BODY INTRUSION OF THE GROUND ELECTRIC FIELD PRODUCED BY OVERHEAD TRANSMISSION LINES

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Problema pătrunderii câmpului electric la sol în corpuri este foarte complicată. Cauzele sunt de natură specifică şi privesc caracteristicile acestui câmp (rotitor, intensitate variabilă, comportament nesinusoidal în raport cu cel al tensiunii, care este sinusoidal).Rezolvarea problemei constă în stabilirea relației ce descrie pătrunderea acestui câmp în corpuri, cu definirea mărimilor care intervin şi a relațiilor pentru acestea. Stabilirea erorilor de principiu de măsurare a intensității câmpului electric la sol, pentru un sistem de măsură, nu este posibilă fără cunoaşterea acestei relații.

Body intrusion of the ground electric field is a much more compliated problem because of the specifie characteristics for this electric field (rotary, variable intensity and non-sinusoidal, following the sinusoidal variation of voltage). Determination of the relation for body intrusion this electric field with definition on analytical expression for the notes of this relation is the solution of the problem in debate. Determination of the principal errors in a specific measurement system for ground electric field is possible if only this relation is a known..

Keywords: Ground electric field, relation of body intrusion.

1. Introduction

The problem of body intrusion of the ground electric field produced by overhead transmission lines (in general) is known and therefore carefully studied [1],[2]. It is considered that this electric field is harmonic. The problem becomes complicated in the case in which it does not retain its harmonic characteristic, and much more complicated when there is no quasi-stationary regime.

The electric field at ground level, emitted by the overhead transmission lines, cannot be associated with a harmonic behavior, as variation in time and space [3]. Consequently, the problem of body intrusion of the electrical field becomes more complicated.

The necessity of addressing of this issue, under upper mentioned conditions, is dictated by the adequate measurement systems problem, so the measurement of its intensity could be done with an error margin kept within an acceptable range. Also, another important aspect is given by the assessment of influence of the ground electric field inside the human body.

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And we are limiting the only to these two aspects, considered to be mainly important for present paper.

2. Ground electric field

2.1. Definitions and mathematical relations

The electric field produced by the overhead transmission lines (OTL) in the immediate surrounding space represents a pollution factor, being included in the assembly of electromagnetic states which represent a pollution of this kind. This issue was address by electromagnetic compatibility study with surrounding environment EEMC (Environmental Electromagnetic Compatibility). In order to reach this stage of the study, is necessary to achieve a level of understanding of general characteristics of it starting from a definition performed in the general constructive context of an OTL. On the basis of this data is established an analytical algorithm and then is created a measurement system which is needed to be as accurate as possible.

Given a plane which is perpendicular to the OTL axis, and a point with coordinates *x* and *y*; *x* represents the distance to the OTL axis and *y* represents the height with respect to the ground. Due to practical calculation reasons, the height with respect to the ground is considered to be y = 0 m (ground level electrical field), or y = 1.8 m (ground level electric field –definition conditions). It is considered that this is the height at which the influence of electrical field emitted by the OTL has a major impact upon the human body.

The particularities of the geometry of the OTL is very interesting (as location) at the points situated at the middle of the mid-span and at the maximum value of the sag. In these particular locations, the intensity of electric field value is maximal, so it will show the presence of major polluting influences if is to be considered the one situated at 1.8 m and not the one at ground level.

These two conditions are embedded in the definition of ground level electrical field. The algorithm of ground level electrical field calculation for an overhead electrical line, as it is known from current literature, determine the electrical charge at the conductor surface (in complex expression) and then, by means of a vectorial-phasorial method the projections onto coordinate axes of the electric field vector produced by the OTL are obtained:

$$\overline{E_x}(x,y|y=1{,}8m) = 18\sum_{i=1}^{n_{phases}} F_i(x,y|y=1{,}8m)\overline{Q_i} \text{ ,[kV/m]} \quad (1)$$

$$\overline{E_y}(x,y|y=1{,}8m) = 18\sum_{i=1}^{n_{phases}} G_i(x,y|y=1{,}8m)\overline{Q_i} \text{ ,[kV/m]} \quad (2)$$

and as general expressions [3]:

$$\overline{E_x}(x,y|y=1{,}8m)=a(x,y)+jb(x,y)\text{ ,[kV/m]} \quad (3)$$

$$\overline{E_y}(x,y|y=1{,}8m)=c(x,y)+jd(x,y)\text{ ,[kV/m]} \quad (4)$$

where:

