CASE STUDY: A COMPARATIVE ANALYSIS OF THE ELECTRIC FIELD NEAR LOW FREQUENCY ELECTRIC LINES

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REZUMAT. Aceasta lucrarea analizeaza monitorizarea si diagnosticarea cu ajutorul campului electric pentru o linie electrica de joasa frecventa, in diferite regimuri de functionare (normal sau de defect) cu ajutorul a trei metode diferite: prima presupune modelarea utilizand programul EMTP, iar a doua si a treia metoda presupun determinari directe in situ a campului electric. A doua metoda se bazeaza pe masurarea directa a campului electric cu un dispozitiv patentat de autori. Ultima metoda utilizeaza un dispozitiv special (METRAHIT) pentru masurarea directa a campului electric. Rezultatele obtinute sunt comparate.
Cuvinte cheie: EMTP (ElectroMagnetic Transients Program), EMC (Electromagnetic Compatibility), METRAHIT.

ABSTRACT. This paper analyzes the monitoring and diagnosing using the electric field for one low frequency line, for different operating status (normal and short circuit) using three different methods: the first one is modeling using EMTP program and the second and third methods are for directing measuring in situ of the electrical field.The second method is based on a device patented by the author. The last one uses dedicating tool (METRAHIT).The obtained results are comparing.
Keywords:EMTP (ElectroMagnetic Transients Program), EMC (Electromagnetic Compatibility),METRAHIT

1. INTRODUCTION

In the last years, two directions with more numerous applications in electrical engineering, namely electromagnetic compatibility, monitoring and diagnosis of the systems and electrical equipments have highlighted. According to the definition given by the 77-th Committee of IEC, the electromagnetic compatibility (EMC) represents the ability of electronic apparatus, equipment or system to operate in proximity of electromechanical devices, without causing or suffering unacceptable degradation in output or performance. Also, an important and recently topic has express concerns about the effects of the human exposure to the electromagnetic field produced by any type of the power equipment. There are many studies done on this topic, some in high frequency fields, in case of medium voltage broadband power line systems [1], or in case of radio-frequency who can interfere with electromagnetic fields [2]. Regarding these issues it is very important to study major problems [3], [4] like:

-To estimate, by calculation and measurements, the strength of the electric field.

-To emphasize its effects, generally, on living bodies and, especially, on humans [5].

The first one is an electrical question; the second one is starting to be a biological one [6]. In the literature, there are many studies on the same theme and, given these issues, at CIGRE sessions, one of the favorite subjects has been dedicated to the mechanism of the living body's exposure to electric and magnetic fields and the influence of the power equipment design on the level of their accompanying field.

For a correct diagnosis of electrical equipment or electrical installation, it needs a proper monitoring. One of the most important parameters of monitoring it is represented by the electromagnetic field [7], but using the modeling and simulation of the electromagnetic field can be obtain important information about the status of equipment/installation.

The modeling and simulation of the electric field can be done with the procedures already used on the large scale in EMC. The originality of this paper represents the comparation between the results obtained through modeling and simulation in EMTP [8] for one low frequency line and comparing with the results obtained from directly measurement. The advantage is the simulation of electrical cause for finding the different effects and comparing. It is possible to made simulations in the permanent regimes, transient regimes or forced regimes (in case of presence of non linear circuit elements). The non symmetric voltage regimes are referring to the situation when one or two phases conductor are interrupted, or the voltage is present on all the three phases, but the voltage system is non symmetrical.

The main purpose of this paper is to highlight the possibility of using the electromagnetic map -the information contained in the electric and magnetic field generated by each electrical equipment and device of electrical equipment, in the process of monitoring, diagnosing, controlling and commanding them: in our case study is one low voltage line with low frequency.

Also, by the achievement of advanced software and hardware structure can be realized intelligent devices, important components in the structure of the electric power systems including both transportation and distribution systems.

The electromagnetic field is generated by the electrical equipment and installation, which can lead to a different kind of perturbations in the equipment functioning or can cause the malfunctioning of the equipment and devices nearby (over voltage, over currents, excessive heating of high voltage power line conductors).

