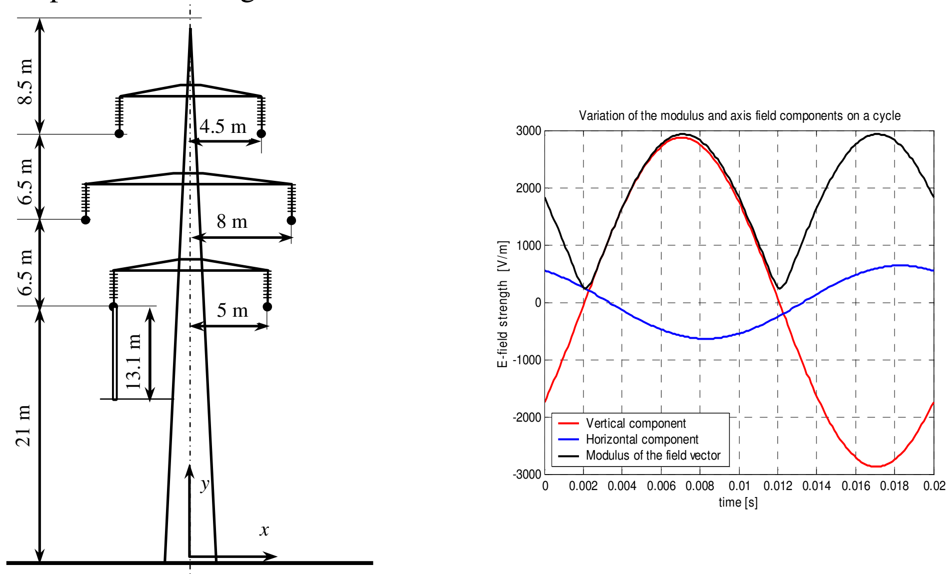
Assuming that the problem are plane-parallel type and the regime is quasi-stationary, the procedures for computing the power frequency fields produced by power lines, have been described in numerous works [4...7]. Therefore, only the particularities of these fields will be outlined .

Under a three-phase system in open-air (power lines, bus bar) electric and magnetic fields are rotating fields, the field vector describing, in general case, during a cycle of alternating voltage, an ellipsis. This can degenerate, depending on the location of the observation point in relation to the conductors, in a circle or straight line. Variation in time of the axis components of the field is sinusoidal, the phase angle between them, phase angle and peak values depending on the position of observation point. Variation in time of the resulting vector field modulus is non-sinusoidal. This variation is illustrated (in Figure 1b), with reference to the electric field for a point located outside the symmetry axis of a 220 kV double-circuit line (at 10 m of it) at 1 m above the ground, in the middle of the span.

Therefore, once the line is energized, the modulus of the vector field does pass through zero only in the points where one of the components (horizontal or vertical) is zero. Practically, this can be achieved only for the points located on or near the ground, where there is only one component of the field. The ratio between the peak value (maximum value of the modulus vector field) and the r.m.s. value of a field produced by sources with sinusoidal variations in time is $\sqrt{2}$.

3. Calculation and experimental determination of power frequency fields produced by high voltage power lines

Close to the ground, for three-phase high voltage lines, the electric field becomes almost uniform, the field lines are almost parallel and equidistant and the vertical component is predominant. Figures 2 and 3 show the axis actual values calculated for the electrical field, in the case of double-circuit overhead line, 220 kV, represented in Fig. 1a.



a) b)

Fig.1. Sketch of a tower for 220 kV double-circuit line (a) and time variation of electric field components on axis and elliptic vector modulus (coordinates of calculation point: x=10 m, y =1 m).

