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STUDY OF LOW FREQUENCY MAGNETIC FIELD OF INDOOR DISTRIBUTION SUBSTATIONS

BY

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Abstract. In this paper we presented some measurements of the low frequency magnetic field from indoor distribution substation. Using two automatic measuring instruments we made both spot measurement and automatic long-term survey presenting the spatial and temporal variability of the magnetic field in five areas with indoor distribution substation. Correlating the time of spot measurement, with that of automatic survey we estimate the magnetic field values to reduce the errors due to the temporal variation. With the values obtained after estimating the field, we draw maps for the entire zone of an indoor distribution substation. The results were compared with the maximum permissible limits by national and international standards and we found that they were not exceeded. However, in all five areas the values of the magnetic field were above the threshold of 400 nT taking into account long-term exposure, which can lead to biological effects on health, especially for children.

Keywords: low frequency magnetic field; automatic survey; spot measurements; magnetic flux density; biological effects.

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1. Introduction

The human exposure to low frequency magnetic fields (Turner *et al.*, 2014) is a great concern in the residential environment (Sadafi *et al.*, 2003). For this reason, numerous studies have been carried out in this field (Zaryabova *et al.*, 2013). The values obtained near the transformer substations (Hossam *et al.*, 2010), (Kuusiluorna *et al.*, 2002) are compared with the maximum limits allowed by the international (ICNIRP, 1998; ICNIRP, 2010; Directive, 2013; IEEE 2019; WHO 2007) and national standards (Hotărâre, 2016).

The problems encountered when measuring the low frequency magnetic field are due to a large spatial and temporal variability (Pop *et al.*, 2011). That is why special equipment's (David *et al.*, 2019) are needed that allows both spot measurements (Mariscotti, 2009) and automatic long-term survey. For a good interpretation of the results, it is recommended to represent the spatial and temporal variability of the field in the maps and graphical forms, (Mujezinovic *et al.*, 2022) respectively statistical processing.

In our paper we presented a study of the low frequency magnetic field of indoor distribution substations (IDS) (Keikko *et al.*, 2009) from five different areas (Morega *et al.*, 2014) of residential environment. When performing the study, we used two automatic measuring instruments made in our laboratory (Pavel *et al.*, 2018) that allow both spot measurement and automatic long-term survey (Nica *et al.*, 2016).

For all five areas, images with studied IDS, measurement point, spatial and temporal variation of the magnetic field and a statistical processing of results were presented. Finally, the values obtained were compared with the maximum permissible limits and with the maximum threshold of 400 nT (Meeker, 2016) taking into account the biological effect (Koeman *et al.*, 2014) for long-term exposure (Huss *et al.*, 2018), especially for children (Konstantinoudis *et al.*, 2018).

2. Materials and Methods

For the magnetic flux density survey near IDS with U_N = 24 kV, I_N = 630 A and f_N = 50 Hz, two automatic instruments with three orthogonal axes sensor (B_x, B_y and B_z) were used. Also, we determine the root mean square (rms) value of B_r according to Eq. (1).

$$B_r = \sqrt{B_x^2 + B_y^2 + B_z^2} \tag{1}$$

These instruments can measure the magnetic field in the frequency band 50 Hz - 100 kHz with a measurement uncertainty ± 5% and can record the effective and peak to peak values of the magnetic field, both in the time and frequency domain, as well as the period in which the measurements were performed. One of the instruments was positioned at a fixed point (P) near the IDS that made an automatic long-term survey with a measurement step of approximately 1 second. The second instrument was used to spot measurement around IDS, longitudinally and transversely at several points, at 1 meter height from ground and 1 meter between them, so that a matrix of measurements can be made necessary to draw a field map. Because the magnetic field has a fairly large temporal variability, each measurement obtained by the spot measurement method is made at different times ($B_{SM}(P_1, t_1)$, $B_{SM}(P_2, t_2)$,.. $B_{SM}(P_k, t_i)$). Therefore, taking into account the magnetic field variability from automatic long-term survey ($B_{LTS}(P, t_1)$, $B_{LTS}(P, t_2)$,.. $B_{LTS}(P, t_i)$), we can estimate (David *et al.*, 2020) the measured values by the spot measurement method for the same moments as the automatic long term survey. The magnetic field estimation (Pavel *et al.*, 2023) was made according to Eq. (2):

