ANALYSIS OF ELECTROMAGNETIC FIELDS IN INTERCONNECTING SUBSTATIONS BETWEEN WTG AND NATIONAL POWER SYSTEM

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This paper deals with the analysis of electric and magnetic fields in high-voltage substations connecting renewable energy sources. The development of large capacity parks based on renewable energy sources required new substations for interconnection with the National Power System. These new substations have small sizes and a reduced number of equipment in order to achieve a compact construction. In addition, a concern regarding the impact of electric and magnetic fields on environment and occupational health has appeared. The analysis of electric and magnetic fields must be done in the design stage. The programs developed based on MATLAB software provide a solution for the analysis of electric and magnetic fields within electrical substations and in the vicinity of power lines.

Keywords: electric field, magnetic field, substation, electrical installation, renewable energy sources

1. Introduction

Along with deregulation of the energy market, the interconnection of renewable energy sources required the development of new substations for interconnection with the National Power System. The interconnection substations with wind parks and solar parks to the power system determined a challenge regarding the influence of electric and magnetic fields on environment and substation operating personnel.

Nowadays, the environment, health and personnel safety are the main focus of public society, ecological organizations and media. These are highly influencing the political priorities, regulations, standards, local authorities, international treaties, industry trends and many other society factors [1].

The analysis of the influence of low frequency electromagnetic fields on biological structure represents a difficult task. Studies were initiated in order to coordinate all available information regarding the influence on biological structure of low frequency electromagnetic field [1].

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The high and very high voltage installations, at power frequency (50 Hz), represent the most common source of electric fields affecting the human beings. These installations determine values of electric and magnetic fields exceeding the natural electric field (100 ... 150 V/m) or the natural magnetic field. The effects on human beings depend on electric field intensity and exposure duration [2].

The electromagnetic energy absorption by the human bodies depends of:

- frequency and polarity;
- environment characteristics (temperature, pressure, humidity);
- biological parameters (dielectric properties, size and form of tissue);
- position of the body in field, as well as some short term conditions (the existence of any screening or concentration field elements).

For the assessment of personnel exposure risk, a particular importance is represented by the daily, monthly or annually monitored dose of electromagnetic fields [3].

In this paper, the level of electromagnetic fields within the interconnecting substations, between renewable energy sources (wind park) and power system, is analyzed. These types of substation have certain characteristics like: small sizes because of the issues raised by the acquisition and land price and a relatively reduced number of equipment.

2. Effects and limits of electric and magnetic fields for specialized staff from substations

Simultaneously with the construction of high voltage electric lines and substations increases their influence on the environment. Hence, the countries with developed power systems elaborated specific regulations and standards regarding the environmental impact of power grids.

Some epidemiological studies, with statistical processing of data, highlight a direct connection between the exposure to electric and magnetic fields, and the people health.

In the near future, the research in this area will lead to clearer results. As consequence of this, new criteria in the design of electric installations and equipment will be defined, such that to not affect the health of operating personnel [4].

Further studies on human exposure to electromagnetic fields are determined by:

- the increase of electromagnetic impact in residential areas, in public places, and in usual occupational environments;
- the occurrence of occupational environments characterized by high electromagnetic emissions (electric installations, industrial installations using important electric currents etc.);

- acknowledgement that biological effects are cumulative and a particular interest should represent the quantity of disturbances in a time interval [5].

Standardization activity about human exposure to electromagnetic fields is a major current concern. Thus, exposure limits are established by:

- national standards: Berufsgenossenschaft der Feinmechanik und Electrotechnik – Germania (BFE), Russia, American Conference of Governmental Industrial Hygienist - S.U.A. (ACGIH), Poland, Japan, Check Republic and Slovakia);
- projects of international standards: International Commission on Non-Ionizing Radiation Protection (ICNIRP), Comité Européen de Normalisation Electrotechnique (CENELEC).
- recommendation of the independent international professional organizations: US Environmental Protection Agency (USEPA), World Health Organization (WHO), National Radiological Protection Board (NRPB), and International Radiological Protection Association (IRPA) [1].

