Electromagnetic environment of the overhead transmission lines in low and high frequency

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Abstract: - The high voltage overhead power lines produce around them electric and magnetic fields of low and high frequency, induced currents and potentials, directly or by electromagnetic coupling, generating in this way some electromagnetic environment disturbances All these are included in the category of pollution sources. This paper presents some aspects of the electromagnetic disturbances due to transmission lines with impact on the environment: electromagnetic field of 50 Hz around the power electric lines of different voltage and configurations, as well as the electromagnetic disturbances oscillating with a frequency ranging from 0,15MHz to30 MHz annoying the communications, produces directly or by coupling phenomena with the structures or other electric lines existing in the vicinity. The values of such disturbances are necessary to point out when the field exceeds the limit values in terms of the European limits recommendations. The numerical algorithm was developed to obtain a quick assessment of the disturbances that can be considered as operating parameters.

Keywords: - environment, electric field, magnetic field, critical zones, overhead transmission lines, coupling

1.Introduction

The electromagnetic disturbances generated by high voltage overhead transmission lines represent an aspect of electromagnetic compatibility, but these can be included in the category of electromagnetic pollution sources. Thus, this is dedicated to point out the following disturbances due to transmission lines:

- Disturbances at low frequency (50 Hz), electric and magnetic fields, induced voltages in the installations in close proximity of the transmission lines, installations that can be touched by the operating staff members.
- Disturbances at high frequency under the form of electromagnetic fields oscillating with a frequency ranging from 0.15 to 30 MHz which annoy the radio communications.

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

The limit values (*basic 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 basic concordance restrictions) for electric and magnetic field in 0÷10 kHz domain are the following [1, 2]:

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

The reference values are established by the access category (table 1).

Table 1

Access	f	Electric field [V/m]	Magnetic field [μT]
professional	0.025…0.82 kHz	500/f	25/f
	0.065…1 MHz	610	2.0/f
public	0.025…0.82 kHz	250/f	5/f
	0.15…1MHz	87	0.92/f

A complex computational method for the quick assessment of the electromagnetic pollution was performed, using a database comprising various data about the line route, configuration and design of power lines. The user can choose the transmission line with given parameters of the line configuration in order to investigate its influence upon the electromagnetic impact of the line.

2 The analysis of the electric and magnetic fields of 50 Hz

The power frequency electric and magnetic fields can be evaluated by assuming the power lines to be infinite long and parallel to the ground. At a certain point in space, the magnetic field has components along x-, y- and z-axis, while the electric field has components only along the x- and y- axes. The z-component of the magnetic field can be neglected. The resultant field is a rotating vector that describes an ellipse in space and time.

2.1 Electric field analysis

The distributions of the electrical field for different configurations of power transmission lines of 400 kV and 220 kV are presented in figures 1-3 with the limits recommended by international scientific institutions [1,2].

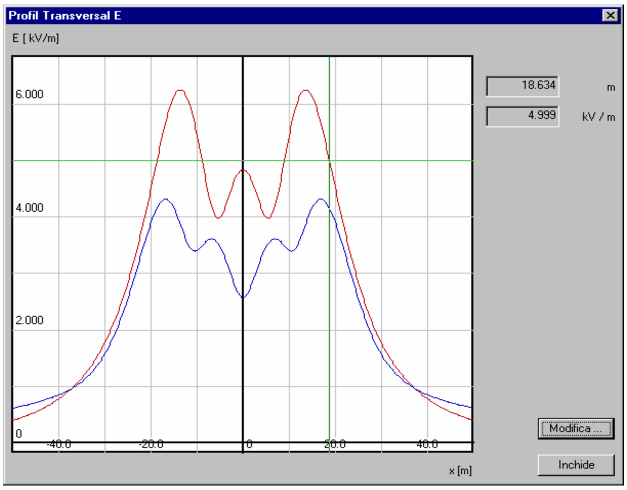

Fig.1 The electric field of a 400 kV line:
red -horizontal arrangement 3 cond./phase; blue -delta arrangement 3 cables./phase

In the figures 1-3, the limit value for the public access (5 kV/m) was exceeded for some transversal profiles of overhead transmission lines of 400 kV.