Taking into account the facts mentioned above in this paper, we focus on the developing the modern monitoring and diagnose techniques. Using information contained in the electromagnetic radiation field for electrical equipment and devices it can give us information about of different phases that equipment and devices are facing while on service.

2. Modeling of the electric field near low frequency electric lines

Theoretical aspects:

At any point, M of space, the electric field represents the applied force on the unit of the electric charge, placed in this point:

$$\overline{F}(M) = q\overline{E}(M) \qquad (1)$$

Where $\overline{F}$ is the force, q is the electric charge and $\overline{E}$ is the electric field strength.

Except the classical methods, which exclusively are applicable for one system with simple geometry, the electrical fields and potentials can be computed using the following methods: analytical, numerical, Monte Carlo, reduced models.

In case of three-phase installation, the electrical field calculation can be provided using the equivalent loads method applied in one perpendicular plane on the overhead conductors' line. The general mathematical relationship used for the overhead conductors' stranded line loads has this form:

$$\left[\underline{q}\right] = [C][\underline{U}] \qquad (2)$$

Where:

$$\underline{q} = \begin{bmatrix} \underline{q}_1 \\ \underline{q}_2 \\ \dots \\ \underline{q}_n \end{bmatrix} \qquad (3)$$

$\left[\underline{q}\right]$ is the electrical loads matrix, $[C]$ is the own and mutual capacitances matrix and

$$U = \begin{bmatrix} u_1 \\ u_2 \\ \dots \\ u_n \end{bmatrix} \qquad (4)$$

$[U]$ is the voltages matrix.

The $[C]$ matrix can be calculated using the $[P]$ matrix reversal, where $[P]$ is the matrix of the line voltage coefficients. These coefficients were obtained from the direct application of the images theory, presented in Figure 1.

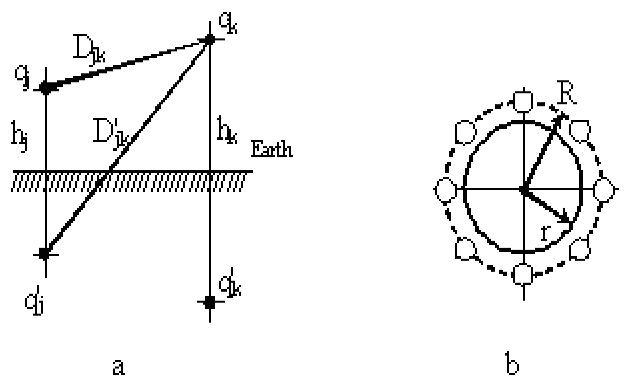

Fig. 1. Application on the image theory for the four tor cables on the overhead line

$$P_{jj} = \frac{1}{2\pi\varepsilon_0}\ln\frac{2h_j}{r_j},$$

$$P_{jk} = \frac{1}{2\pi\varepsilon_0}\ln\frac{D'j_k}{D_{jk}},$$

$$P_{jk} = P_{kj} \text{ with j, k = 1, 2…n} \qquad (5)$$

ε_0 is the vacuum permeability.

h_j, h_k are the distances between q_k and q_j and the own images.

According to this theory, the land can be replaced with the conductors images in relation with the own plane.

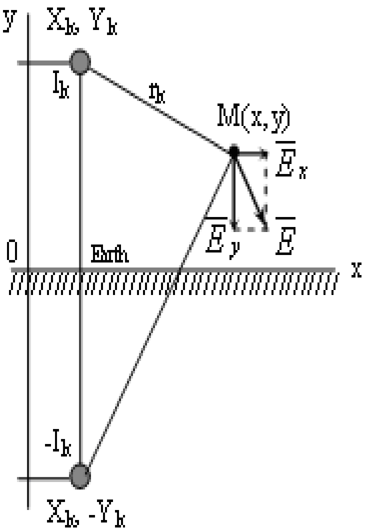

Fig. 2. Electric field components

The calculation of the electric field intensity (Figure. 2) is done according to Gauss theorem, with this formula:

$$\overline{E}(M) = \frac{1}{2\pi\varepsilon_0} \sum_{k=1}^{n} \frac{q_k r_k}{r^2 k} \qquad (5)$$

Direct measurement tool in situ:

The author's patented tool for directly measuring in situ is made according to the theoretical aspects presented in this part of the paper.