- $F_i(x,y|y=1{,}8m)$ and $G_i(x,y|y=1{,}8m)$ are spatial functions which define ground electric field in one point of space $M(x,y|y=1{,}8m)$, by its projections onto rectangular axes;
- $\overline{Q_i}$ is electric charge (expressed in complex) at the surface of the conductors which compose *i*-th phase, in μC/m.

Of a special interest are the expressions of the ground level electrical field projections onto rectangular axes, as its time variation, which means:

$$E_x(x,y|y=1{,}8m,t)=a(x,y|y=1{,}8m)\cos\omega t+b(x,y|y=1{,}8m)\sin\omega t\text{ ,[kV/m]} \quad (5)$$

$$E_y(x,y|y=1{,}8m,t)=c(x,y|y=1{,}8m)\cos\omega t+d(x,y|y=1{,}8m)\sin\omega t\text{ ,[kV/m]} \quad (6)$$

and the expression of the ground level electrical field is:

$$E_x(x,y|y=1{,}8m,t)=\sqrt{E_x^2(x,y|y=1{,}8m)+E_y^2(x,y|y=1{,}8m)}\text{ ,[kV/m]} \quad (7)$$

2.2. General characteristics of ground electric field

In special literature are available the general characteristics of ground electric field, which are very important for addressing upper mentioned problem [3], [4], [5], [6]. The main ones could be synthesized in sequel:

- it is considered that the intensity of ground electric field is variable and non-sinusoidal, following the sinusoidal variation of voltage;
- direction and sense of electric field vector, due to the fact that it is a rotary field, are not constant (in a semi-period have of one direction and in other semi-period have opposite direction). The direction of the vector is variable non-synchronic, which means that it shows a time-variable phase difference with respect to the rotary synchronic axis obviously variable synchronic with respect to the time;
- the aspect of polarization of which is responding an arbitrary field (i.e. ground level electric field) is important for its two defining components (E_{max}/E_{min} and the direction of the large axis of the time-

dependant evolution ellipse), shows an important variation according with the point of definition of the ground electric field. A strictly vertical polarization in characteristic for only one point in space.

2.3. Observations regarding the relationship between electric field that surrounds the bodies and ground electric field in which the bodies are immersed

For an arbitrary direction of ground level electrical field vector, the electrical field vector external to a surface Σ has a certain intensity, direction and direction, which depend on the shape of this surface. When its direction corresponds to the direction of the normal vector $\vec{n}$ on the surface, in the points which fulfill this condition and are situated on this surface, the intensity of exterior electrical field is maximal. This could be named *pole* electric field. It could be established a relationship between ground electric field and pole electric field, by performing experiments in uniform electric field. It is obvious that the relationship will depend on the shape of Σ surface. This is of a great importance for the establishment of the base-principle of the ground electric field measurement, by using an array of tools (spherical dipole, parallelepiped-shaped dipole, parallel planes and so on).

This question is also very important, emerging from the characteristics of the ground electric field and especially from the time-dependant non-harmonic evolution of the voltage. Therefore is absolutely necessary to be established the specific relation, which describes the phenomena of body intrusion of the ground electric field.

3. Relation between ground electric field and bodies. Body intrusion phenomena

By expanding the discussion towards the case of material bodies placed in harmonic electrical field, when these bodies are situated into ground level electrical field produced by the overhead aerial lines E_{ground} the conductivity and the permeability of the material show some particularities which require an explanation beyond the association within a single measure; the complex electrical conductivity, as it is used in harmonic.

