A Procedure for Assessment of Maximal Electromagnetic Field Values from Urban Power Substation

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Abstract—The paper deals with an assessment procedure of the maximal electromagnetic field values related to urban power substation. Assessment of maximal electromagnetic field values from urban power substations are of great interest for both power utilities and the general public. This work provides an assessment procedure for the maximal magnetic field values from urban power substations based on a limited number of measured values, thus reducing the required measurement effort. The technique used in this work comprises the multiquadric approximation of a field quantity obtained using the discrete measured data set. The approximation sufficiently handles multidimensional multiextreme functions by interpolating their discrete values accurately. Subsequently, the maximal value of a field quantity is evaluated by minimizing the negative multiquadric approximation via a stochastic optimization method - differential evolution. Therefore, the implemented procedure provides the maximal value assessment on the basis of a limited number of measured values, thus reducing the experimental cost. Moreover, measurement results of ELF magnetic fields produced by urban power substation are analysed for better understanding of the influence of various field sources.

***Keywords*—**Electromagnetic fields, Differential evolution, Multiquadric approximation, Power substation

I. Introduction

AN assessment of the maximal electromagnetic field quantities (electric field, magnetic flux density, etc.) generated by various sources has continuously been of great interest. During the 20th century, environmental exposure to manmade electromagnetic fields has been steadily increasing as the growing demand for electricity and ever-advancing technologies and changes in social behavior have created more and more artificial sources. Utilities in particular are interested in the sources and levels of magnetic fields associated with their transmission lines, feeders, substations and related equipment. In recent years, human health linked with effects of exposure to power frequency magnetic fields near substations and overhead lines has made a great concern to the public. In addition, ELF magnetic fields have been suspected of causing various types of negative health effects. The possible effect of ELF magnetic field exposure in occupational and residential environments raises the question of how electric and magnetic fields are created, and what effects they may have. The research undertaken within this work has been focused only toward the technical aspects of the maximal value assessment related to urban power substations, not considering the health effects.

The procedure of maximum assesment includes a stochastic optimization method as well as the multiquadric approximation of field quantity [1]-[7]. A spatial function representing a quantity considered may have a number of local extremes arising from complex distribution of electromagnetic field sources. Consequently, an application of the stochastic optimization method - differential evolution [1]-[3],[6],[7] for finding the global extreme of the function, is a useful tool for the maximum evaluation. Also, the procedure of maximum assessment is carried out using a multiquadric approximation [4]-[6] of field quantity. The approximation based on the radial basis functions is capable to handle multidimensional multiminima functions by interpolating their non-uniformly scattered data, accurately. The procedure could be applied to various EM field problems not depending on the frequency range.

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II. Maximum assessment

The procedure for estimating the maximal value of electromagnetic field quantity is outlined in a couple of steps: (A) multiquadric approximation of field quantity, (B) minimization of objective function.

A. Multiquadric approximation

The vector of independent parameters, represented by the space co-ordinates, can be written by:

$$\mathbf{P} = \begin{bmatrix} x & y & z \end{bmatrix}^t . \qquad (1)$$

The parameters are generally subjected to both inequality and equality constraints:

$$g_m(\mathbf{P}) \geq 0, m = 1,2,\ldots,n_{t1}, \qquad (2)$$

$$h_m(\mathbf{P}) = 0, m = n_{t1} + 1, n_{t1} + 2, ..., n_{t1} + n_{t2}, \quad (3)$$

where n_{t1}, n_{t2} are the total numbers of inequality and equality constraints, respectively.

Applying the procedure, a vector related with the maximal value of field quantity is assessed, fulfilling the imposed constraints. The measurement of discrete field quantity values would require rather high effort, if applied to a large number of parameter vectors. Hence, the procedure of the maximum assessment is performed via the multiquadric approximation [4]-[6] of field quantity.

The approximation is determined by:

$$FV_{MQ}(\mathbf{P}) = \sum_{j=1}^{M_p} c_j r(\mathbf{P})_j \ , \quad (4)$$

where: M_p is the chosen number of measurement points P_j, having the measured field quantity values $FV_j(P_j)$ and c_j stand for the approximation coefficients, while

$$r(\mathbf{P})_j = \sqrt{\left\|\mathbf{P} - \mathbf{P}_j\right\|^2 + h_z}, \ j = 1,2,...,M_p \quad (5)$$