There are also some additional remarks:

- The critical area delimited by the electric field restriction E_{lim}=5kV/m is significantly reduced when the nominal voltage rises;
- The presence of one or two protection conductors for double circuit overhead line affects with few meters the size of the critical zone.

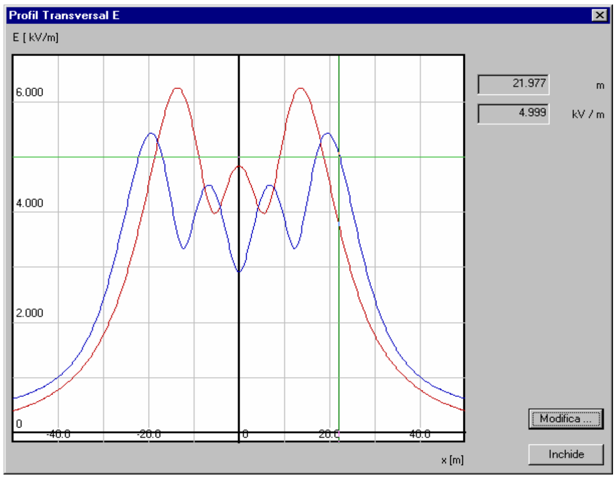

Fig.2 The electric field of a 400 kV line
red -double circuit Donau 2 protection conductor;
blue -double circuit 1 protection conductor

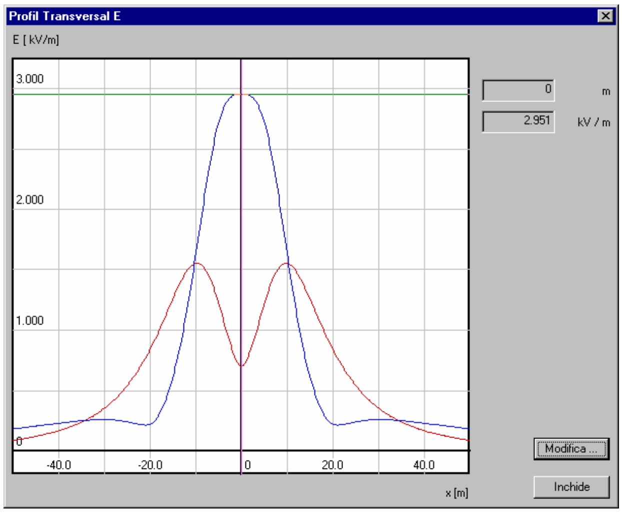

Fig.3 The electric field of a 220 kV transmission line:
red -double circuit hexagon; blue -double circuit flat

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2.2 Magnetic field

Figure 3 depicts the profile of the magnetic field in the case of a 400 kV line for different configurations. One can notice that the most important computed 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.

The basic restriction for magnetic field is 2T.

3. The analysis of high frequency electromagnetic fields

The high and very high voltage power lines are sources of high frequency electromagnetic fields due to the corona discharges.

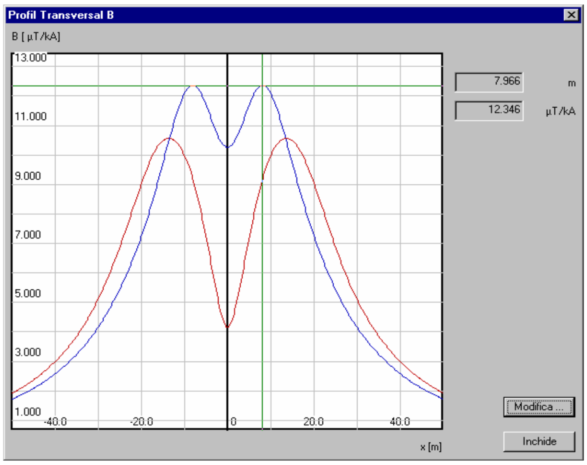

Fig.4 The magnetic field of a 400 kV line: red - double circuit hexagon; blue -double circuit;