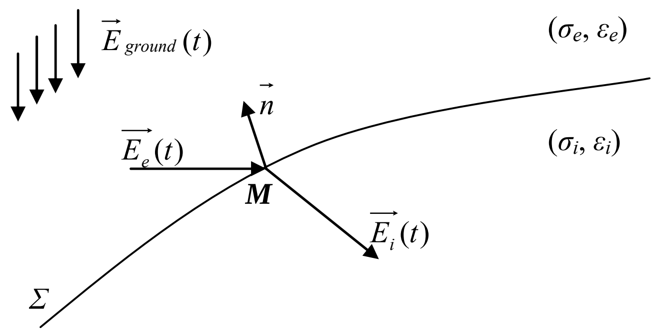

Fig. 1 Electric field at passing through a separation surface situated between two environments

where:

$\vec{E}_{ground}(t)$ - ground electricfield vector;

σ_e- air conductivity (exterior, linear and isotropic environment);

ε_e- air permittivity;

σ_i- conductivity of the body material (interior, linear and isotropic environment);

ε_i- permittivity of the body material;

$\vec{n}$ - normal (unity) vector onto separation surface Σ ;

$\vec{E_e}(t)$ -exterior electrical field vector of the body immersed in local electrical field

$\vec{E_i}(t)$ - electric field vector inside the body.

According with the issues presented in the Fig. 1, the conditions of passing through Σ surface can be formulated. It was observed that the intensities of the two electric fields $\vec{E_e}(t)$ and $\vec{E_i}(t)$ respectively, are variable with respect to the time, being produced by the ground electric field which has variable intensity with respect to the time (rotary and elliptic electric field).

The local form of electric flux, defined by the separating surface Σ has the expression:

$$div_\Sigma \vec{D} = \rho_\Sigma \tag{8}$$

$$\vec{n}\vec{D_e} - \vec{n}\vec{D_i} = \rho_\Sigma \tag{9}$$

where:

$\vec{D}$ - electrical induction vector;

ρ_Σ - superficial density of electric charge on the separation surface Σ.

By using the law which defines the relation between electrical induction ($\vec{D}$) and electric field intensity ($\vec{E}$), it emerges the following relation (see relation 10) in the case of ground electric field in presence of a surface Σ (see Fig. 1).

$$\vec{n}\left[\varepsilon_e \overrightarrow{E_e}(t)\right] - \vec{n}\left[\varepsilon_i \overrightarrow{E_i}(t)\right] = \rho_\Sigma(t) \tag{10}$$

By derivation with respect to the time, the following relation is obtained:

$$\vec{n}\varepsilon_e \frac{d}{dt}\left[\overrightarrow{E_e}(t)\right] - \vec{n}\varepsilon_i \frac{d}{dt}\left[\overrightarrow{E_i}(t)\right] = \frac{d}{dt}\left[\rho_\Sigma(t)\right] \tag{11}$$

The passing condition of the electric conduction density current vector ($\vec{J}$) through the separation surface Σ, in this case, from $\overrightarrow{J_e}$ to $\overrightarrow{J_i}$, as a consequence of electric charge conservation law, can be written as:

$$\vec{n}\overrightarrow{J_e}(t) - \vec{n}\overrightarrow{J_i}(t) = -\frac{d}{dt}\left[\rho_\Sigma(t)\right] \tag{12}$$

By referring to electrical induction law, $\vec{J} = \sigma\vec{E}$, valide for the two environments, the relation (12) becomes:

$$\vec{n}\sigma_e \overrightarrow{E_e}(t) - \vec{n}\sigma_i \overrightarrow{E_i}(t) = -\frac{d}{dt}\left[\rho_\Sigma(t)\right] \tag{13}$$

By summing up the relations (12) and (13), the following relation is obtained:

$$\vec{n}\left\{\sigma_e \overrightarrow{E_e}(t) + \varepsilon_e \frac{d}{dt}\left[\overrightarrow{E_e}(t)\right]\right\} - \vec{n}\left\{\sigma_i \overrightarrow{E_i}(t) + \varepsilon_i \frac{d}{dt}\left[\overrightarrow{E_i}(t)\right]\right\} = 0 \tag{14}$$

This relation defines the basis of the phenomena of body intrusion of the ground electric field produced by the OTL.

