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Electric and magnetic field generated by electric equipments. Influences upon the environment

UNGUREANU MARILENA, CRISTESCU D., CODRUTA ROMAN, ROSCA RALUCA
Department of Energetic
University "Politehnica" of Bucharest
313 Splaiul Independentei, sector 6, Bucharest
ROMANIA

Abstract: - In the present, a continuous regard on the electric and magnetic field generated by the high voltage equipment operating at low frequency exist, which interferes with the biologic systems or by inductive or capacitive effects with other equipments or structures in the close proximity. The present paper analyses the electric and magnetic filed generated by the electric power transmission lines and by the high voltage substation in terms of the European limits values recommendations. The authors used a computational method for the quick assessment of the electromagnetic fields starting from a MS Access database comprising different configurations and design for the Romanian power lines. The survey system was developed in Visual C++ and displays a friendly graphic interface. To make more analytical comments about the magnetic induction B, the authors used the method of the current dipoles existing in the literature.

Key-Words: - electric field, magnetic field, environment, limits, critical zones, overhead transmission lines.

1 The interest for the subject

The presence of a low frequency electromagnetic field generated by transmissions lines may produce some undesirable effects:

- the direct action about living organisms by induced currents in their bodies;
- the currents which could rich out values as 10 mA/m^2 [1, 2];
- the induced voltages from inductive or capacitive coupling which could cause annoying contact currents or even deadly for humans or animals or dysfunctions of the electrical equipment.

In these conditions a survey of electric and magnetic fields generated by electrical installations is necessary in order to avoid some unpleasant events.

Without a general international accord, a constant regard with the principal problems exists and some settlement about the limit values of these fields in the vicinity of the transmission lines was emitted.

The limit values (*basically restrictions* defined as specific values in regard to biological effects which must be control and *reference levels* defined as measurable parameters used to verify the basically concordance restrictions) for electric and magnetic field in 0÷10 kHz domain are the following [1, 2]:

- *The basically restriction* for electric field in the case of a field parallel exposure with the whole body is:

42 kV/m (peak value) for 0 - 0,1 Hz; 30 kV/m (peak value) for f > 0,1 Hz, and f > 50Hz.

- *The basically restriction* for magnetic field is 2T.

The reference values are established by the access category: public or professional are present in table 1 and table 2, respectively.

Table 1

Access	f [Hz]	Electric field [kV/m]	Time [h]
professional	50 - 150	1500/ *f* *(30 - 50Hz)*	t <80/E*
public	0,1 - 60	10	-
* limits with the total time of the exposure			

Table 2

Access	f [Hz]	Magnetic field
professional	0,4 - 1500	80/f in mT (1,6 mT for 50 Hz)
public	1,15- 1500	32/ f in mT (0,66 mT for 50 Hz)

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2 The analyse of critical zones generated by overhead power lines

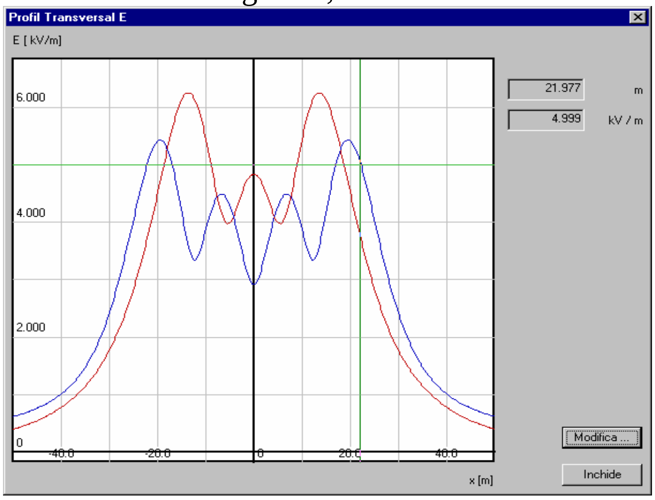
2.1 Electric field analyse

The distributions of electrical field for different configurations of Romanian electric lines are presented in figures 1-3 where the mentioned limits were mark. The general conclusion is: *the limit value for the public access (10 kV/m) not cross any overhead electric line profile.*

Some remarks could be also making:

- the critical area delimitated by the electric field restriction E_{lim} =5 kV/m is more reduced since the nominal voltage rise;
- the presence of one or two protection conductors for double circuit overhead line affects with few meters the size of the critical zone;
- the influence of tower geometry and the arrangement of phases are showed in figures 3a and 3 b.