The value of M_p should be a compromise between opposite requirements: the higher accuracy of the multiquadric approximation and the lower measurement effort. The shift parameter h_z can be determined by means of: (i) a statistical method reported in [5], (ii) a few additional samples used for the error estimation [6], (iii) choosing h_z smaller than the average spacing of the measurement points. The unknown coefficients c_j are calculated from the matrix equation:

$$\mathbf{c} = \mathbf{r}^{-1} \cdot \mathbf{FV} \ , \quad (6)$$

where :

$$r_{ij} = \sqrt{\left\|\mathbf{P}_i - \mathbf{P}_j\right\|^2 + h_z}, i, j = 1,2,...,M_p \ , \quad (7)$$

$$\mathbf{FV}=[\, FV_1(\mathbf{P}_1) \quad FV_2(\mathbf{P}_2) \quad \cdots \quad FV_{M_p}(\mathbf{P}_{M_p})\,]^{\mathrm{t}} \quad (8)$$

Hence, the discrete field quantity data, obtained by the measurement, are related with M_p sample points only, thus reducing the required measurement effort of the assessment procedure.

B. Minimization of objective function

Minimization of the objective function $-FV_{MQ}(\mathbf{P})$, resulting in the maximal value of field quantity assessed, is formulated by:

$$min(-FV_{MQ}(\mathbf{P})), \quad (9)$$

In order to perform the minimization procedure, i. e. to find the global minimum, a stochastic optimization method – differential evolution (DE) is applied [1]-[3], [6],[7]. The stochastic optimization method shows the well-known advantages over the gradient-based methods, namely: (i) the parallel global minimum search technique, (ii) the simplified set-up of the optimization task and (iii) the ability to find the global minimum.

A constant number n_p of parameter vectors, representing members of a population, is used in each generation G:

$$\mathbf{P}_{i,G}, i = 0,1,...,n_p - 1 . \quad (10)$$

The population of the first generation is chosen randomly via *rand* function. There are several variants of DE algorithms. The one, using the best population vector to generate a new population member, is selected as a part of the proposed technique. Hence, for each $\mathbf{P}_{i,G}$ there is the corresponding vector:

$$\mathbf{V}_{i,G+1} = \mathbf{P}_{best,G} + F(\mathbf{P}_{r_1,G} - \mathbf{P}_{r_2,G}) , \quad (11)$$

where: $\mathbf{P}_{best,G}$ is the member with the lowest objective function value of the generation G, r_1, r_2 denote randomly adopted integers from $[0,n_p-1]$, F is a real factor controlling the amplification of a weighted difference.

To enhance a new population diversity, the crossover of the vectors $\mathbf{V}_{i,G+1}$ and $\mathbf{P}_{i,G}$ is introduced, by which the new parameter vector:

$$\mathbf{U}_{i,G+1} = [u_{0i,G+1} \ \ u_{1i,G+1} \ ... \ u_{(n-1)i,G+1}]^t \quad (12)$$

is obtained as:

$$\mathbf{U}_{i,G+1} = \begin{cases} v_{ji,G+1} & for \ \ j = \langle k_n \rangle_n, \langle k_n + 1 \rangle_n, ..., \langle k_n + L_n - 1 \rangle_n \\ p_{ji,G} & for\ all\ other\ j \in [0, n-1] \end{cases} \quad (13)$$

where: n is the total number of independent parameters, $\langle \ \rangle_n$ stands for the modulo function with modulus n, k_n denotes the randomly chosen integer from $[0,n-1]$, L_n is the number of exchanged parameters from $[1,n]$.

The evaluation algorithm of L_n is given by the following pseudo-code lines:

```
Ln = 0;
do {
   Ln = Ln + 1
} while (rand ( ) <probC) and (Ln <n));
```

where: $prob_C$ denotes the crossover probability used as a control variable.

If the resulting vector $\mathbf{U}_{i,G+1}$ gives the objective function value lower than the one corresponding to the vector $\mathbf{P}_{i,G}$, and if $\mathbf{U}_{i,G+1}$ fulfils the constraints, as well, it replaces $\mathbf{P}_{i,G}$ being a population member of the generation $G+1$: $\mathbf{P}_{i,G+1} = \mathbf{U}_{i,G+1}$. Otherwise, $\mathbf{P}_{i,G}$ is retained as a member of the generation $G+1$. The vector providing the maximal value of field quantity equals the best vector assessed upon the prescribed number of generations:

$$\mathbf{P}_{max} = \mathbf{P}_{best,G_l}\ , \tag{14}$$

where G_l is the number of the last generation. The corresponding maximal value is given by:

$$FV_{MQ}^{MAX}\,(\,\mathbf{P}_{max}\,) = \sum_{j=1}^{M_p} c_j r(\,\mathbf{P}_{max}\,)_j\ . \tag{15}$$

III. EXAMPLE OF MAXIMAL FLUX DENSITY ASSESSMENT

The procedure is illustrated on the assessment of the maximal magnetic flux density generated from two typical medium-voltage to low-voltage (MV/LV) indoor urban power substations. Urban power substations in Croatia reduce medium voltage *10 kV* to primary distribution low voltage *0.4 kV*. Measurements of magnetic fields produced by the operation of typical indoor urban power distribution substations have been conducted in the area around the substation. A brief description of the instrument used for measurements is provided. Descriptions as well as the cabin configuration of the substations are given.