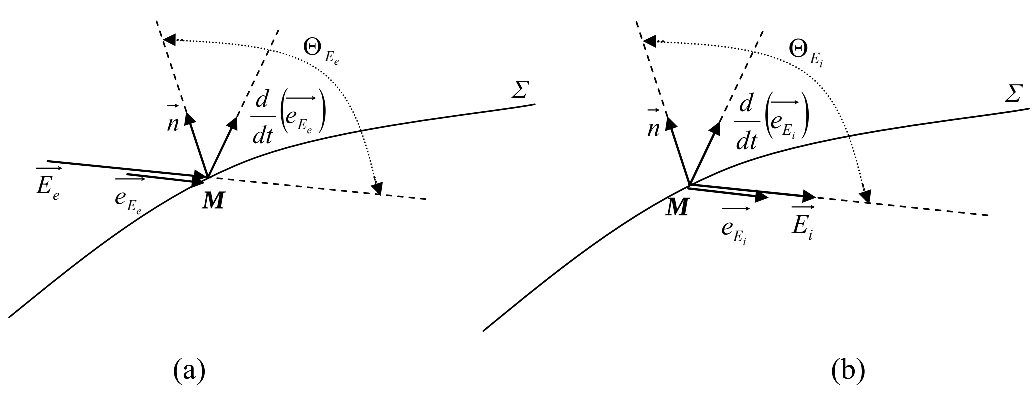

Fig. 2 Outside electric field vector (a) and inside electric field vector (b)

It was considered the point ***M*** of the surface *Σ* as being the point of ground level electrical field intrusion. For an arbitrary time moment *t* and with respect to the expressions of the electrical field vector in the two environments separated by the *Σ* surface, that are:

$$\overrightarrow{E_e}(t) = E_e(t)\overrightarrow{e_{E_e}}(t) \tag{15}$$

$$\overrightarrow{E_i}(t) = E_i(t)\overrightarrow{e_{E_i}}(t) \tag{16}$$

and the two time-dependant evolution versors of the two electrical field vectors, $\overrightarrow{e_{E_e}}(t)$ and $\overrightarrow{e_{E_i}}(t)$ respectively, the relation (14) becomes:

$$\vec{n}\left\{\sigma_e\overrightarrow{E_e}(t)+\varepsilon_e\frac{d}{dt}\left[\overrightarrow{E_e}(t)\right]\right\}=\sigma_e\left(\vec{n}\overrightarrow{E_e}(t)\right)+\varepsilon_e\frac{d}{dt}\left(E_e(t)\right)\left(\vec{n}\overrightarrow{e_{E_e}}(t)\right)+\left(\varepsilon_e E_e(t)\right)\left(\vec{n}\frac{d}{dt}\left(\overrightarrow{e_{E_e}}(t)\right)\right) \tag{17}$$

but:

$$\vec{n}\overrightarrow{E_e}(t) = E_e(t)\cos\Theta_{E_e}(t) \tag{18}$$

$$\vec{n}\overrightarrow{e_{E_e}}(t) = \cos\Theta_{E_e}(t) \tag{19}$$

$$\vec{n}\frac{d}{dt}\left(\overrightarrow{e_{E_e}}(t)\right) = \pm\sin\Theta_{E_e}(t) \tag{20}$$

replacing into equation (17), it was obtained:

$$\begin{aligned}&\vec{n}\left\{\sigma_e\overrightarrow{E_e}(t)+\varepsilon_e\frac{d}{dt}\left[\overrightarrow{E_e}(t)\right]\right\}=\sigma_e E_e(t)\cos\Theta_{E_e}(t)+\\&\varepsilon_e\cos\Theta_{E_e}(t)\frac{d}{dt}\left(E_e(t)\right)\pm\varepsilon_e E_e(t)\sin\Theta_{E_e}(t)\end{aligned} \tag{21}$$