Electric field variation in the vicinity of a overhead transmission line was obtained with the computing program PEM described in [5] developed in C ++ which displays a friendly user graphic interface developed in Visual Basic



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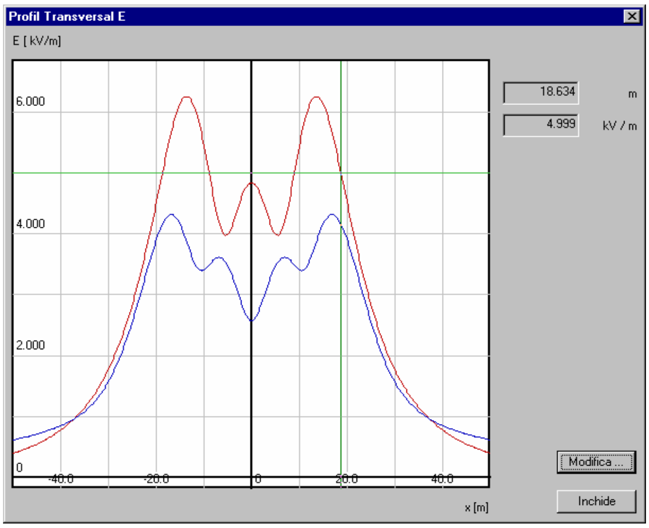
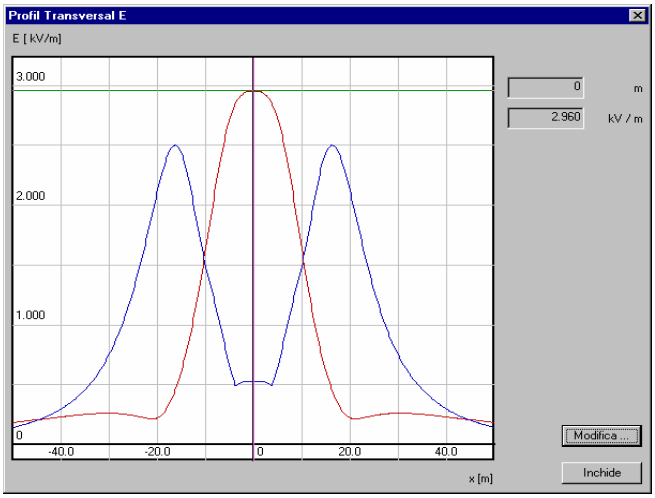


b.

Fig.1 The electric field of a 400 kV different line
a. red -double circuit Donau 2 protection conductor; blue -double circuit 1 protection conductor
b. red -horizontal arrangement 3 cond./phase; blue -delta arrangement 3 cond./phase.



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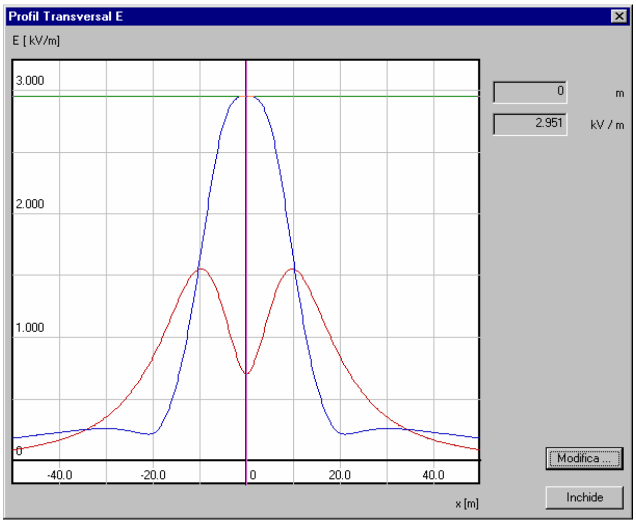

b.