For a symmetrical (in mirror) arrangement of phases over tower axis (from top to the ground, ABC-ABC, called untransposed), lateral electric field profile is shown in Figure 2, and for an ABC-ACB (transposed) arrangement of phases in Figure 3. Distance to ground of the calculation point was 1 m in both considered cases. The examples show that, for double-circuit lines, an additional factor of influence is the relative position of phases having the same name-out of the conductor's arrangement. The favorable case, relative to the ground field values, is the one where the phases are "transposed". As reference for double-circuit lines, Figure 4b presents a calculated lateral profile for single circuit overhead lines, with distances between phases and ground identical with the minimum distance conductor to ground of the line presented in Fig. 4a. It must be noted that the maximum electrical field values are higher than those corresponding to double-circuit lines, one of the causes being the phase's disposal in the same horizontal plane.

For the case illustrated in Fig. 2, the ratio between vertical and horizontal component varies (for non-zero values of horizontal component) between 3.5 and 174. If the field measurement is performed using a uniaxial probe that evaluates only the vertical component, the maximum error made in this case is below 4%. Even for theoretical cases when the horizontal component reaches 0.5 of the vertical component, measurement error will be only approx. 12%.

For single-circuit lines, the r.m.s. value of electric field strength is directly proportional to the applied voltage, but for double-circuit lines, the above statement would be valid only if both circuits are energized. In operation could be cases when one of the circuits is not energized. If the layout of phases is ABC-ABC (untransposed), the maximum field is reduced by approx. 21% if one circuit is disconnected (Fig. 5).

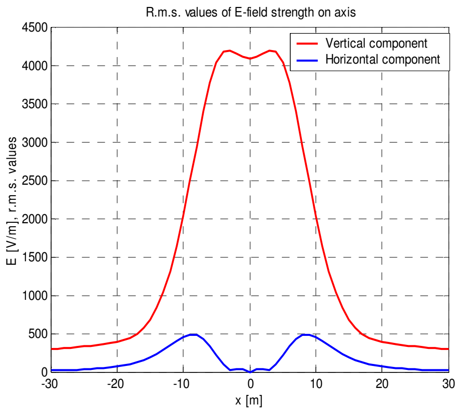


Fig.2- Axis components of electric field produced by a 220 kV double-circuit line with untransposed phases.

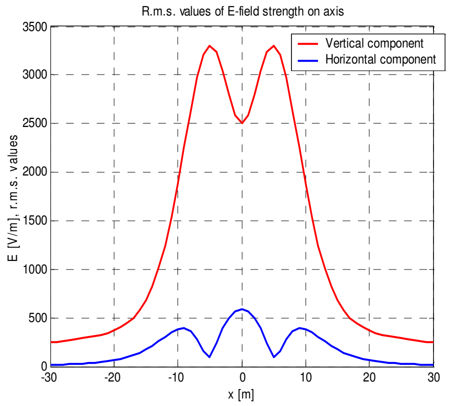
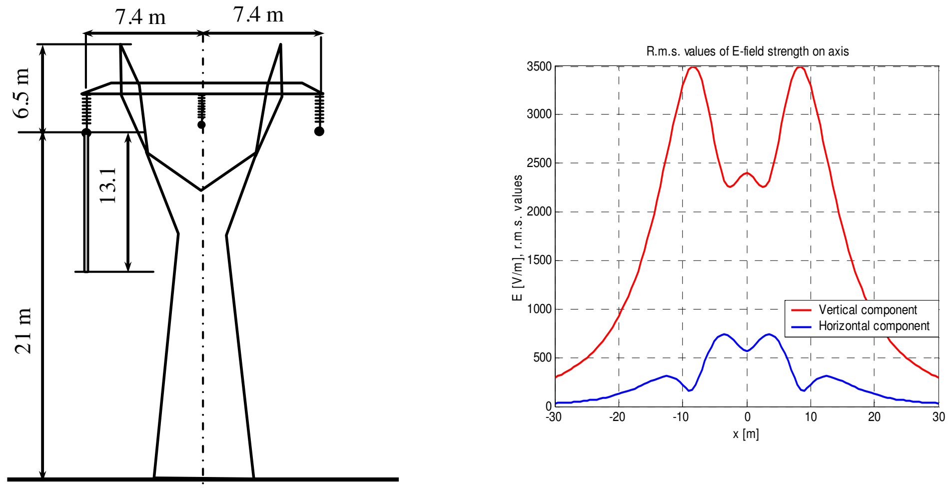


Fig.3- Axis components of electric field produced by a 220 kV double-circuit line with transposed phases.



a) b)

Fig.4- Axis components of electric field produced by a 220 kV single-circuit line; a) tower geometry; b) lateral profile of electric field.