In Figure 3a,b is presented this original device for measuring alternating electric field strength [9].

The voltage ΔU, generated by the electret sensor, is processed in electronic block 2 (preamplifier, low-pass filter, amplifier) and the output signal of the diagram is proportional with the measured electric field strength, and it is displayed on the indicating meter 3.

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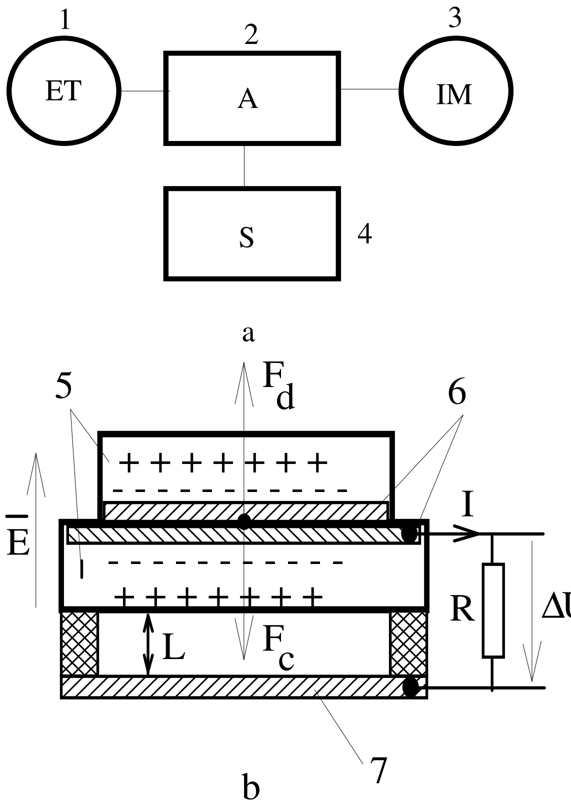

Fig. 3. a. Electret sensor: block diagram:1.electred sensor, 2.amplifier, 3.indicating meter, 4.source figure; b.electret sensor: 5.double sheet electret, 6,7.electred sensor

The main tehnical characteristics of the patented devices are presented in table 1.

Table 1

Measuring field	Measuring range	Accuracy
Alternative electric field	0.0 ….300.0 V/m	0.1 V/m

The information obtain with this patent dispositive can be used together with one neuronal artificial network (ANN). But also, we can use it for the simulation process of the artificial intelligence. One ANN can be considered as a matrix function that provides an approximate model of a system.

A three layer ANN, shown in Figure 4, which consists of input, a hidden and an output layer, is adapted to implement the proposed application. The capability accuracy in the estimation depends on the number of input nodes, hidden nodes and output nodes. Starting from the computation results, an ANN can be trained to analyze the possibility to realize the monitoring and diagnostic on the base of magnetic and electric field of low frequency emitted by the equipment and systems [10].

Creating a system monitoring/diagnostics using artificial intelligence will be the purpose for a next paper.

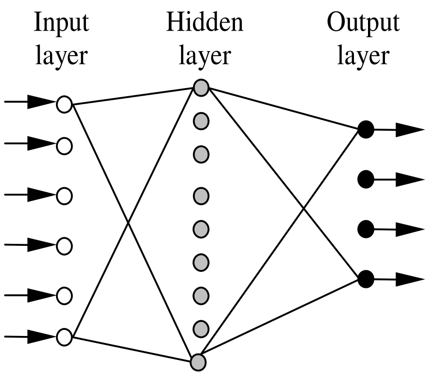

Fig. 4 ANN architecture

Artificial intellingence allows, based on information from the electric field, regardless of the method use to determine (modelling, simulation, direct measurement) creating control and command systems which can be able to disconnect or connect a system for the balance of the system. Also, based on the information of the field, the artificial intelligence system allows to couple and uncouple the system in order to take over the consumers. For example, if a power line overloads occur the consumers of that line can be taken over by a different system.