Fig.2 The electric field of overhead transmission line of 220 kV in different configurations
a. red -double circuit hexagon; blue -double circuit flat
b. red -simple circuit; blue -double circuit hexagon.

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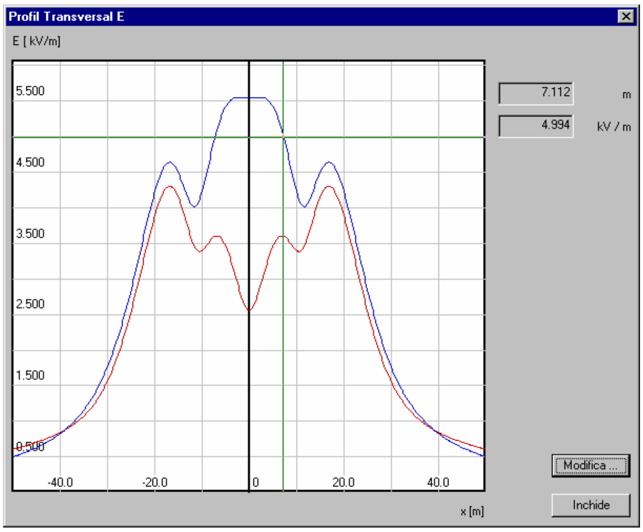
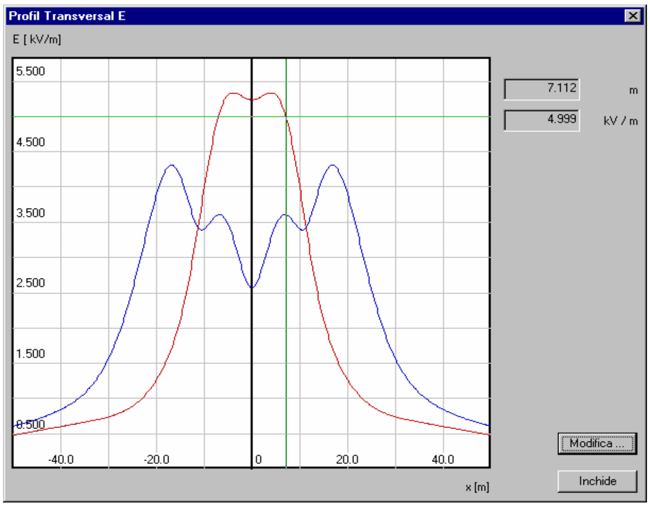


a.



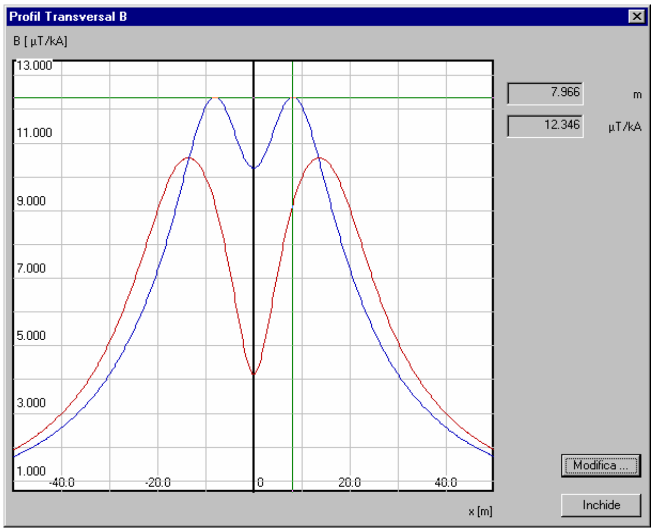
b.

Fig.3 The electric field of overhead transmission line of 400 kV in different configurations with marked critical area:
a. red -phases ABC; blue -phases BCA; b. red -double circuit hexagon 2 cond/phase; blue - double circuit delta arrangement.