$$\vec{n}\left\{\sigma_i\overrightarrow{E_i}(t)+\varepsilon_i\frac{d}{dt}\left[\overrightarrow{E_i}(t)\right]\right\}=\sigma_i\left(\vec{n}\overrightarrow{E_i}(t)\right)+\varepsilon_i\frac{d}{dt}\left(\overrightarrow{E_i}(t)\right)\left(\vec{n}\overrightarrow{e_{E_i}}(t)\right)+\left(\varepsilon_i E_i(t)\right)\left(\vec{n}\frac{d}{dt}\left(\overrightarrow{e_{E_i}}(t)\right)\right) \tag{22}$$

but:

$$\vec{n}\overrightarrow{E_i}(t) = E_i(t)\cos\Theta_{E_i}(t) \tag{23}$$

$$\vec{n}\overrightarrow{e_{E_i}}(t) = \cos\Theta_{E_i}(t) \tag{24}$$

$$\vec{n}\frac{d}{dt}\left(\overrightarrow{e_{E_i}}(t)\right) = \pm\sin\Theta_{E_i}(t) \tag{25}$$

replacing into equation (22), it was obtained:

$$\begin{gathered}\vec{n}\left\{\sigma_i\overrightarrow{E_i}(t) + \varepsilon_i\frac{d}{dt}\left[\overrightarrow{E_i}(t)\right]\right\} = \sigma_i\overrightarrow{E_i}(t)\cos\Theta_{E_i}(t) + \\ \varepsilon_i\cos\Theta_{E_i}(t)\frac{d}{dt}\left(E_i(t)\right) \pm \varepsilon_i E_i(t)\sin\Theta_{E_i}(t)\end{gathered} \tag{26}$$

By replacing the equation (14) and grouping the terms, it was obtained:

$$\begin{gathered}\left[E_e(t)\left(\sigma_e\cos\Theta_{E_e}(t) \pm \varepsilon_e\cos\Theta_{E_e}(t)\right) + \left(\alpha_{dE_e}(t)\varepsilon_e\cos\Theta_{E_e}(t)\right)\right] - \\ \left[E_i(t)\left(\sigma_i\cos\Theta_{E_i}(t) \pm \varepsilon_i\cos\Theta_{E_i}(t)\right) + \left(\alpha_{dE_i}(t)\varepsilon_i\cos\Theta_{E_i}(t)\right)\right] = 0\end{gathered} \tag{27}$$

with following explanations:

$$\frac{d}{dt}(E_e(t)) = \frac{E_{e,n}\dfrac{\partial E_{e,n}}{\partial t} + E_{e\perp n}\dfrac{\partial E_{e\perp n}}{\partial t}}{E_{e,n}^2 + E_{e\perp n}^2}E_e(t) \tag{28}$$

or

$$\frac{d}{dt}\left[E_e(t)\right] = \alpha_{dE_e}(t)E_{e(t)} \tag{29}$$

and, respectively,

$$\frac{d}{dt}(E_i(t)) = \frac{E_{i,n}\dfrac{\partial E_{i,n}}{\partial t} + E_{i\perp n}\dfrac{\partial E_{i\perp n}}{\partial t}}{E_{i,n}^2 + E_{i\perp n}^2}E_i(t) \tag{30}$$

or

$$\frac{d}{dt}\left[E_i(t)\right] = \alpha_{dE_i}(t)E_{i(t)} \tag{31}$$

The quotations $E_{e,n}$, $E_{e\perp n}$, $E_{i,n}$ and $E_{i\perp n}$ are defined in Fig. 3 .