Modeling and simulation and direct measuring of electromagnetic field

It exemplifies the principle proposed through the analyze [11], of the “electric map” of a low-voltage three-phase installation, having the conductors placed as in Figure. 5a, b. The model is used for the calculation of the field map.

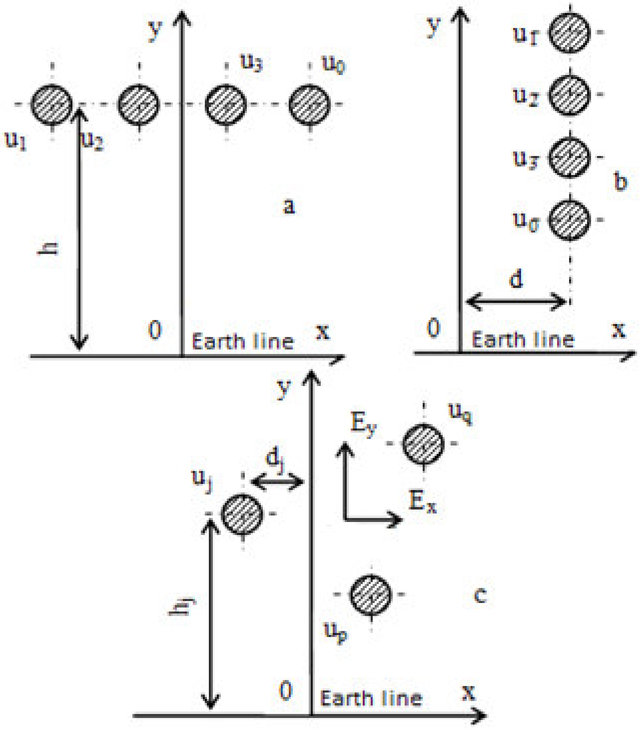

Fig. 5. Three phase system: a. horizontal plan conductors; b. vertical plan conductors; c. electric field map calculation.

For modeling this line, it was used an elaborated program in EMTP. The model for this low frequency line it is a very complex one, and because of the big number of TACS devices, the program for field calculation was performed in two sequences. The output data from the first sequence is the input data for the second sequence. The second sequence is generating the final output data.

The graphical data results are represented in the following figures for field calculation was performed also in two sequences. The results data for the EMTP simulation are represented in the following figures, for a different kind of operating regimes: symmetrical and non symmetrical state, for horizontal and vertical components. These results are shown in graphic form.

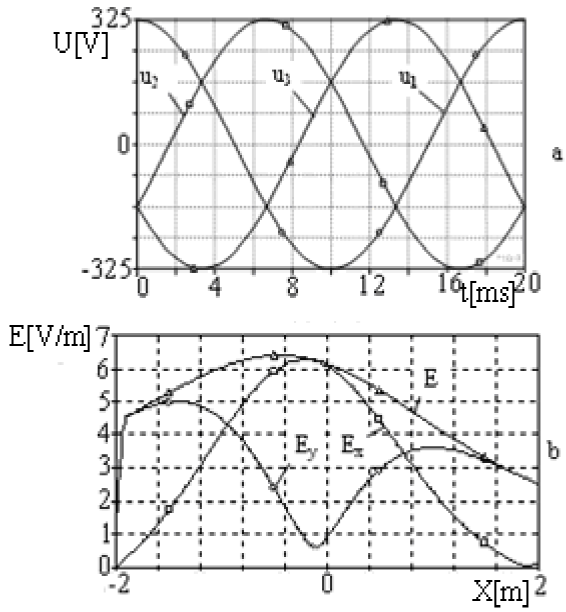

Fig. 6. Horizontal plan conductors symmetrical state: a. voltage [V]; b. electric field strength [V/m].

In Figure 6 are represented graphical the numerical results of the calculation for the electric field strength in the symmetrical state (RMS), in horizontal plan conductors, in points situated at 4 m high referenced to ground (h=4m, referenced in Figure 6a), 2 m - to conductors plan and between ±2 m referenced to the vertical axe (Figure 6a). By Ey, Ex it is noted the RMS values of the electric field strength components, and E is the resultant electric field strength (Figure 6b).