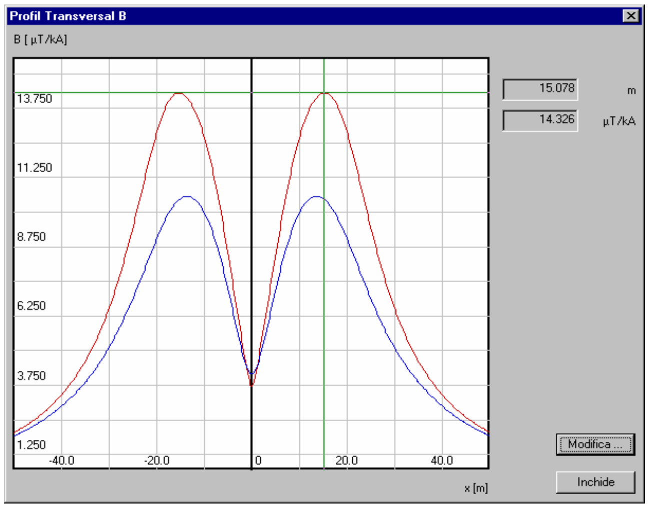
2.2 Magnetic field analyse

2.2.1 The analytical method

Using the program PEM [5], the figures 4 a and b depict the profile of the magnetic field in the case of a 400 kV line for different configurations. To notice that the most important calculated values are in order of 10-30 μT/0.5 kA while the current for a carrying power of 400 MVA has a value about 0.6 kA.



a.



b.

Fig.4 The magnetic field of overhead transmission line of 400 kV in different configurations:
a.red -double circuit hexagon;blue -double circuit Donau; b. red -1protection conductor; blue –2 protection conductor.

2.2.2 The current dipoles method

For the computing the magnetic field the paper used to the method of Kaune and Zaffanella named as “the method of current dipole” [7], which put in evidence analytically the elliptical polarisation of the magnetic field.

Following this method, for a set of conductors shown figure 5 the magnetic flux of density **B** in units of Tesla (T) is:

$$\mathbf{B} = \frac{\mu_0}{2\pi}\sum_{1}^{N} \mathrm{I}_k \frac{\mathbf{u}_z \times (\mathbf{r}-\mathbf{r}_k)}{|\mathbf{r}-\mathbf{r}_k|^2} \qquad (1)$$

where μ_0 is the magnetic permeability of air, I_k is the current intensity of the conductor k, **r** is the position of the considered point, $\mathbf{u}_z$ is the unit vector of the positive current flow.

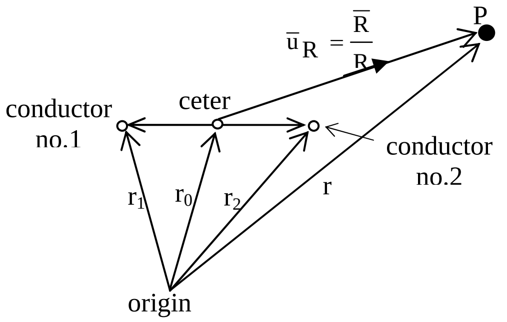


Fig.5a Cross section of power line showing origin location of the conductors in the centre of the line and filed point P

Introducing a new reference origin in plain z=0, at the approximate centre of the system defined by $\mathbf{r}_0$ the equation (1) became:

$$\mathbf{B} = \frac{\mu_0}{2\pi}\sum_{1}^{N} I_k \frac{\mathbf{u}_z \times (\mathbf{R} - \mathbf{d}_k)}{|\mathbf{R} - \mathbf{d}_k|^2} \qquad (2)$$

The factor $\frac{1}{|\mathbf{R} - \mathbf{d}_k|^2}$ from the right side term of (2) could be expanded using the binominal theorem and the equation (2) will be wrote as a sum of some components:

$$\mathbf{B}(R) = \mathbf{B}_1(R) + \mathbf{B}_2(R) + \mathbf{B}_3(R) + \mathbf{B}_4(R) + \ldots, \qquad (3)$$

where:

$$\mathbf{B}_1(R) = \frac{\mu_0}{2\pi R}\sum_{k=1}^{N} I_k (\mathbf{u}_z \times \mathbf{u}_R) \qquad (4)$$

and $\mathbf{B}_2(R)$ $\mathbf{B}_3(R)$,… heaving complicate expressions. For distances R >> distance between conductors and the field point, in the following we considered only the first and the second order terms.