$$B_e(P_k, t_i) = B_{SM}(P_k, t_j) \cdot \frac{B_{LTS}(P, t_i)}{B_{LTS}(P, t_j)} \tag{2}$$

where: B_e (P_k, t_i) is the estimated magnetic field in P_k point and time t_i , $B_{SM}(P_k ,t_j)$ is the magnetic field measured in P_k point at time t_j using spot measurement method, $B_{LTS}(P, t_i)$, $B_{LTS}(P, t_j)$ are the values of the magnetic field obtained from the long term survey in a fixed point P, near IDS, at time t_i, respectively t_j where, i=1..n-1, j=2..n and k=2..n.

Also, we can estimate all measured values by the spot measurement method for the same time, thus resulting a magnetic field map obtained as if the measurements had been made at the same time on the entire area.

The temporal variability of the magnetic field was determined, as a percentage, according to the minimum and maximum value obtained at automatic long-term survey for each area.

In Fig. 1 is presented IDS intended for the power supply of Mall, respectively the measurement points. We also notice that IDS Mall is positioned between a street and a student residence (SR) that also has IDS.

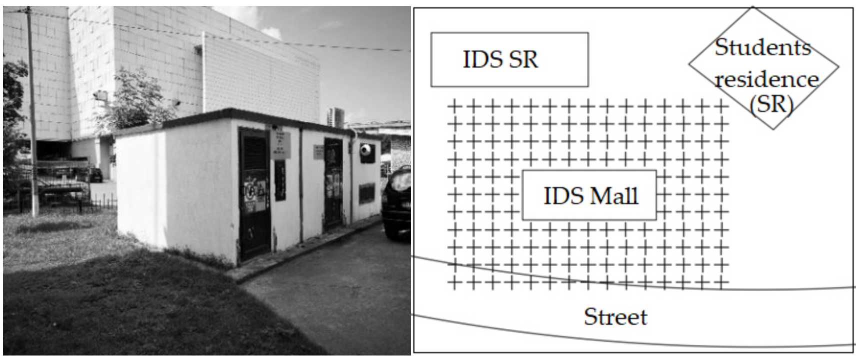

Fig. 1 – Indoor distribution substation and measurement points in Zone 1.

IDS from Zone 2 is located in a parking of a new residential area and its image and measurement points can be seen in Fig. 2.

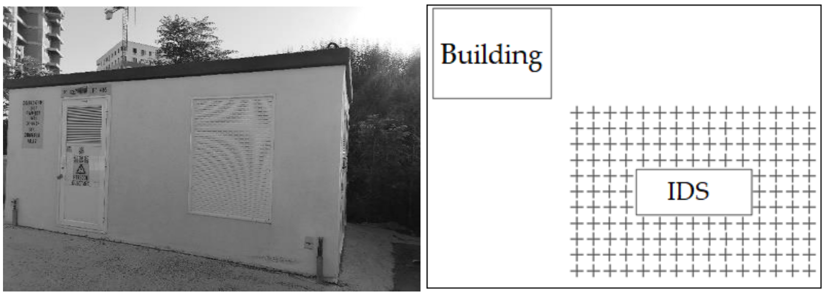

Fig. 2 – Indoor distribution substation and measurement points in Zone 2.

The following two areas have IDS for power supply to Hypermarkets. In Zone 3 we have two IDS for the same Hypermarket located between them and an Overhead Power Line, as can be seen in Fig. 3. It should be noted that there is also a pedestrian access road along the overhead power line.