The magnetic flux density from substation has been determined via the computations or/and measurements [8]-[17], where a number of the three-dimensional as well as the contour plots has been shown. Nevertheless, they provided a useful description of the field characteristics, no technique incorporating certain optimization method for assessing the maximal value of the flux density has been proposed in these papers.

A. Magnetic Fields from Urban Power Substation

A substation consists of switching, controlling and voltage step-down equipment arranged for distributing electricity to residential, commercial, and industrial loads. Magnetic field environment in and outside substations is of concern to the electricity utility industry and the public.

Substations are often placed in buildings where people spend a significant part of the day. Common locations are cellars. Therefore, the installation and presence of MV/LV substations in urban areas is a difficult task when considering electromagnetic human exposure to power frequency magnetic fields. For technical reasons, as well as the impossibility of finding a place for the substation, there is often no option but to construct indoor urban power substations within buildings. Whenever possible, they are made as stand-alone indoor substations burdened with additional costs (construction works, additional equipment, doors, etc).

The flux density distribution significantly depends on current distribution between individual lines and buses [10]. Also, an unbalance of the three-phase current system could result in the greater flux density values due to the significant currents flowing through the feeder neutrals, grounding conductors, ground grid loops, as well as the other metallic structures in the power substation. Moreover, nonlinear loads and sources are found to be the cause of the current distortion, thus affecting the flux density values. In particular, the single phase nonlinear loads produce zero sequence odd harmonics (3rd, 9th, 15th, etc.), having a "multiplying effect" on the neutral return wires. Magnetic fields produced by urban power substations are in general, elliptically polarized since magnetic fields are typically produced by multiple current sources that are not necessarily in phase. Elliptical polarization assumes that there are no harmonics present in the field. The polarization of fields with harmonic content is more complicated. The magnetic flux density vector including multiple frequencies can trace a complicated, three-dimensional pattern [18]. Therefore, power substation is considered to represent a complex source of magnetic flux density produced by different equipment (power cables, transformers, overhead lines, bus-bars, etc.).

B. Measurement of Urban Power Substation Magnetic Fields

Substation magnetic fields are more complex and more difficult to measure than magnetic fields near power lines or homes. Currently, there are no established protocols for measuring magnetic field produced by urban power substations. Since the field pattern produced is quite complex it is difficult to characterise it in a simple way. This situation leads to incomparable data and confusion regarding the results of various research studies. Before developing a measuring method various items are to be considered i.e. all sources of magnetic field (types and locations of transformers, panels and other electrical devices), substation layout and geometry and electrical diagrams of substation elements (incoming and outgoing cables, buses…). Consequently, a decision regarding format of data and spacing between measurements is to be made. Large spatial and temporal variability in the magnetic field demands extensive measurements in and around urban power substations and background information regarding conditions during the measurement. In general, magnetic field measurements can be done in two ways (i) Spot measurement in fixed space-time points (ii) Measurements of human exposure. *Spot measurements* are used to identify the magnetic field levels. Spot measurements vary from *single spot measurements* to *site monitoring* (continuous measurement, repetitive measurement, manual recording, automatic data logging, averaging). Spot measurements represent a “snapshot” in time of the magnetic field level, and can be very poor indicators of temporal and spatial variability of the field [19]. In order to understand the nature of field sources better, spot measurement over an extensive area is more reliable. *Measurements of human exposure* or *personal measurements* are usually integrated in larger studies of health aspects (biological and epidemiological) and provide information on time-location activity of the subject to be examined. Usually, a portable instrument, with option to measure *time–weighted-*

average (TWA) directly, is to be carried by the subject during the measurements [20].

In this work, fixed space-time measurements were taken around two typical indoor urban power distribution substations in Split, Croatia.

C. Measurement Uncertainties

Measurement uncertainties are associated with: (i) Instrument properties (type, design, calibration) (ii) Unknown spatial distribution of the field, (iii) Temporal variations (fluctuations of load current i.e. magnetic field) and (iv) Non-uniform fields.