The first order term defined by (4) could be simplified replacing the current phasers sum for the *N* conductors with the net current I_0:

$$\mathbf{B}_1(R) = \frac{\mu_0 I_0}{2\pi R}\mathbf{u}_z \times \mathbf{u}_R \qquad (5)$$

which mean that the first order term of magnetic field is equal with the magnetic field produced by a unique current I_0 placed in the centre of the system. Any rotation of $\mathbf{u}_R$ through an angle $\delta\theta$ produces a rotation of $\mathbf{B}_1$ with the same angle and same directions. The phaser $\mathbf{B}_1$ is linearly polarised and the magnitude is:

$$B_1 = \sqrt{\mathbf{B}_1 \cdot \mathbf{B}_1^*} = \frac{\mu_0 |\mathbf{I}_0|}{2\pi R} \qquad (6)$$

The second order term which could be called a dipole term is given by (7):

$$\mathbf{B}_2 = \frac{\mu_0}{2\pi R^2}\left[2(\mathbf{u}_R \cdot \mathbf{M}_2)\mathbf{u}_z \times \mathbf{u}_R - \mathbf{u}_z \times \mathbf{M}_2\right] \qquad (7)$$

where:

$$\mathbf{M}_2 = \sum_{k=1}^{N} I_k \,\mathbf{d}_k \qquad (8)$$

called the moment of the current dipole (fig.5b).

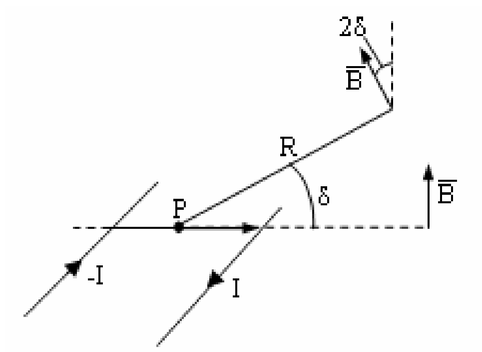


Fig.5b The polarization of the **B**

The direction and module of $\mathbf{M}_2$ are independent of the exact location of the point C, chosen to be the centre of the system of conductors if the net current of the system is zero, $\mathbf{I}_0 = 0$. Any convenient origin can be use:

$$|\mathbf{B}_2| = \sqrt{\mathbf{B}_2 \cdot \mathbf{B}_2^*} = \frac{\mu_0}{2\pi R}\sqrt{\mathbf{M}_2 \cdot \mathbf{M}_2^*} \qquad (9)$$

In this way, the total magnetic field $\mathbf{B}_2$ from a *N* conductors system could be calculate as a sum of the *N* elementary dipoles by introducing of *N* fictitious conductors, all placed in the centre of the conductor system and carrying currents $-I_1$, $-I_2$, $-\underline{I}_3$,.... The sum of these currents is zero and will not change the magnetic field. Since these dipoles had different phases and directions, $\mathbf{B}_2$ will be, in general, elliptically polarized.

The figures 6a and 6b and figure 7 shows the density of magnetic field distribution for an overhead transmission lines (400 kV and 220 kV) from

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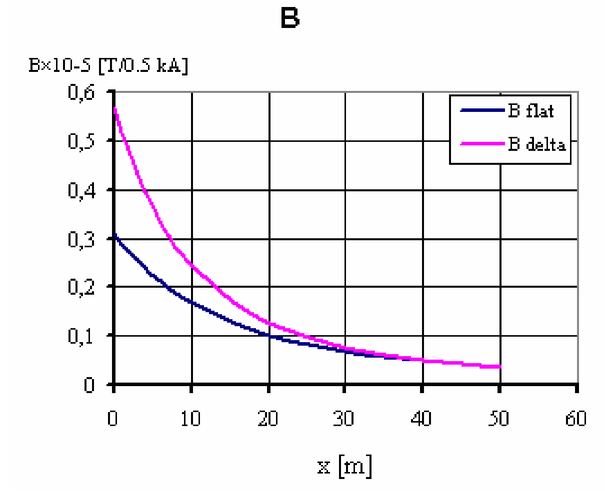
Romania in flat and delta configurations by using this method.