If the double-circuit line has a phase arrangement of ABC-ACB, the maximum field is practically not reduced if one of the circuits is disconnected (Figure 6) but even has a slight upward trend. For both cases considered above, the circuit in the right axis of symmetry of the tower was disconnected (positive coordinates on axis Ox).

Measurements on the 220 kV double-circuit lines were also carried out.

For a line with the arrangement of phases ABC-ABC (untransposed), the comparison between the measured and calculated values is illustrated in Fig. 7. The good correlation between the values can be remarked, although the calculation is performed in the plane-parallel problem assumption.

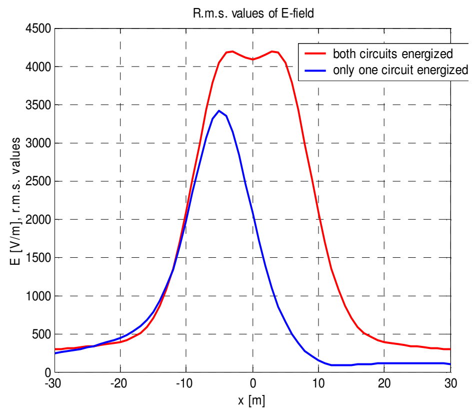


Fig.5- Electric field lateral profile (expressed in r.m.s. values of resultant) of 220 kV double-circuit line, with untransposed phases, with both or a single circuit energized.

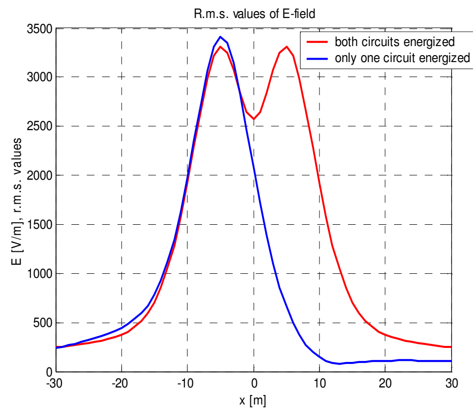


Fig.6- Electric field lateral profile (expressed in r.m.s. values of resultant) of 220 kV double-circuit line, with transposed phases, with both or a single circuit energized.

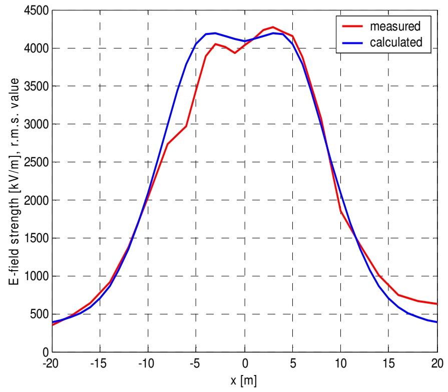


Fig.7- Electric field lateral profile (expressed in r.m.s. values of resultant) of 220 kV double-circuit line, with untransposed phases, both circuits being energized: calculated and experimental data.

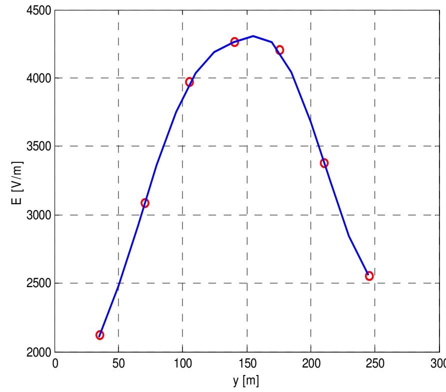


Fig.8- Electric field longitudinal profile (expressed in r.m.s. values of resultant) of 220 kV double-circuit line, with untransposed phases, with both circuits energized.