The uncertainties in the first category are usually refered as measurement accuracy. Uncertainty due to spatial distribution can be reduced by providing extensive measurement in and around the substation. Magnetic fields have unknown temporal variations. Temporal variations are known to be one of the largest sources of uncertainties for electromagnetic field measurements [21]. Thus, while a spot measurement at some location may be performed with good accuracy, it will not be possible to specify with confidence what the variability will be without additonal measurement [19]. High uncertanities can occur when measuring highly non-uniform fields close to the source of the field [22].

D. Urban Power Substations - Description and Configuration

A newer constructed indoor urban power substation in Croatia consists of input and output medium-voltage supply cables that lead to a medium-voltage switchboard installed upstream the transformer. Downstream the transformer is a distribution switchboard that connects various numbers of outgoing low-voltage distribution cables. Older constructed substations have a 3-phase medium-voltage bus and boxes instead of an medium-voltage switchboard.

Urban power substation Škrape 10 is located in the centre of the town Split, Croatia. Two features made this station suitable candidate for magnetic field measurements: (i) it supplies a high-density urban area; (ii) the outside area is relatively uncluttered allowing a closely space grid of measurement points to be defined over an extensive area around the substation. Figures 1. to 4. show a geometrical layout of the substation and numbered list of equipment. Two primary feeder cables coming from cable duct are connected to the horizontal bus bar through incoming and outgoing switch. The bus height is *3 m*. The bus is connected to the transformer through the circuit breaker and line switch placed in the box. Transformer secondary connected to *0.4 kV* switchboard is supplying 10 low voltage outgoing distribution circuits. The transformer and all other equipment except the bus bar are placed at the ground level.

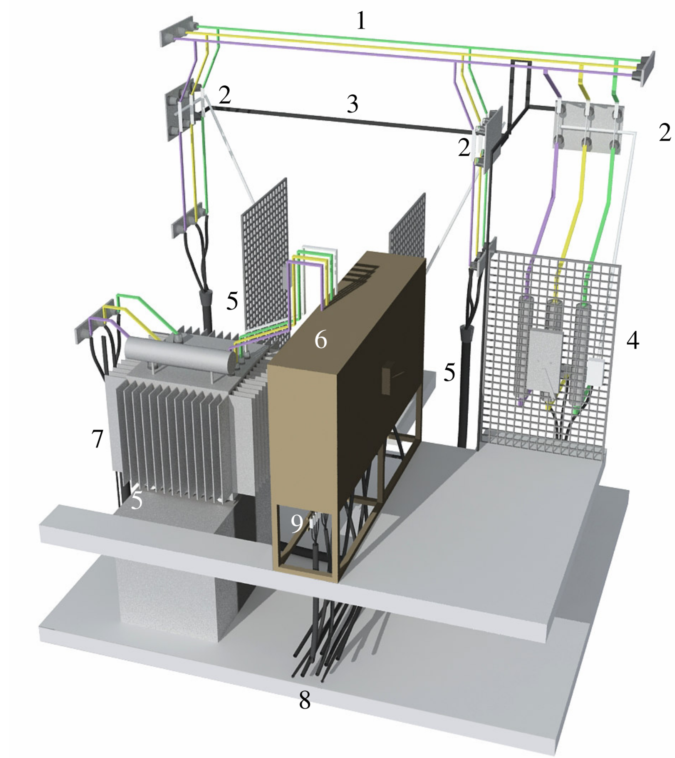

Figure 1: Equipment of urban power substation Škrape 10

1. Medium voltage rigid bus
2. Medium voltage switch
3. Bonding wire
4. Medium voltage circuit breaker box
5. Medium voltage cable
6. Low voltage switchboard
7. Transformer
8. Low voltage cables
9. Low voltage fuses