a



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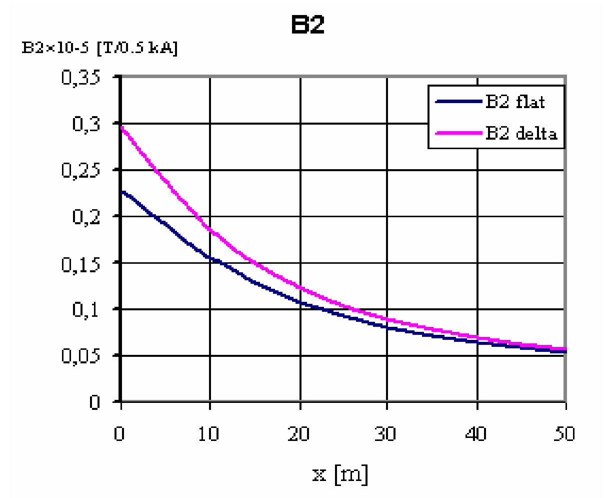


Fig.6 The magnetic induction distribution for some configurations of a 400 kV overhead transmission line:

a- magnetic induction **B** = **B**$_1$ +**B**$_2$;

b - magnetic induction **B**$_2$

Some remarks can be done:

- in figure 6a is presented the magnetic field distribution considering only the first two terms of equation (3) and (7) for a overhead electric line of 400 kV;
- the **B**$_2$ component have values in the same unit order as **B**$_1$ marking the importance of **B**$_2$;

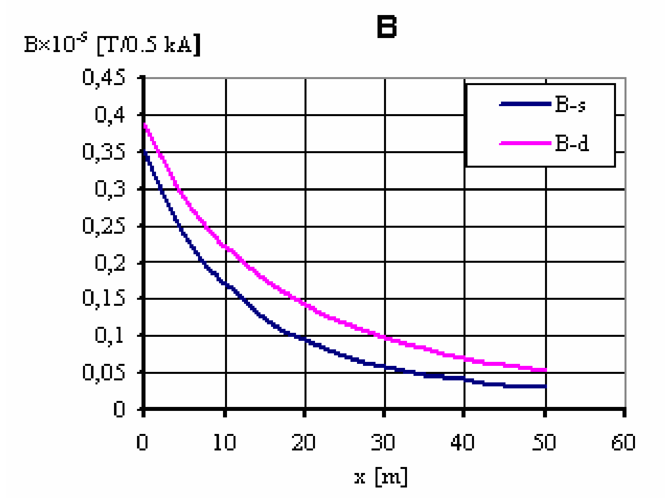


Fig.7 The magnetic induction distribution **B= B$_1$ +B$_2$** for different configurations of a overhead transmission line at 220 kV simple and double circuit

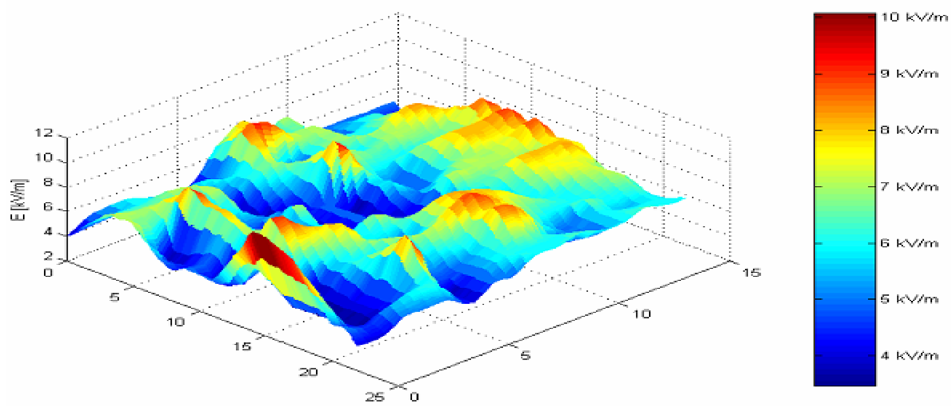
- the calculated values are much lower as the recommended value.