The exposure limits to electromagnetic fields are regulated by 2004/20/EC European Union Directive adopted by the Romanian legislation OMSF 1193/2006 and HG 1136/2006. In these documents the exposure limits values considering the 50 Hz power frequency are established [6], [7]:

- 5 kV/m for electric field intensity (public exposure);
- 10 kV/m for electric field intensity (professional exposure);
- 80 A/m for magnetic field (public exposure);
- 400 A/m for magnetic field (professional exposure).

3. Determination of the electromagnetic fields

3.1. Determination of the electric field in the vicinity of bus-bars within a high voltage substation (method of equivalent charges)

The intensity of the electric field E_j can be determined, at any point P of the space (Fig.1) in the electric field of a charge q_j (charge per length of the bus-bar) placed at height h_j above ground, using [4]:

$$\vec{E}_j = \frac{q_j}{2 \cdot \pi \cdot \varepsilon_0} \cdot \left(\frac{\vec{r}_{jP}}{r_{jP}^2} - \frac{\vec{r}_{j*P}}{r_{j*P}^2} \right) \tag{1}$$

where $\vec{r}_{jP}$ and $\vec{r}_{j*P}$ represent the distances between the point where the charge $+q_j$ is placed and the investigated point *P*, respectively between the point where the charge $-q_j$ (the mirror image of charge $+q_j$) is placed and the point *P*.

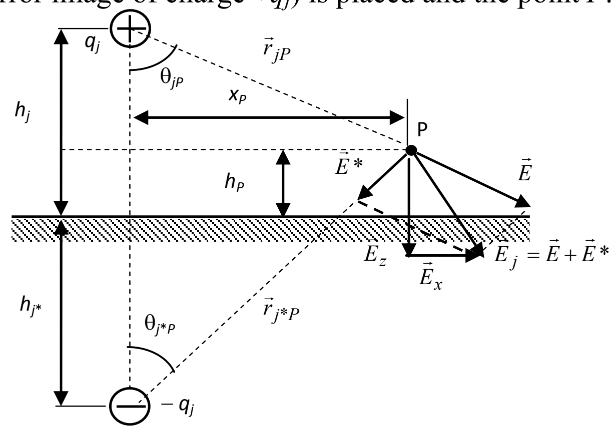

Fig. 1. Determination of electric field intensity at a point in the vicinity of bus-bars within a high voltage substation.

As shown in Fig. 1 [5], the vertical component E_z and horizontal component E_x of the electric field $\vec{E}$ can be calculated, function of the distance x_P to the ground projection of charge q_j and on the height h_P of point *P*:

$$
\begin{aligned}
E_z &= \frac{q_j}{2\cdot\pi\cdot\varepsilon_0}\cdot\left[\frac{h_j-h_P}{\left(h_j-h_P\right)^2+x_P^2}+\frac{h_j+h_P}{\left(h_j+h_P\right)^2+x_P^2}\right];\\
E_x &= \frac{q_j}{2\cdot\pi\cdot\varepsilon_0}\cdot\left[\frac{x_P}{\left(h_j-h_P\right)^2+x_P^2}-\frac{x_P}{\left(h_j+h_P\right)^2+x_P^2}\right].
\end{aligned}
\qquad (2)
$$

3.2. Determination of the magnetic field in the vicinity of bus-bars within a high voltage substation

The determination of the magnetic field intensity *H* and the magnetic field density *B* requires the knowledge of:

- the geometrical configuration of bus-bars and the environment material properties, based on the magnetization curves *B*(*H*) for linear environments;
- the electric currents along the bus-bars.

The magnetic field intensity at any point in the vicinity of bus-bars within a substation, for a single phase configuration can be determined based on the calculation scheme shown in Fig. 2.