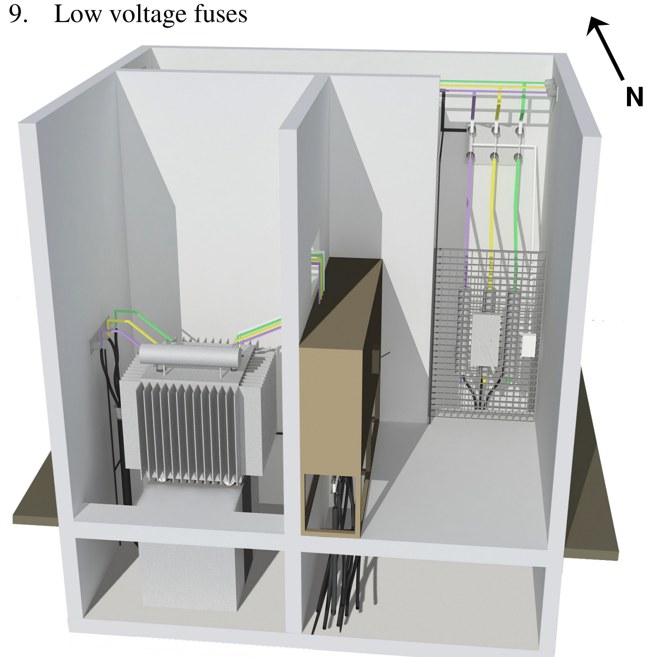

Figure 2: Layout of urban power substation Škrape 10 – southern side

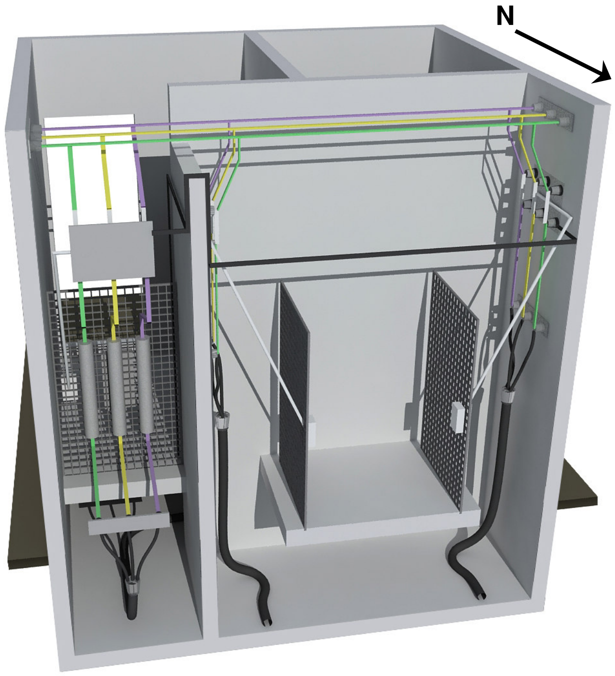

Figure 3: Layout of urban power substation Škrape 10 - northern side

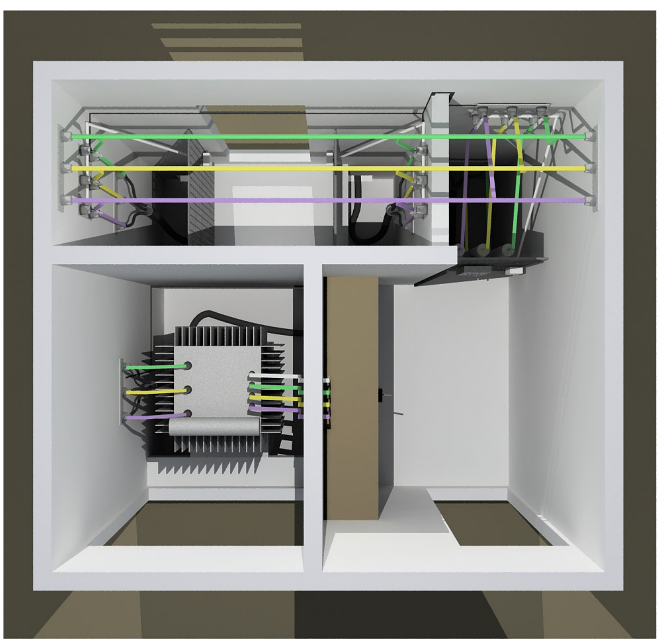

Figure 4: Layout of urban power substation Škrape 10 – top view

Urban power substation Podi 9 is located in Dugopolje in the industrial-commercial zone Podi. This substation has become candidate for magnetic field measurements because it is a typical newer generation substation built. The intention was to check whether this kind of power substation provides smaller value of magnetic field compared with the older type of substations. The extensive area around the substation was also suitable for measurements. *Figures 5. to 7.* show a geometrical layout of the substation and numbered list of equipment. The primary main feeder cables coming from the cable duct are connected to the medium-voltage switchboard. One cable runs to the transformer through the duct with the secondary connected to the low voltage switchboard supplying *9* low voltage outgoing distribution circuits. All equipment is placed at ground level.