In areas 4 IDS, presented in Fig. 4, is located between Hypermarket and a residential area, where there is also a car park.

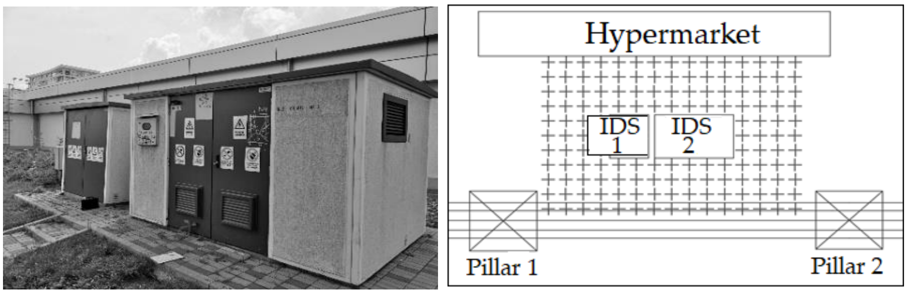

Fig. 3 – Indoor distribution substation and measurement points in Zone 3.

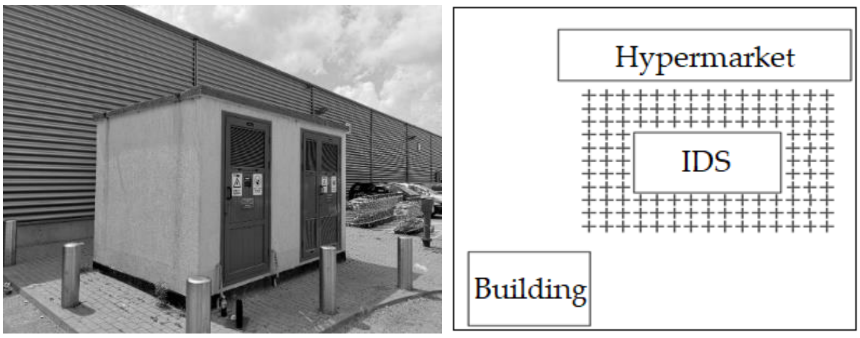

Fig. 4 – Indoor distribution substation and measurement points in Zone 4.

The last studied area has IDS positioned in a parking lot near a building and courthouse. Its image and measurement points are presented in Fig. 5.

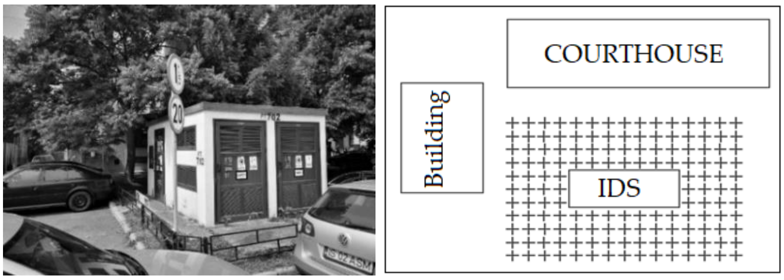

Fig. 5 – Indoor distribution substation and measurement points in Zone 5.

3. Results

The obtained results, for each studied area were represented in the field maps form and some graphs, thus obtaining both the spatial and temporal distribution of the magnetic field generated by IDS from the entire study.

Moreover, the magnetic field variation from the automatic survey was used to estimate the values for each different measuring point, thus obtaining a much more accurate field map.

The highest field value in Zone 1 was 21449 nT and we obtained a temporal variability of 21.42%, according to Fig. 6, respectively Fig. 7.