The magnetic field intensity $\vec{H}$ in any point P, determined by the electric current I, can be expressed as [5]:

$$\vec{H} = \frac{I}{2\cdot\pi}\cdot\left(\frac{r_{jP}}{r_{jP}^2}+\frac{r_{j*P}}{r_{j*P}^2}\right) \tag{3}$$

where r_{jP} and r_{j*P} represents the distances between point P, where the magnetic field intensity is calculated, and the center of the bus-bar through which the electric current I flows, respectively towards the equivalent bus-bar where the current returns through earth.

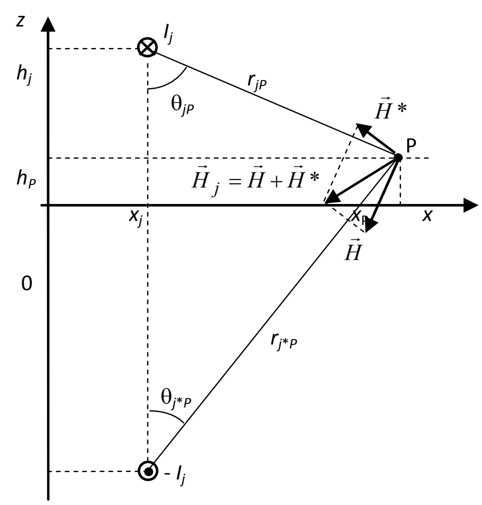

Fig. 2. Determination of magnetic field intensity at a point in the vicinity of bus-bars within a high voltage substation.

Based on (3), the vertical component H_z and horizontal component H_x of the magnetic field intensity in the considered point P are determined using [5]:

$$H_z = \frac{I}{2\cdot\pi}\cdot\left(\frac{\sin\theta_{jP}}{r_{jP}}+\frac{\sin\theta_{j*P}}{r_{j*P}}\right) = \frac{I}{2\cdot\pi}\cdot\left[\frac{x_P-x_j}{(x_P-x_j)^2+(h_j-h_P)^2}+\frac{x_P-x_j}{(x_P-x_j)^2+(h_{j*}+h_P)^2}\right]; \tag{4}$$

$$H_x = \frac{I}{2\cdot\pi}\cdot\left(-\frac{\cos\theta_{jP}}{r_{jP}} + \frac{\cos\theta_{j^*P}}{r_{j^*P}}\right) = \\ = \frac{I}{2\cdot\pi}\cdot\left[\frac{h_j - h_P}{(x_P - x_j)^2 + (h_j - h_P)^2} - \frac{h_{j^*} + h_P}{(x_P - x_j)^2 + (h_{j^*} + h_P)^2}\right]. \quad (5)$$

The absolute value of the magnetic field intensity is defined by:

$$H = \sqrt{H_x^2 + H_z^2}. \quad (6)$$

4. Case study

4.1. Calculation algorithm for electric field

From (1), (2) and based on calculation steps described above, for a three phase configuration, a computational program is developed. The value of the electric field, in the area of bus-bars within a 110 kV substation, is determined. For calculation a real 20/110 kV substation connecting a wind park with a total capacity of 140 MW is considered. In Fig. 5, the flowchart of the algorithm for electric field, in the area of bus-bars within the considered substation, is illustrated. In most cases, the measurement results indicate that the maximum values of the electric field intensity are obtained in the area of disconnectors and circuit breakers [8].

The maximum value of electric field intensity in the bus-bars area is 4 kV/m for the case studied (Fig. 3 and Fig. 4). Obviously, this value does not present a risk for personnel performing maintenance work in the substation.

bus-bars, obtained by applying the algorithm presented in Fig.5

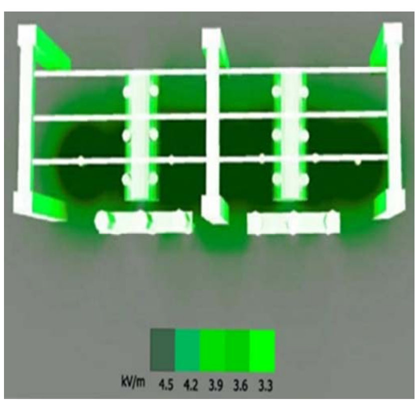

Fig. 3. Electric field distribution [kV/m] in the area of bus-bars, obtained by applying the algorithm presented in Fig.5