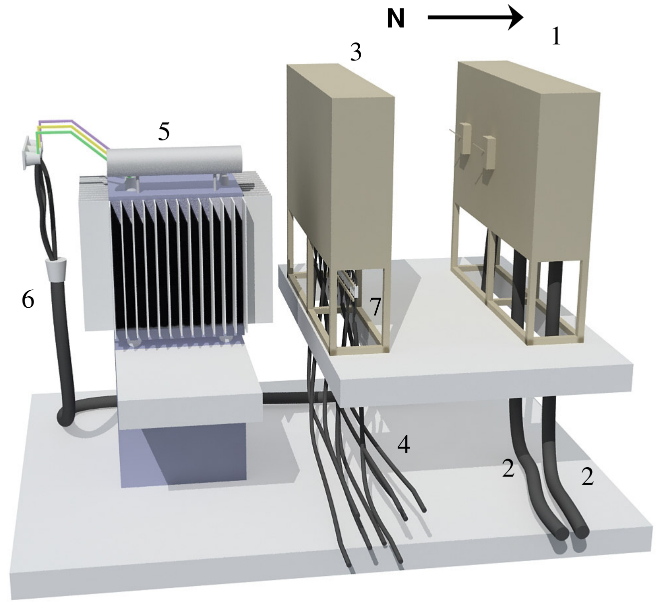

Figure 5: Equipment of urban power substation Podi 9

1. Medium voltage switchboard
2. Medium voltage cables
3. Low voltage switchboard
4. Low voltage cables
5. Transformer
6. Bonding cable
7. Low voltage fuses

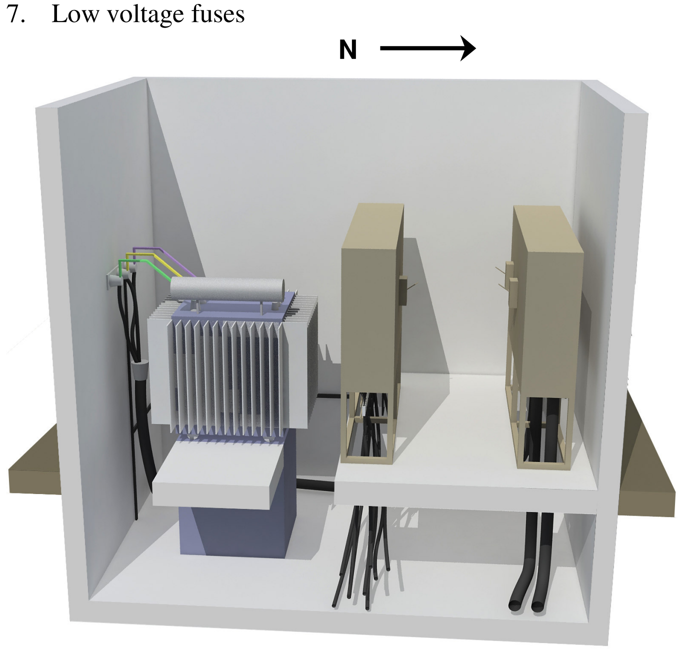

Figure 6: Layout of urban power substation Podi 9– eastern side

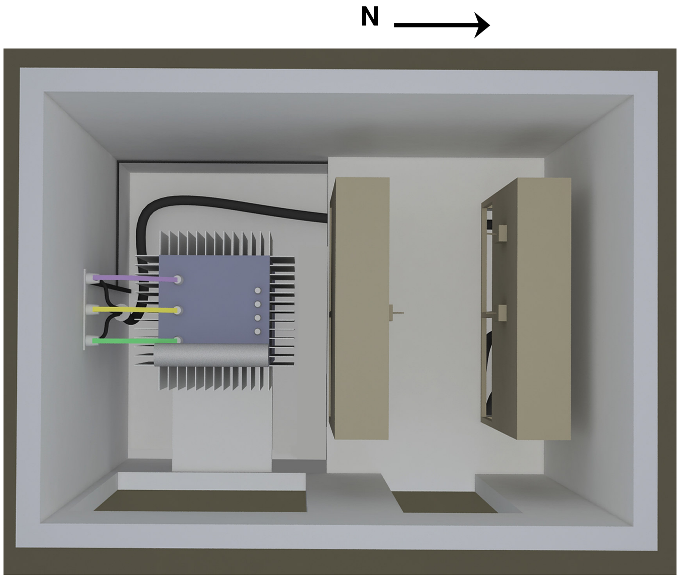

Figure 7: Layout of urban power substation Podi 9– top view

E. *On Site Measurements*

All the flux density levels are measured at a meter above the ground *(z=1m)*. It should be emphasized that there is no possibility of the public exposure within the distribution substation, while the professional exposure is strictly limited to duration. Consequently, the measurements were performed outside the substation, only.