The values for symmetrical state are differing from transient and non symmetrical regimes.

In Figure 7a there are the curves of the RMS electric field strength E2 (in case of two interrupted phases), E3 (in case of one phase conductor interrupted) who can be compared with E_4 curve, calculated on the hypothesis of one symmetrical three phases voltage system. The forms of the E2 and E3 are slightly the same with the E4 curve, but the values are different.

In case of an asymmetrical state, intervened through the voltage switching on one or two phase conductors, there are appearing modifications in the electric map, which can be seen in Figure 7.

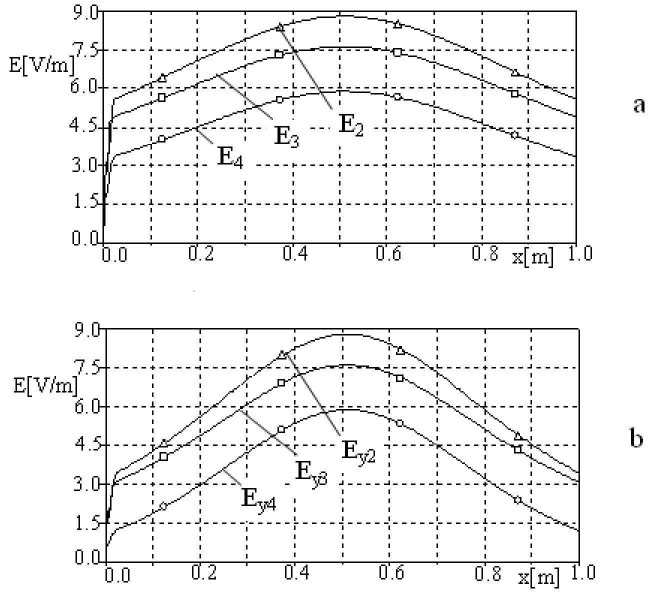

Fig. 7. Horizontal plan conductors, asymmetrical state: a. resultant electric field strength [V/m]; b. vertical component electric field strength [V/m]

The same results are represented in Figure 7b, for the vertical components of the electrical field strength Ey2, Ey3, Ey4.

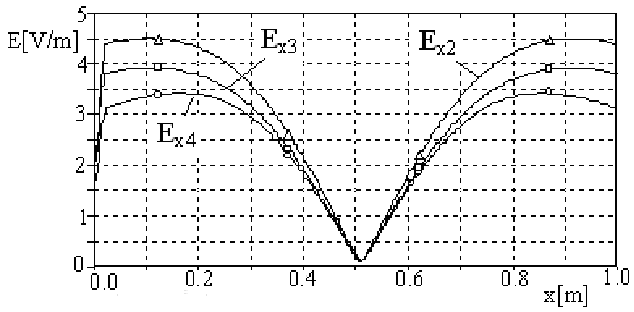

Fig. 8. Vertical plan conductors, asymmetrical state: v/m horizontal component field

Similar results can be provided also in the case when the conductors are placed in the vertical plane (Figure 8 and Figure 9). The features of the notes used in Figure 8 are the same with notes from Figure 9.

In Figure 9 are represented, in graphic mode, the calculation results for the vertical component of RMS electric field strength: Ey2 (in case of two interrupted phases), Ey3 (in case of one phase conductor interrupted), compared with Ey4 curved (calculated in the hypothesis of one symmetrical three phases).

There can be easily observed the differences from the symmetrical regime (Figure 9a), and the nonsymmetrical, the interrupted phases had been influencing the electromagnetic field resultant spectrum.