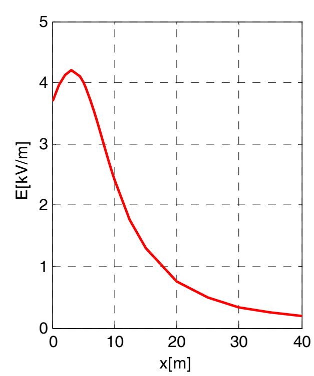

Fig. 4. Numerical result for electric field in the area of 110 kV bus-bars, obtained by applying the algorithm presented in Fig.5

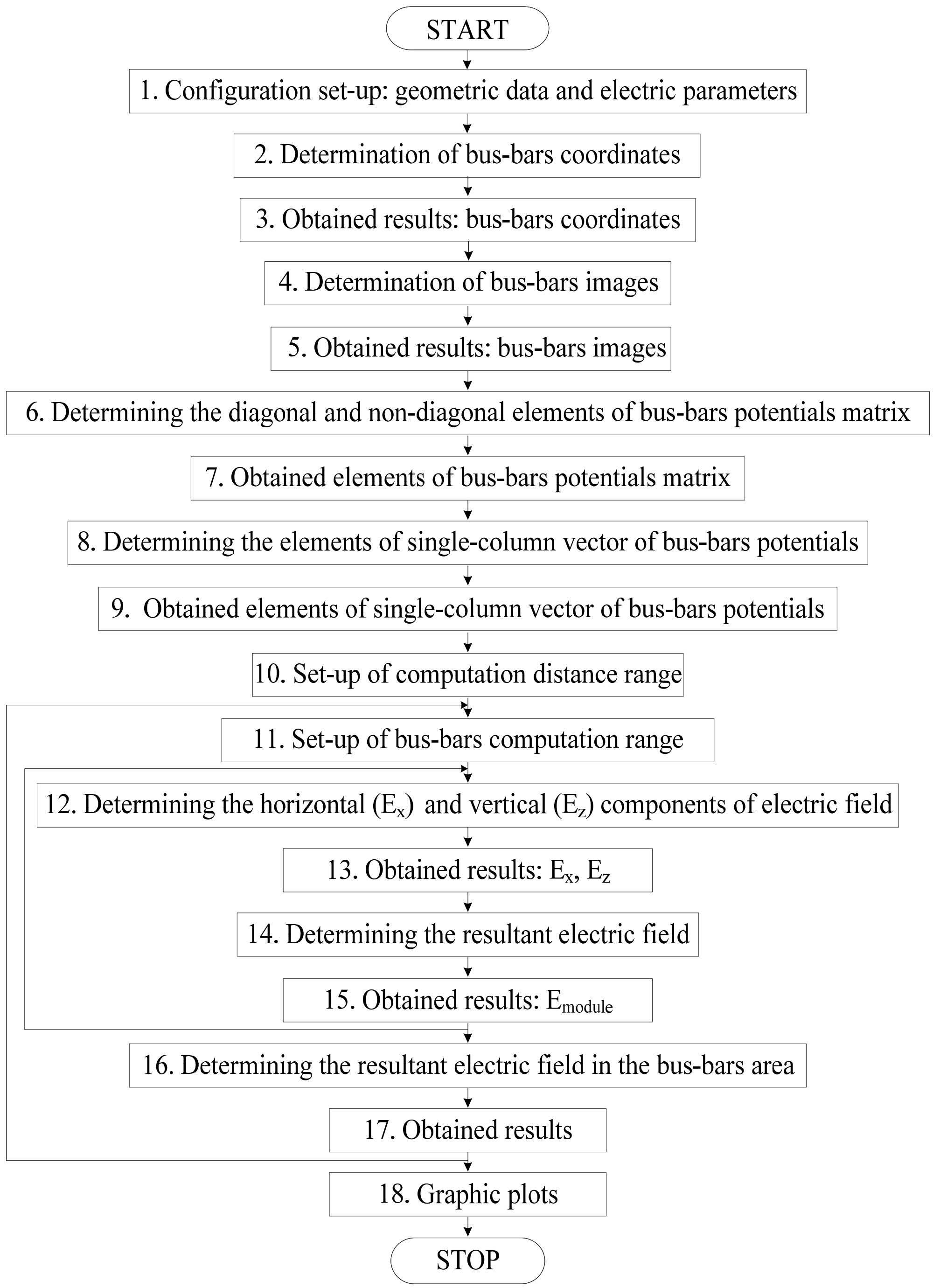

Fig. 5. Flowchart of the algorithm for electric field intensity.

4.2. Calculation algorithm for magnetic field

Based on (3) – (5) and on calculation steps described above, a calculation program using the MATLAB environment it is developed. The program computes the value of magnetic field in the area of bus-bars within the 20/110 kV substation. Using the calculation algorithm for magnetic field, the value of 48 A/m in the area of bus-bars is obtained (Fig. 6 and Fig. 7). The resulted value is not exceeding the exposure limits, both professional and public, in accordance with the current regulations for the 110 kV substations. In most cases, the measurement results indicate that the maximum values of the magnetic