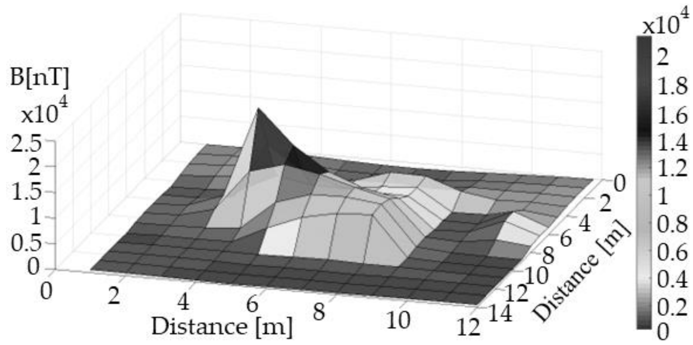

Fig. 6 – Spatial distribution of the magnetic field around IDS in Zone 1.

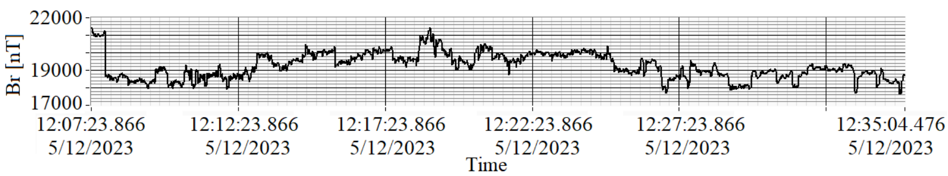

Fig. 7 – Temporal variability of the magnetic field near IDS in Zone 1.

In the second area we obtained slightly lower values (5500 nT), but we have a longer temporal variability than that obtained in the first area studied (41.42%). The obtained results can be observed in Fig. 8 and Fig. 9.

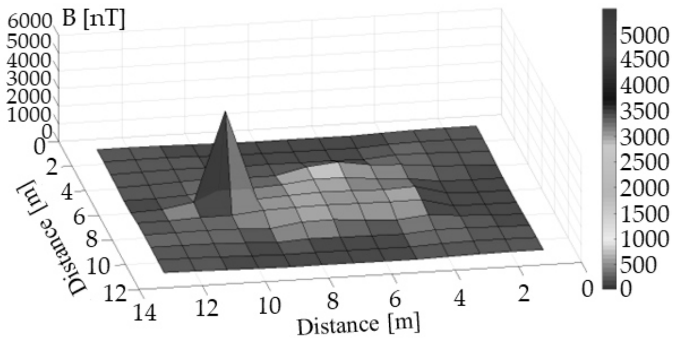

Fig. 8 – Spatial distribution of the magnetic field around IDS in Zone.

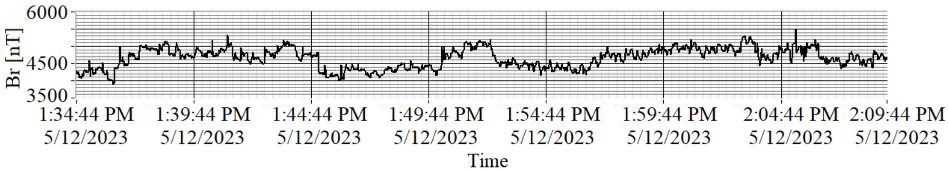

Fig. 9 – Temporal variability of the magnetic field near IDS in Zone 2.

In the third area we identified the lowest value of the magnetic field among all the studied areas. We can see the two peaks in Fig. 10 which represents the maximum values in this area, obtained from the two electrical transformers. The maximum value registered in this area is 2798 nT.

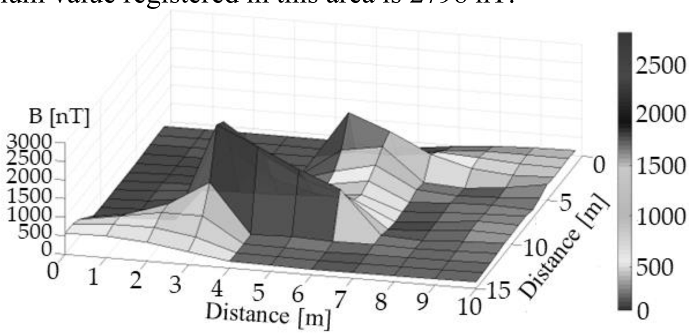

Fig. 10 – Spatial distribution of the magnetic field around IDS 1 and IDS 2 in Zone 3.