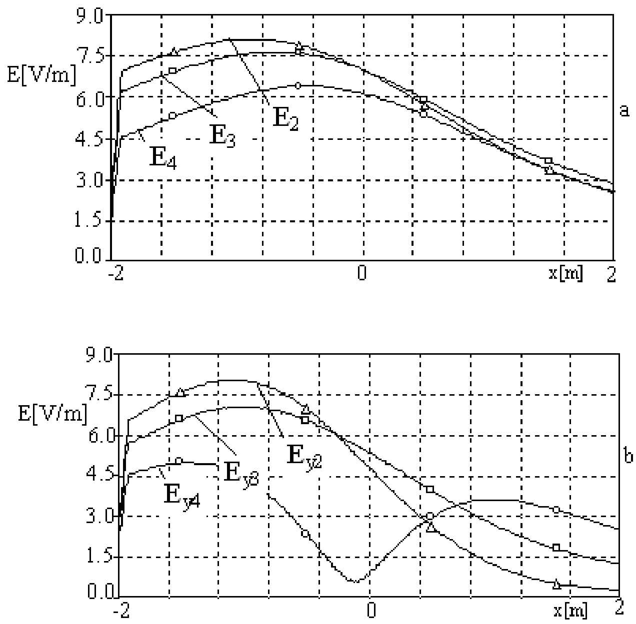

Fig. 9. Vertical plan conductors, asymmetrical state: a. V/m resultant electric fields; b. V/m vertical component electric field.

The validation of the calculation program for electrical field was done through directly measuring in situ: first using the patented tool presented in Figure 4 a, b and the second one directly measuring method was performing using one Metrahit tool. In Figure 10, there are the results of calculation and experimental curves for this directly measuring in situ.

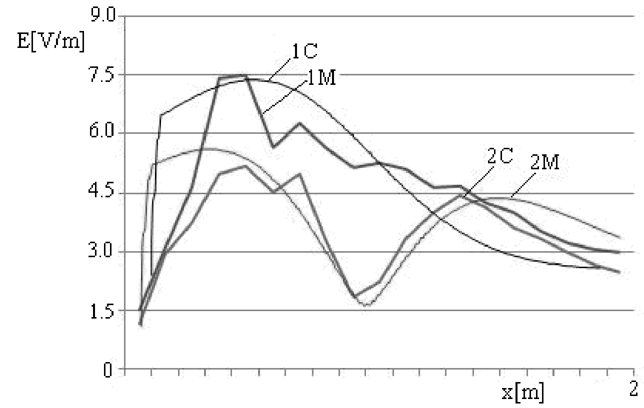

Fig. 10. Experimental results/measurements

The curve 1C and 2C represents the results performed in situ with dedicated patented tool for the case with conductors in vertical plans: figure 1C in case of two interrupted phases, Figure 2C in case of one phase conductor interrupted. In Figure 10 the curves 1M and 2M represent the results obtained through direct measurments with the Metrahit device: 1M represents the case of too interrupted phases si 2M the case of one phase conductor interrupted.

According to Figure 10, the simulating values in EMTP have been validated with directly measurement with two different methods.

4. CONCLUSIONS

The paper presents the results of an analysis on the possibility of monitoring and diagnosis of the electromagnetic radiation field of the equipment and electrical installation.

Based on mathematic model, the electric field of radiation from a low-frequency overhead line is made in EMTP software, a simulation program for this type of field. The simulation allows the calculation of the vertical component, respectively horizontal electric field, at any point in a perpendicular plane to the electric line.

EMTP for electromagnetic field simulation is a rarely used method, with the advantage of connecting in a logic sense, starting by cause to effect, the phenomena of various natures (for example electrical circuit-thermal or mechanical phenomena). In this case, it is the electrical circuit of a low frequency overhead line and its radiation electromagnetic field.

The calculation program was developed by the authors in the EMTP and the curves graphical results are presented in the paper. The program can be applied in the calculation of low frequency electric field in sinusoidal regime or non sinusoidal regime, transient, permanent or forced.

Using this simulation program, it was studied the possibility of diagnosis of a functioning system overhead line with conductors located either in a horizontal or vertical plan, when the three phase voltage is symmetrical or not. It shows the results regarding the operation of the overhead line with a single phase under voltage, 2 or 3 phase voltage.

Onto a physical model of overhead line realized in our laboratory and proper means to measure the field (Metrahit measuring type device), the authors have done experimental measurements, which are according to simulation results. These results have been also validated by using one special device patented by the authors, so the theoretical results are slightly the same with results obtained from direct measurements in situ using two different methods.

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