field are obtained in the area of bus-bars and MV cables of power transformers, as well as into the MV buildings where the electrical currents are higher [8]. During the computation steps, the value of electrical current is considered I = 1 kA, but in reality the electrical current is lower.

The magnetic field distribution in the area of bus-bars within the substation is illustrated in Fig. 8. As shown, the maximum value of the magnetic field resulted close to the middle phase and this value begins to decrease significantly at a distance of 4 meters from the area of bus-bars.

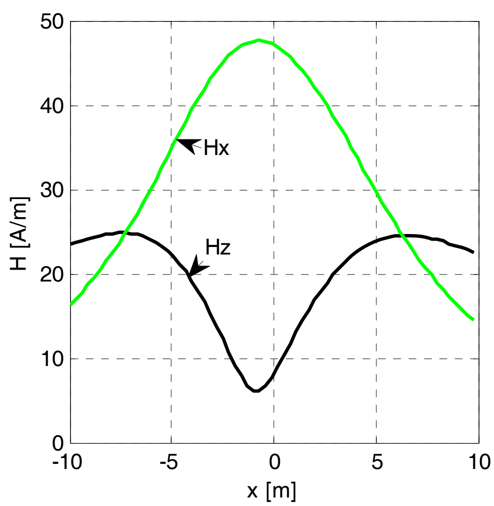

Fig. 6. Numerical results for the components H_x and H_z of the magnetic field [A/m], obtained by applying the algorithm developed in MATLAB environment

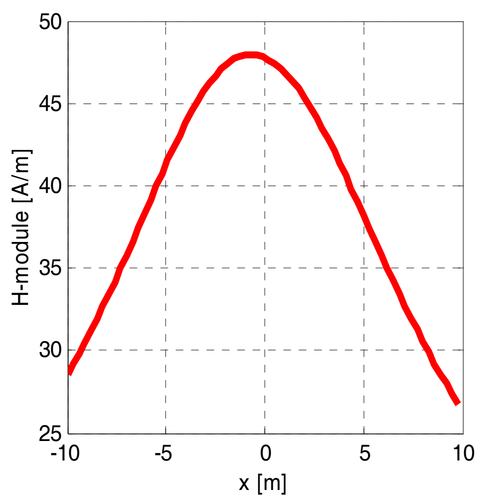

Fig. 7. Effective value of the magnetic field, obtained by applying the algorithm developed in MATLAB environment