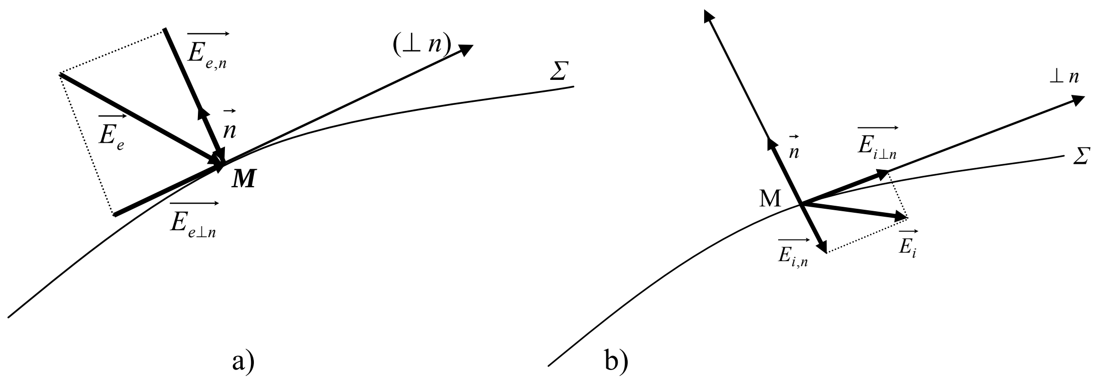

Fig. 3 Projection onto rectangular axes of the outside field vector (a) and inside field vector (b) defined by the separating surface *Σ*

$$E_e = \sqrt{E_{e,n}^2 + E_{e\perp n}^2} \tag{32}$$

$$E_i = \sqrt{E_{i,n}^2 + E_{i\perp n}^2} \tag{33}$$

with following notations:

$$\left(\sigma_e \cos\Theta_{E_e}(t) \pm \varepsilon_e \sin\Theta_{E_e}(t)\right) + \left(\alpha d_{E_e}(t)\varepsilon_e \cos\Theta_{E_e}(t)\right) = \sigma_e^{equiv}(t) \tag{34}$$

$$\left(\sigma_i \cos\Theta_{E_i}(t) \pm \varepsilon_i \sin\Theta_{E_i}(t)\right) + \left(\alpha d_{E_i}(t)\varepsilon_i \cos\Theta_{E_i}(t)\right) = \sigma_i^{equiv}(t) \tag{35}$$

relation (27) becomes:

$$E_e(t)\sigma_e^{equiv} - E_i(t)\sigma_i^{equiv} = 0 \tag{36}$$

This relation represents the passing condition of current density, as time-dependant variation with respect to the time-variation of ground level electrical field, as intensity and direction. The relation (36) was determined for an arbitrary point, defined in space by its coordinates with respect to the chosen axis.

Accordingly with upper explanations regarding electrical field emitted by the overhead electrical lines, the relation (34) can be materialized as follows:

$$E_e(x, y|y = 1{,}8m, t)\sigma_e^{equiv}(x, y|y = 1{,}8m, t) - E_i(x, y|y = 1{,}8m, t)\sigma_i^{equiv}(x, y|y = 1{,}8m, t) = 0 \quad (37)$$

4. Conclusions

In the available literature [6],[7], the relation that establish the phenomena of body intrusion of electrical field, being considered harmonic, is:

$$\vec{n}(\underline{\sigma_e}\,\underline{E_e}) - \vec{n}(\underline{\sigma_i}\,\underline{Ei}) = 0 \quad (38)$$

The two electrical fields, E_e (exterior) and E_i (interior), being harmonic measures, are expressed by their phasors.

Also, the dimensions σ_e and σ_i, defined as electrical conductivities of the two environments, are expressed in complex, that is $\underline{\sigma_e} = \sigma_e + j\omega\varepsilon_e$ and respectively, $\underline{\sigma_i} = \sigma_i + j\omega\varepsilon_i$.

In reality, ground electric field and, by consequence, the two fields (E_e, E_i) must be associated with a harmonic behavior; an application for the relation (38) in the domain of the influence of the electric field and adequate measurement system for the intensity is inadequate and the error in this situation is similar.

Relation (35) keeps a similar appearance with (38), having similar composing elements. The dynamic character of ground electric field (rotary) imposes another observation, in the way of consideration a time-dependant variation within the concept of defining the concepts of electrical conductivity (see (34), (35)).

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