Longitudinal profile experimentally determined for the double-circuit line shows, as expected, that the highest values are found in the maximum sag point and the field significantly decrease near the towers. An illustration is shown in Fig. 8, for a line span of 280 m. The values used to draw the longitudinal profile were the maximum values recorded in the lateral profiles distanced each other at 35 m. The measurements were carried out in conditions where both circuits were in operation.

Magnetic fields produced by three-phase overhead lines also have an elliptical polarization. Unlike electric fields, nearby the ground level each axis component (horizontal or vertical) could be locally dominant. At first glance, the most important component of the magnetic field, near the ground would seems to be the horizontal one because of current direction in the conductors, parallel to the ground. Assessment by calculation and experiment highlight the fact that the value of vertical component is, in many cases, comparable to the horizontal component or greater than, especially in the points beyond the axis line. In these cases, measuring only the horizontal component may introduce significant errors.

Depending on the current in line operation, large variations of the magnetic field strength occur, because this actually follows the curve of load line. For a single-circuit power lines, magnetic field is usually calculated for 1 kA r.m.s. value per phase. Knowing the actual current through conductors, the real value of magnetic field is obtained by multiplying the value of field strength calculated as above with the ratio between real value of current and the reference value (1 kA). These considerations are not valid for double-circuit lines (except the case when the two circuits would have identical loads) because each circuit can be differently loaded, or one of them could be disconnected.

Figure 9 presents the magnetic field components on axis, in the case of a 220 kV single-circuit line (shown in Fig.4a) and loaded at 624 A (considered as nominal value for this overhead line). In the closer points to the axis of the line, the vertical component is greater than horizontal one, while away from the axis, the horizontal component predominates. When both circuits of 220 kV double-circuit line shown in Fig. 1a, with untransposed phases, are identical loaded, the components of lateral profile of magnetic field have the variation represented in Fig. 10. In this case, for the closest points to the line axis the horizontal component surpasses the vertical one, while the vertical component predominates in the remote points from axis of the line. In the points where the two components are equal, measuring only one of them (by using a uniaxial probe) leads to a negative error of 41%.

As with the electric field, magnetic field produced by double-circuit lines with transposed phases is lower compared with those having untransposed phases. Field components variation for this particular case (ABC-ACB)is illustrated in Fig.11.

Despite all the differences that occur between the components variations for the lines with transposed and untransposed phases, resultant magnetic field do not differ substantially for the two double-circuit lines analyzed. Comparative presentation is shown in Fig.12.

Maximum values of the magnetic field produced by 220 kV double-circuit line differently loaded, expressed in percentage terms in relation to their nominal current are presented in Table 1 for line with transposed and untransposed phases respectively. Expressed in absolute values, for any identical load of the two circuits, the line with transposed phases will produce a lower magnetic field compared to the one with untransposed phases.

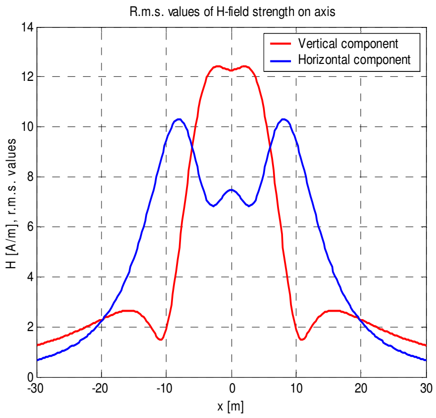


Fig. 9- Magnetic field lateral profile (of axis components) of a 220 kV single-circuit overhead line.