The analytical methods use the concept of the excitation function Γ[4,6]. The excitation function comprises the magnitude and the rate of the variation of the space charges that are related to the electric gradient at the conductor's surface.
The relation for Γ is:

$$\Gamma = 50 - 540/E_{max} + 74\log d - 10\log n \qquad (1)$$

for the rumanian conductors, similar with the CIGRE relation:

$$\Gamma = 70 - 585/E_{max} + 35 \log d - 10 \log n \qquad (1.a)$$

where E_{max} is the maximum electric field strength at the conductor's surface, d and n the diameter and the number of sub-conductors in the bundle.
By using the modal analysis and the Γ excitation function, the evaluation of the radio noise generated by an overhead power line is mainly performed by calculating the matrix of modal currents $[m_{ki}]$ coefficients:

$$[m_{ki}] = \frac{1}{2}\left[\frac{1}{\sqrt{\alpha_k}}\right][N]^{-1}\frac{[C]}{2\pi\varepsilon_0}[\Gamma_i] \qquad (2)$$

where α_k represents the attenuation coefficient of propagation mode k, $[N]^{-1}$ is the inverse of the Clark modes matrix, $[C]$ is the matrix of capacitances, and $[\Gamma_i]$ is the diagonal matrix of unitary generation functions.
The matrix of unitary modal currents:

$$[I_{ki}] = [N] \cdot diag(m_{ki}) \qquad (3)$$

The unitary modal field produces by phase k on phase I at distance x from the electric line is:

$$H_{0ki}(x) = 60\sum_{i=1}^{N'} I_{ki}\left[\frac{h_i}{h_i^2 + x^2} + \frac{h_i + 2p}{(h_i + 2p)^2 + x^2}\right] \qquad (4)$$

where p is penetration depth of the magnetic fields in the earth.
The RI field generated by each phase under certain working and meteorological conditions:

$$H_k(x) = 20\log\sqrt{H_{0k1}^{\ 2} + H_{0k2}^{\ 2} + H_{0k3}^{\ 2}} + \Gamma_k \qquad (5)$$

Figure 9 depicts with red line a tranversal profile of a high frequency electric field generated by a 400 kV transmission line for fair weather.

4 The analysis of coupling phenomena between overhead transmission lines

4.1 Problem coupling formulation

Along their routes, high voltage overhead power lines cross over power lines of lower rated voltage which results in an enhancement of the electric field intensity on the conductor surface that may trigger corona discharges on lines that usually do not exhibit this phenomenon or may amplify the high frequency currents.
The influence of the corona discharges due to the increase of the electric field intensity is perceptible up to 1 km distance on each side of the crossing point. This enhancement depends on the crossing angle, as well as, of the voltage levels of the two power lines.

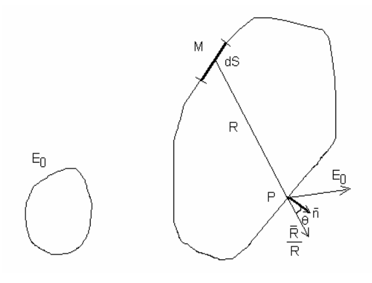

Fig. 5 The electric field source and a body on which appears a charge

If a charged body generates an electrostatic field $\overline{E}_0$ and in the neighborhood of the source a body, initially free of charge is located, on the surface of this one an electrical charge will appear. The charge will vary along its surface.

This charge tends to cancel out the electric field inside the body. The equation, which describes this phenomenon, is:

$$\sigma(P) = \frac{1}{2\cdot\pi}\cdot\int_{S_P}\sigma(M)\cdot\frac{\overline{R}(PM)}{R^3}\cdot\overline{n}'\cdot dS + 2\cdot\varepsilon_0\cdot\left(\overline{E}_0\cdot\overline{n}\right) \quad (6)$$

and the notations corresponds to figure 5.

4.2 Algorithm for evaluating the effect of the intersections of the overhead power lines

In the case of the intersection of two power lines, the integration is performed along a curve on the surface where the induced charge is maximal and the electric field is perpendicular on the surface of the crossed line, respectively. This simplification can be done since the conductor radius is very small in comparison to the distance between the lines.

The computations are based on the principle of the superposition of the effects: the lower voltage line is considered un-energized, thus without electrical charge.

For the source line it is assumed that the charge is located entirely in the middle of the conductor.