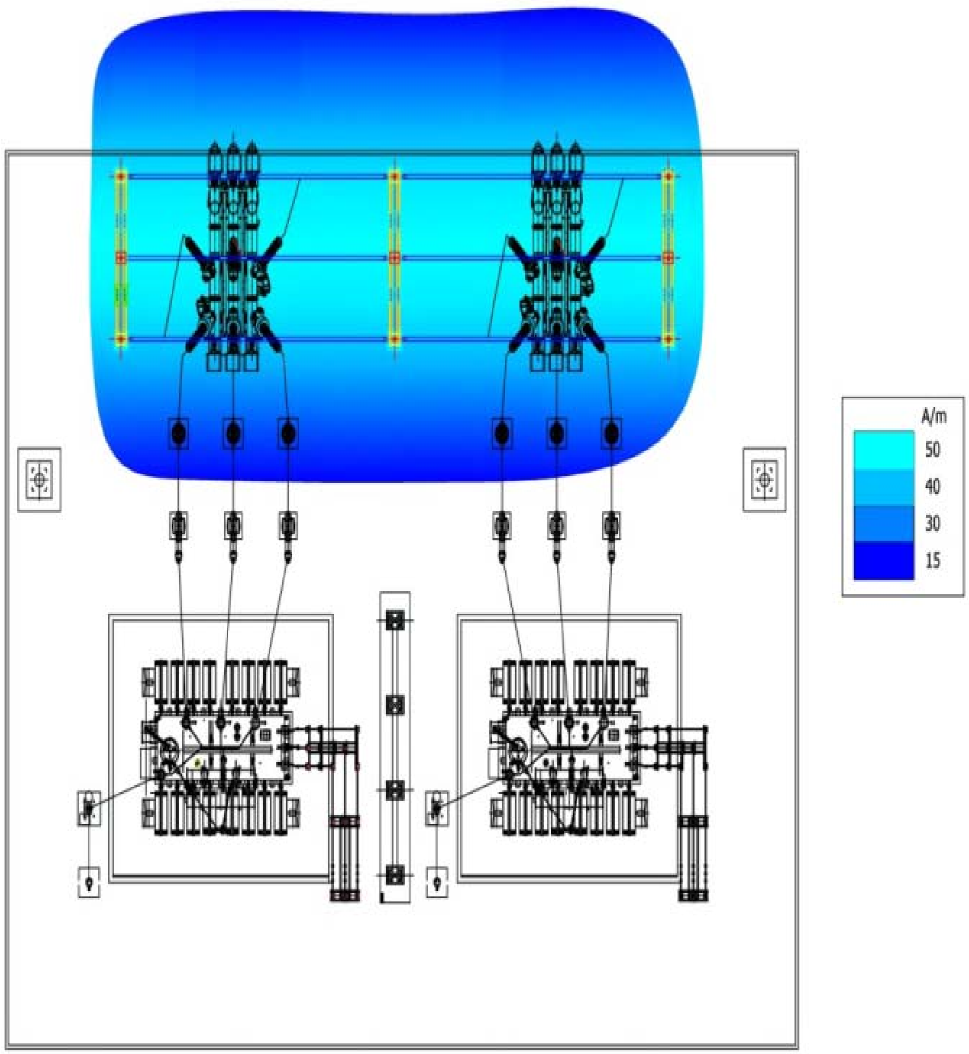

Fig. 8. Magnetic field distribution in the analyzed substation [A/m]