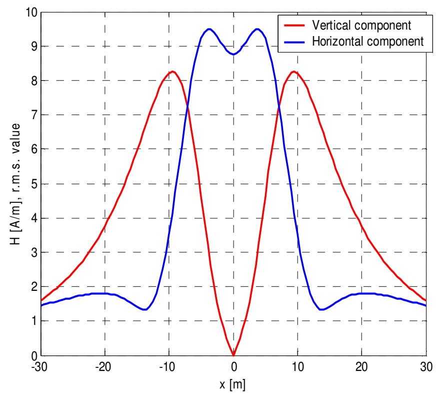


Fig. 10- Magnetic field lateral profile (of axis components) of a 220 kV double-circuit overhead line, with untransposed phases, at identical nominal current loads of the two circuits.

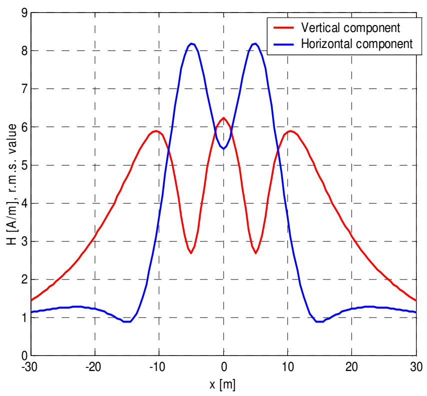


Fig. 11- Magnetic field lateral profile (of axis components) of a 220 kV double-circuit overhead line, with transposed phases, at identical nominal current loads of the two circuits.

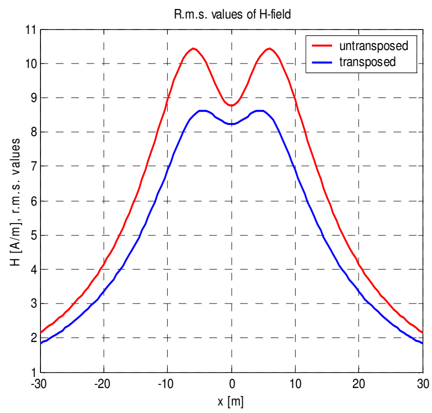


Fig. 12- Magnetic field lateral profile (of axis components) of a 220 kV double-circuit overhead line, with transposed and untransposed phases, at identical nominal current loads of the two circuits.

4. Conclusions

Assessment by calculation and experiment of the power frequency fields produced by 220 kV overhead lines highlighted the fact that the magnetic field, even at nominal loading of the line, is one order of magnitude smaller than the allowable human exposure limits for large public. Double-circuit lines with transposed phases produce both electric and magnetic fields near ground with lower values comparing with those with untransposed phases. At unbalanced loads of the circuits, the maximum value of the magnetic field decreases (for identical percentages and compared with nominal loads) more pronounced for the line with untransposed phases.

Table 1

Maximum values of magnetic field at 1 m above the ground, at different loads of double-circuit lines

Load of the circuits (relative to the nominal current)		Maximum relative magnetic field strength (related to the corresponding value for the case of identical nominal current loads of the two circuits)	
circuit 1	circuit 2	Line with untransposed phases	Line with transposed phases
		%	%
0 %	100 %	75	91
10 %	90 %	69	81
20 %	80 %	64	72
30 %	70 %	59	63
40 %	60 %	54	55
50 %	50 %	50	50
100 %	100 %	100	100

Regarding electric field values, they had not exceeded 4.5 kV/m. It was also highlighted the advantage that presents, in terms of field values in their vicinity, the double-circuit lines with transposed phases. Exploration of the electric field near the towers shows the minimum values of longitudinal profile, because the conductors have maximum distance from the ground and the tower concentrates the field lines on its superior portion.

Phases transposition of the double-circuit lines is a simple and inexpensive way (compared with other possible solutions, such as increasing the tower height) to reduce electric and magnetic fields near the ground.

R E F E R E N C E S

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