Even if we obtained the lowest value of the magnetic field in all 5 areas studied, we have a temporal variability of 113.42%, as can be seen in Fig. 11.

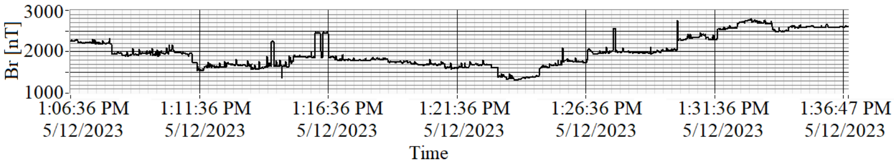

Fig. 11 – Temporal variability of the magnetic field near MTS 1 in Zone 3.

In the 4-th studied area we identified the highest value of the magnetic field in the entire study, namely 30955 nT, according to Fig. 12 and we also got, following long-term automatic survey a temporal variability of the magnetic field of approximately 214.49%, as can be seen in Fig. 13.

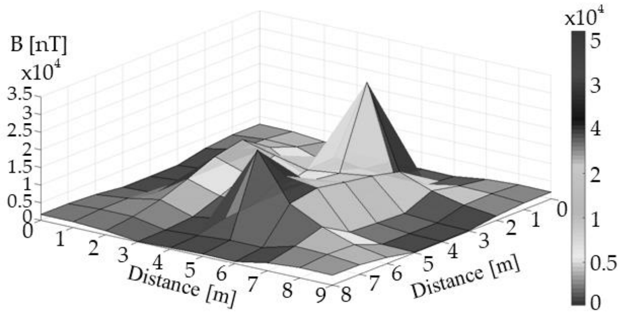

Fig. 12 – Spatial distribution of the magnetic field around IDS in Zone 4.

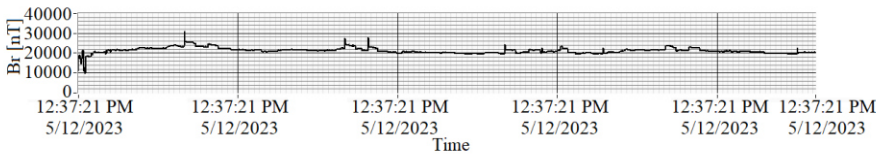

Fig. 13 – Temporal variability of the magnetic field near IDS in Zone 4.

In the last studied area, the maximum value of the recorded field is 23470 nT (Fig. 14) and its temporal variability was approximately 13.8% (Fig. 15), being the smallest variation of all other areas studied.

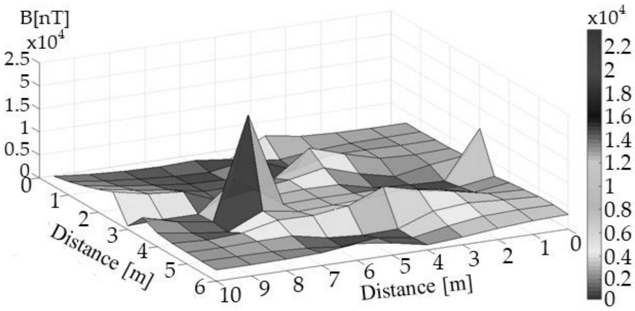

Fig. 14 – Spatial distribution of the magnetic field around IDS in Zone 4.