Thus, Equation 1 takes the form:

$$\sigma(r) = \frac{1}{2\cdot\pi}\cdot\int_a^b\sigma(r_1)\cdot K(r,r_1)\cdot dr_1 + 2\cdot D_{0n}(r) \quad (7)$$

where: r is the position vector of the calculation point and r_1 is the position vector of the current point,

$$K(r,r_1) = \frac{(\overline{r}-\overline{r}_1)\cdot\overline{n}}{\left|\overline{r}-\overline{r}_1\right|^3} \quad (8)$$

represents the derivative of the Green function along the $\overline{n}'$ direction; $D_{0n}(r)$ is the electric induction at the calculation point.

Equation (7) is a Fredholm equation of second kind which general form is:

$$f(t) = \lambda\cdot\int_a^b K(t,s)f(s)ds + g(t) \quad (9)$$

This equation can be solved numerically by choosing an appropriate approximation of the integral like the Gaussian quadrature rule [6].

The discrete form of the Equation (3) is [7]:

$$f(t_i) = \lambda\sum_{j=1}^{N} w_j K(t_i,s_j)f(s_j) + g(t_i) \quad (10)$$

where: $f(t_i)$ – the value of the unknown function at quadrature abscissas t_i ; g(ti) – the value of the *g(t)* at quadrature abscissa t_i; w_j – the integration weight associated to abscissas t_j; $f(s_j)$ - the value of the unknown function at quadrature abscissas s_j; $K(t_i, s_j)$ – the kernel value at points t_i, s_j; $\tilde{\lambda}$a constant.

Let f_i be $f(t_i)$, g_i the vector $g(t_i)$, and K_{ij} the matrix $K(t_i, s_j)$. It is defined:

$$\tilde{K}_{ij} = K_{ij}w_j \quad (11)$$

By using matrix notations, equation 4 becomes:

$$\left(I-\lambda\tilde{K}\right)\cdot f = g \quad (12)$$

Thus the solving of the integral equation is reduced to a linear system equation with N variables where N represents the number of quadrature nodes.

4.3 Analysis results

The analytical results point out the existence of coupling phenomena between overhead transmission lines of different rated voltage.

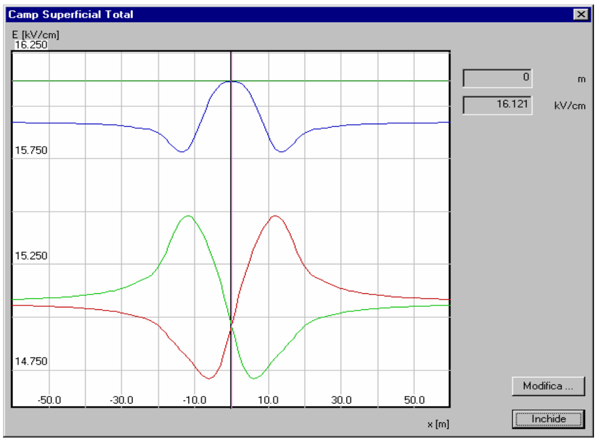

Fig.6 Distribution of surface gradient of a 220 kV line over crossed by an 400 kV line at π/4

Thus, the effect of the coupling induction phenomenon between a 220 kV transmission line crossed over by a 400 kV line calculated with the same program is presented in figure 6. The gradient is increased with about 20 %.

The figure 7 presents the over crossing of two high voltage transmission lines: one of 400 kV and another on 750 kV.

Other remarks with respect to the influence of the crossing angle upon the electric field intensity are the followings:

- The maximal and minimal values of the electric field on each phase decreases slightly with the decrease of the crossing angle and tends to a value corresponding to the parallel running of the two lines;

- The maximal values of the field on the external phases shift towards remote distances, which correspond to the projections of the distances between the higher voltage line phases on the lower voltage line.

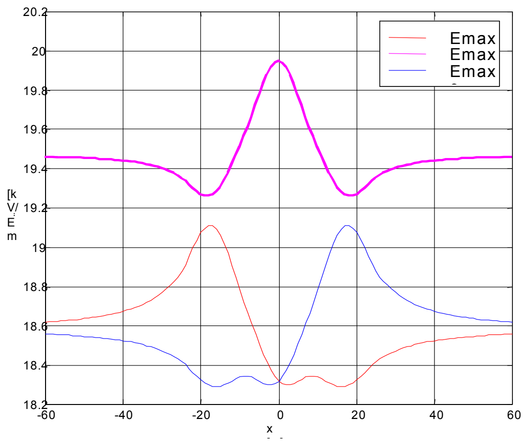

Fig. 7 The electric gradient profile for a crossing of a 400 kV with a 750 kV line at angle π /4

The calculations point out that the length of the over crossed line presents a substantial increase of the electric field does not exceed 50 m on both sides from the external phases of the field source line.