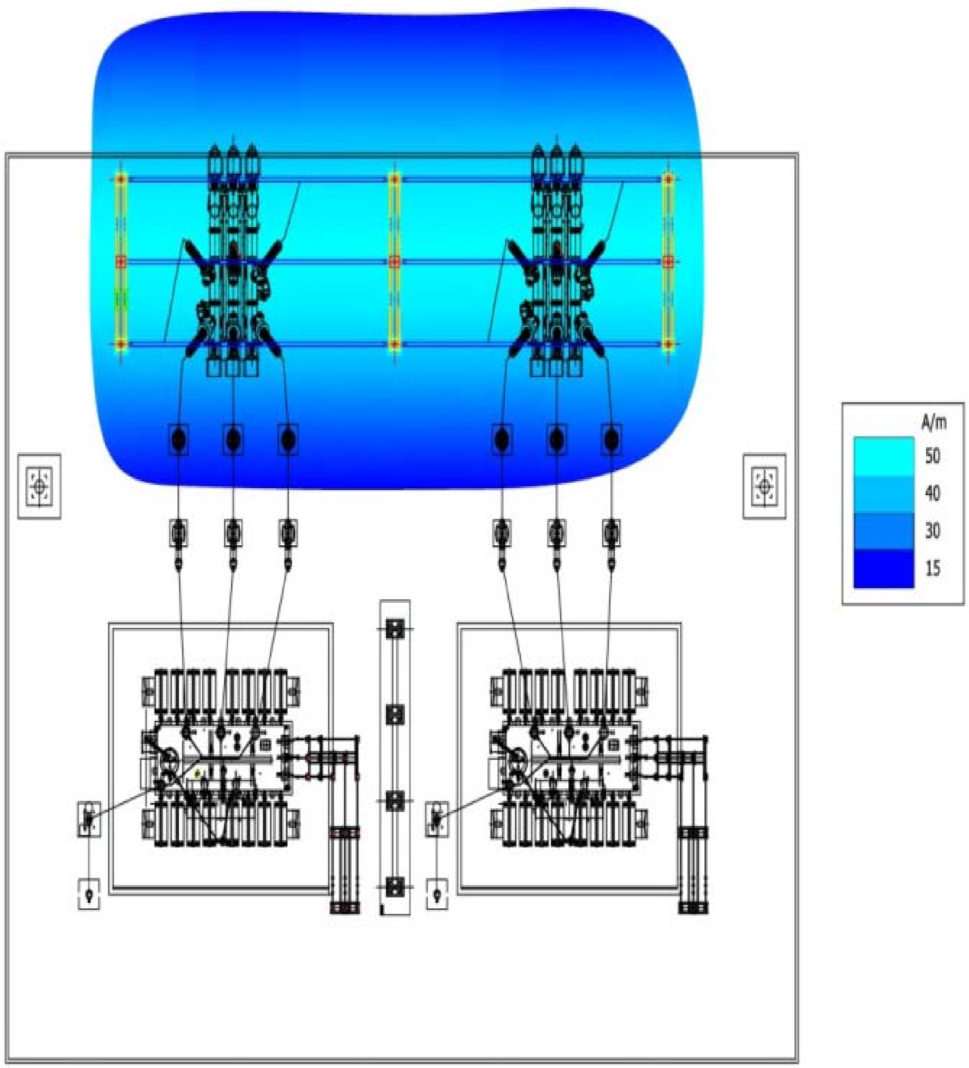

Fig. 8. Magnetic field distribution in the analyzed substation [A/m]

5. Conclusions

The development of wind parks required new substations of small sizes, with a reduced number of equipment and minimum settled distance between them in order to achieve a compact construction [9]. In most cases, the latter is the factor that prevails in choosing the substation layout, being necessary the analysis of electromagnetic fields configuration.

Within the substations, the electromagnetic fields determination is difficult, due to the complexity of metal structures and equipment. Therefore, the determination of the values for the electric field *E* and for the magnetic field *H* is based on measurements [10]. Calculations performed are very important in the design phase.

In section 2, the effects and limits of electric and magnetic fields for operational personnel from substations are presented. The calculation elements of electric and magnetic fields are investigated in section 3, considering the electric and magnetic fields from substations connecting WTG to National Power System. In section 4, the case study for a substation interconnecting a wind park with a total capacity of 140 MW is conducted. The impact of the electromagnetic fields in the connection substation with NPS is analyzed.

Considering the bus-bars of a 20/110 kV substation, the results indicate areas where the electromagnetic fields values are exceeding (middle phase) the exposure limits established by the existing standards.

The knowledge of the electromagnetic fields level, and the analysis of areas where the intensities have higher values allow the designer to establish the most effective measures to limit these field values [11]. The programs developed in MATLAB software provide a complete solution for the analysis of electric and magnetic fields within substations and in the vicinity of power lines. In general, the areas with high values of electric field do not coincide with the areas with high values of magnetic field.

R E F E R E N C E S

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