The three-axis ELF µT-meter – *Model 4090/F20-T*, produced by *Sypris*, was used to acquire the flux density values. The ELF meter has an accuracy of *1%*, resolution of $0.01\mu T$, frequency response of *20* to *2000 Hz (3 dB)* and measuring range of *0.01* to $199.9\ \mu T$, as well. All the measurements have been carried out in accordance with international standard *IEC 61786* [23], which was also adopted as a Croatian standard in *December of 2003* with the field sensors one meter above the ground. All measurements for one substation were made within one hour to obtain the set of measurement results with little fluctuation in the distribution load. Measurements were started in a time of a peak day demand. The measurements were taken manually. A three-dimensional plot of measurement points is shown in *Figure 8*. The measurements were recorded as vector of independent parameters with coordinate system in the centre of the substation:

$$\left\lfloor x, y, B_{(z=1m)} \right\rfloor \tag{16}$$

During the field measurements, the mean and instantaneous values of three-phase currents at the low-voltage side of transformers and outgoing cables were also recorded in order to define uncertainties due to temporal variations of the field.

Graphical presentations of measured and approximated values are divided in 8 sections (Southern, South eastern, etc..) as shown in Figure 9.

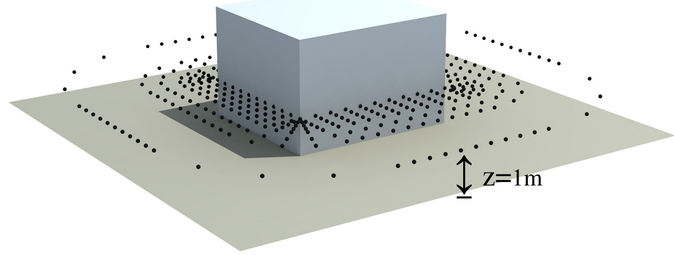

Figure 8: Three-dimensional plot of measurement points

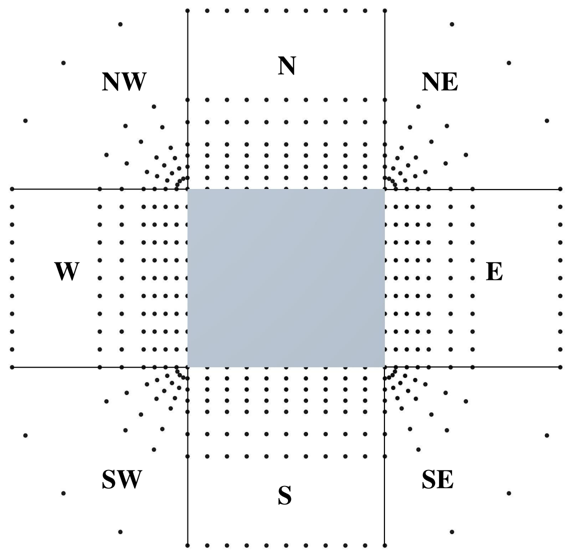

Figure 9: 8 sections for graphical presentation

F. *Results*

At the low-voltage side of the transformer the nominal values of phase currents were: $I_1=293\ A$, $I_2= 256\ A$, $I_3= 236\ A$ for substation Škrape 10 and $I_1=364\ A$, $I_2= 337\ A$, $I_3= 382\ A$ for substation Podi 9.

Temporal variations are presented as fluctuations of load current around the nominal value. Fluctuation of load current for substation Škrape 10 was between -8.5% and +7.4% of nominal value while fluctuation of load current for substation Podi 9 was between -5.3% and +5.4% of nominal value.

It is clear that uncertainties associated with temporal variations of the load current/magnetic field exceed uncertainties associated with calibration process and instrument design. The parameters x and y (1), yielding the maximal flux density value, have to be evaluated ($z=1m$). Restrictions are determined in the form of geometric equality and inequality constraints (2), (3) defining an acceptable change interval of the parameters:

- *Urban* power *substation Škrape 10*
  (-6.25m ≤ x ≤ 6.25m, -6m ≤ y ≤ 6m) \ (-2.25m < x <2.25m, -2m < y < 2m), z=1
- *Urban* power *substation Podi 9*
  (-5.7m ≤ x ≤ 5.7m, -6m ≤ y ≤ 6m) \ (-1.7m < x <1.7m, -2m< y < 2m).

The shift parameter h_z is chosen to be *0.01*, thus being considerably lower then distance values between the measurement points.

Sections of the multiquadric approximation of the power substation are shown in *Figures. 10 - 17*, respectively.