4.4 Effects of the increasing of the conductor gradient upon the environment

A more important coupling effect is pointed out in the case of the two transmission lines: a 400 kV line crossing over a 220 kV line or 750 kV with 400 kV lines.

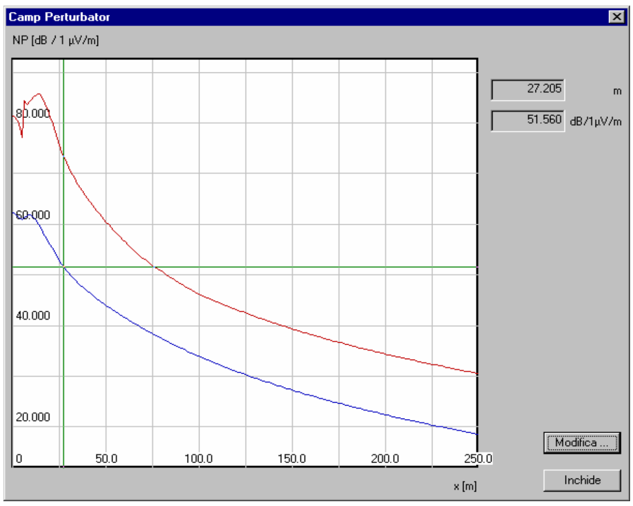

Fig.8 Comparison between the high frequency fields of a 220 kV line: blue– single power line ; red – power line overcrossed by a 400 kV line

The analytical result is given in figures 6 and 7, but the physical result is visible by the appearance of high frequency electric fields around the conductors in the range of radio frequencies appear in figures 8 and 9. The calculation frequency is 0.5 MHz [3].

The variation of the maximal electric field intensity on the surface of the conductors of a 400kV overhead power line crossed over by a 750 kV for a crossing angle of π/4 given in figure 7 leads to an increase of the disturbing field at the same value obtained by rain weather (fig10).

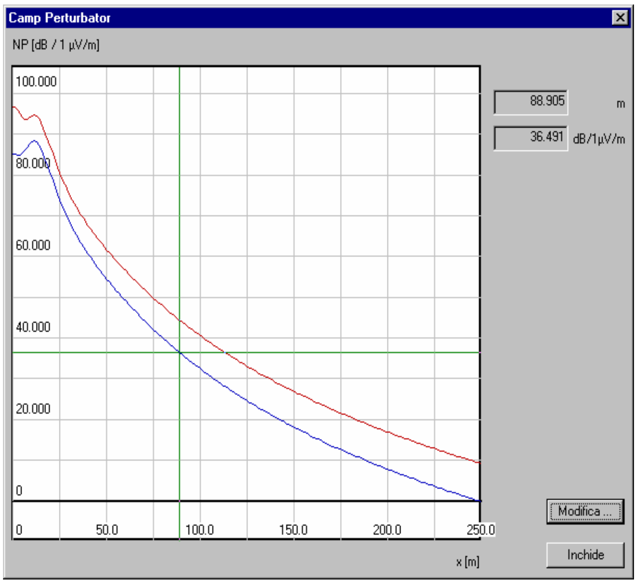

Fig. 9 High frequency field (0.5 MHz) in the case of a 400 kV overhead line crossed over by a 750 kV line compared to the case of a single 400 kV power line.

5 Some experimental results

5. 1 Electric and magnetic field of 50 Hz

Figures 10 depicts the analytical distribution curve, as well as the values of electric field of 50Hz measured in different points around the line in the case of a 110 kV double circuits with one circuit energized.

Figure 11 depicts the analytical distribution curve, as well as the values of magnetic field of 50 Hz measured in different points around a line of 110 kV single circuits with one circuit energized.

The measuring results obtained for the Rumanian overhead transmission lines are in compliance with the analytical results presented above.