The figure 7 presents the magnetic induction distribution generated by an overhead transmission line in a flat configuration for simple and double circuit at 220 kV, considering only the first two terms from equation (3). The resultant values are much smaller then the values for 400 kV.

3 The electric and magnetic field in substations

In a HV substation the distribution of the electric field presents exceeds in some areas the limit value. A suggestive representation of the electric field that was measured under the bus-bar of a substation and the critical zones using a colour guide are depicted in figure 8. On the access ways appear values between 5 and 10 kV/m.

Fig.8 The electric field distribution measured under the bus-bar of a 400 kV substation



Figures 9 and 10 depict the distribution of the electric and magnetic fields as iso-fields curves with all the values marked.

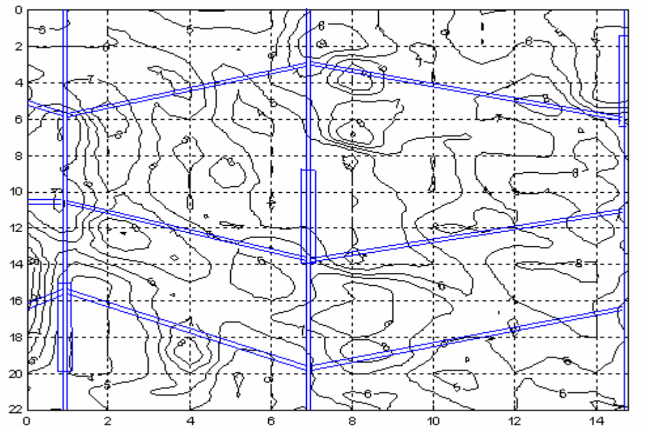


Fig.9 The iso-line electric field under the bus-bar of a 400 kVsubstation at h=1,8m

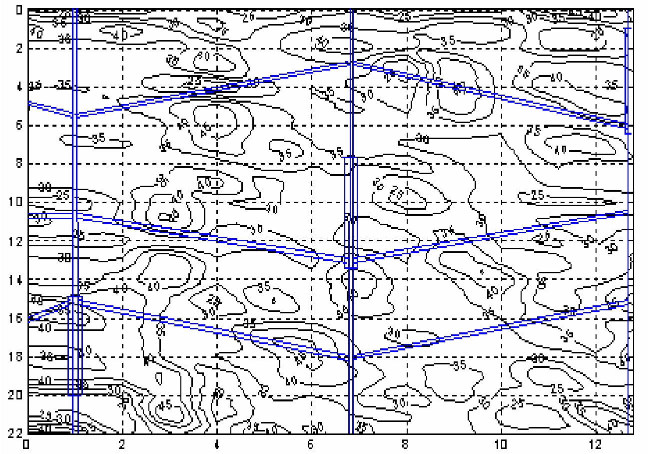


Fig.10 Magnetic iso-field lines correspond with the area from figure 8 and figure 9 at h=1 m

4 Conclusions

The well-known values of the **E** and **B** is quite important in order to evaluate the impact on the environment by establish of the critical areas where the recommend values are exceeded. Is necessary to take in to account the physical phenomenon that generates the fields with an elliptical polarization of the vector **B**. This implies higher values comparative with those obtained by classical methods.

- The elliptical variation of a magnetic field is characterized by the values of a semi- major and a semi-minor axes. The semi-major axis is often called maximal field because is equal with the maxim value which can be read with a single-axis field meter.

- **B** will be linearly polarized if and only if the components of the real and imaginary component of $\mathbf{M_2}$ are the same direction for elementary moments. $\mathbf{M_2}$ and $\mathbf{B_2}$ will be linearly polarized if and only if the line's conductors all lie in the same plan (flat configuration).

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