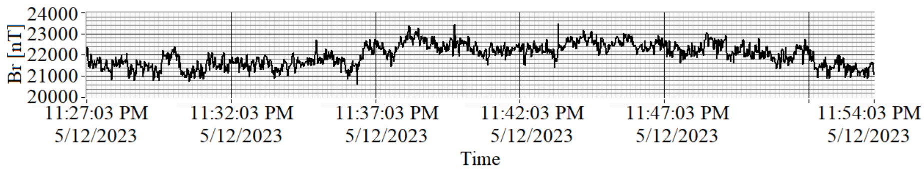

Fig. 15 − Temporal variability of the magnetic field near IDS in Zone 4.

Finally, we performed a statistical processing of the results for all the studied areas, where we represented, according to Table 1, the area and period of the automatic survey, the number of measurements, the minimum, average, maximum values and standard deviation and the time in which the average value in a survey is exceeded, expressed as a percentage.

Table 1

Statistical processing of measurements in all areas studied

Survey		Number of measurements	Brms [nT]				$\frac{t_{over\ average}}{t_{survey}} x100$ [%]
Area	Period [mm:ss]		Min.	Average	Max.	Standard dev.	
Zone 1	*[27:41]*	*1633*	*17665*	*19213*	*21449*	*729*	*46.23*
Zone 2	*[34:29]*	*1930*	*3889*	*4655*	*5500*	*285*	*53.73*
Zone 3	*[30:11]*	*1715*	*1311*	*1982*	*2798*	*368*	*38.66*
Zone 4	*[46:10]*	*2713*	*9843*	*21104*	*30955*	*1502*	*49.02*
Zone 5	*[27:16]*	*1531*	*20623*	*21998*	*23470*	*519*	*51.01*

4. Conclusions

With the numerous appearances of electrical and electronic equipment, the consumption of electricity has inevitably increased, leading to the emergence, in the residential environment, of many IDS. Due to this, in this study, we paid close attention to the magnetic field generated by these sources.

When conducting the study, we used two automatic measuring instruments, which can perform both spot measurement and automatic long-term survey. At the same time, these instruments, in addition to processing the values of magnetic induction, also stores the time during which each measurement was made, which helped us make a correlation between spot measurement and automatic long-term survey. This was used to estimate the magnetic field for the entire area around IDS, as if all measurements had been made at the same time.

The obtained results were represented in the maps form for the spatial variation of the magnetic field, respectively in the graphics form resulting in its temporal variability. Finally, we realized a statistical processing of the results and we noticed that the highest value of the field was identified in Zone 4, namely 30955 nT.

Comparing recorded values with the maximum permissible limits, according to the national and international standards, in all area this limit didn't exceed. However, in all areas, we have identified values over the 400 nT threshold, which is a concern especially for children, taking into account long-term exposure.

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STUDIUL CÂMPULUI MAGNETIC DE JOASĂ FRECVENȚĂ AL STAȚIILOR DE DISTRIBUȚIE INTERIOARE

(Rezumat)

În această lucrare am prezentat câteva măsurători ale câmpului magnetic de joasă frecvență din câteva stații de distribuție interioare. Folosind două instrumente automate de măsură, am făcut atât măsurări în anumite puncte, cât și supravegheri automate pe termen lung pentru a determina variabilitatea spațială și temporală a câmpului magnetic în cinci zone cu stații de distribuție interioară. Corelând timpul de la măsurările din anumite puncte, cu cel al măsurărilor din supravegherile automate, putem estima valorile câmpului magnetic pentru a reduce erorile datorate variației temporale. Cu valorile obținute după estimarea câmpului, putem trasa hărți pentru întreaga zonă a unei stații de distribuție interioară. Rezultatele au fost comparate cu limitele maxime admise de standardele naționale și internaționale și am constatat că acestea nu au fost depășite. Totuși, în toate cele cinci zone, valorile câmpului magnetic au fost peste pragul de 400 nT, luând în considerare expunerea pe termen lung, ceea ce poate conduce la apariția unor efecte biologice asupra sănătății, mai ales la copii.