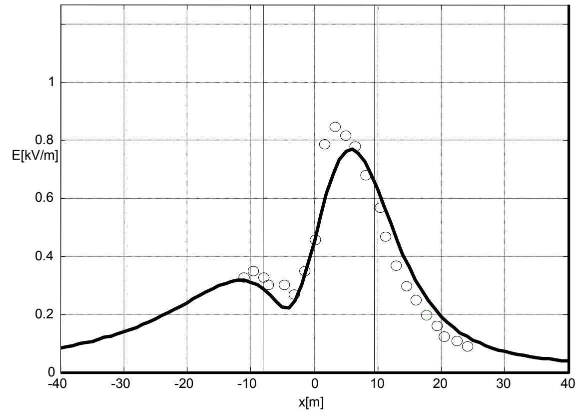

Fig. 10 Electric field of 50 Hz measured around the line in the case of a 110 kV double circuits with one circuit energized.

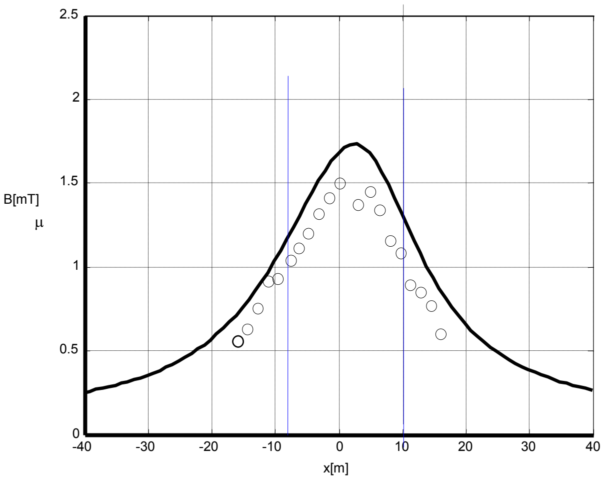

Fig. 11 Magnetic field of 50 Hz measured around the line in the case of a 110 kV single

5.2 High frequency field

The measurements, as well as the analytical evaluations presented in figure 10 show that the consequences – such the high frequency electric field due to this increase are observed on a length of the "victim" line of about 500 m on both sides from the crossing point.

6. Conclusions

The calculations, as well as the measurements, show the consequences in low frequency as well in high frequency that the electric high voltage networks can have upon the environment or they affect the distribution or transmission power lines.

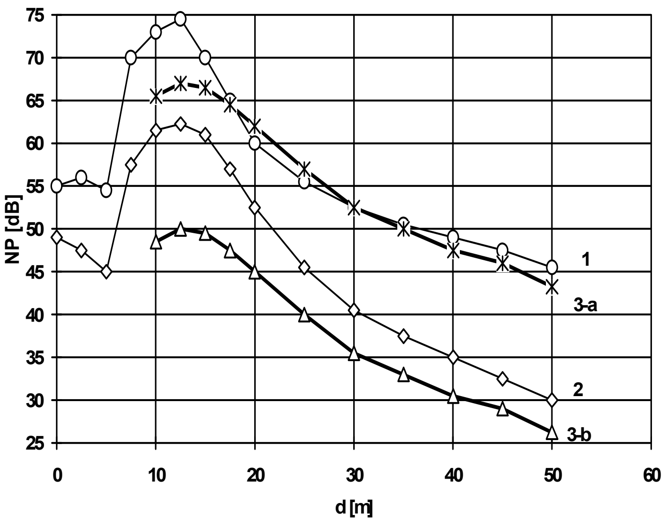

Fig.10 High frequency electric field in dB around a
4 400 kV line (3x450 mm^2 Ol-Al) over crossed by a
7 750 kV line (5x450 mm^2 Ol-Al) [4]:1- in the first
8 span after the over crossing; 2 - in the second span after crossing: 3– in the middle of the span of a 400 kV line: a- fair weather; b – rain weather.

The complex numerical algorithm developed within a scientific project was used for assessing other aspects of electromagnetic impact of the high voltage overhead power lines upon the environment like induced currents ant voltages in pipe-lines or other type of structures, critical zones where the recommended or limits values are exceeded either for 50 Hz or high frequency.

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