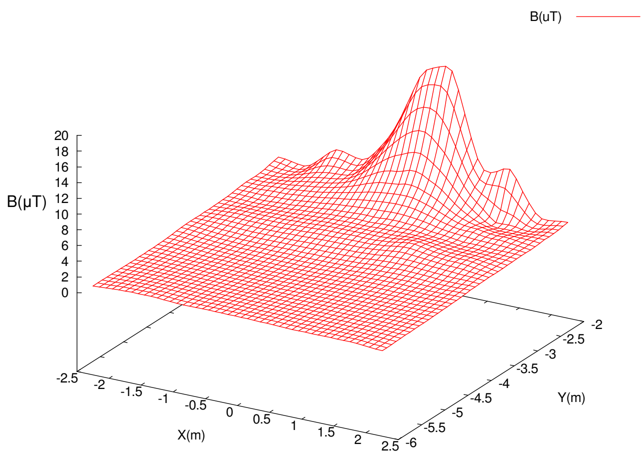

Figure 10: Section of the flux density approximation – Substation Škrape 10 - Southern side

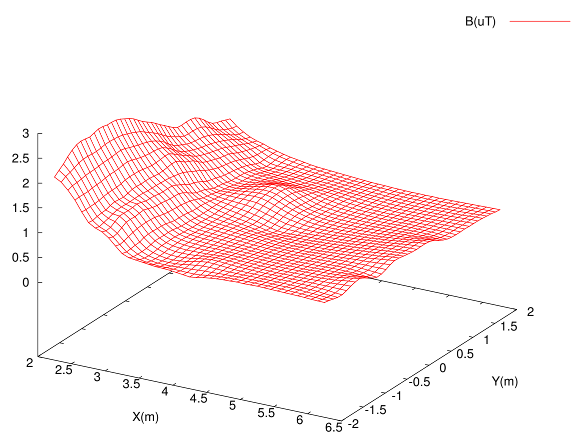

Figure 11: Section of the flux density approximation – Substation Škrape 10 – Eastern side

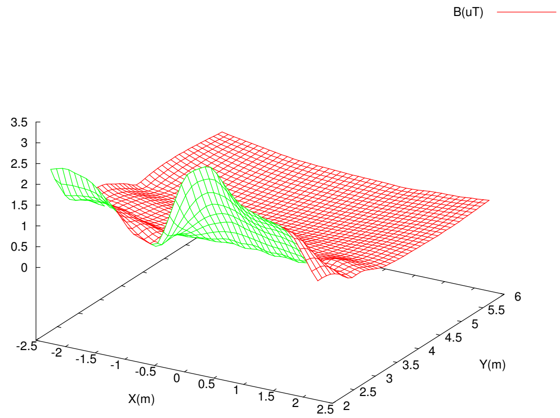

Figure 12: Section of the flux density approximation – Substation Škrape 10 - Northern side

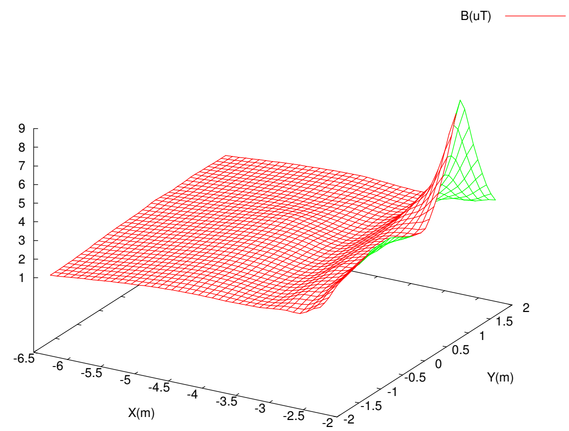

Figure 13: Section of the flux density approximation – Substation Škrape 10 - Western side

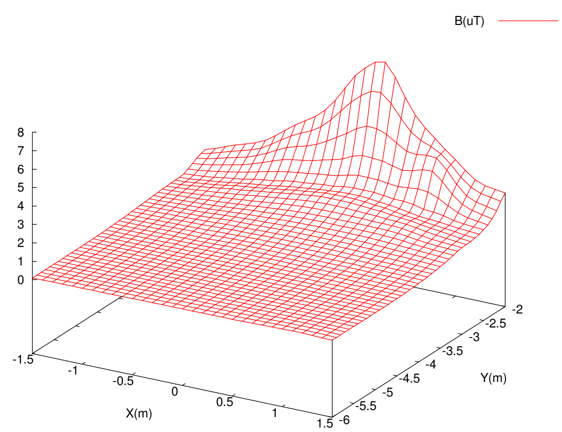

Figure 14: Section of the flux density approximation – Substation Podi 9 - Southern side

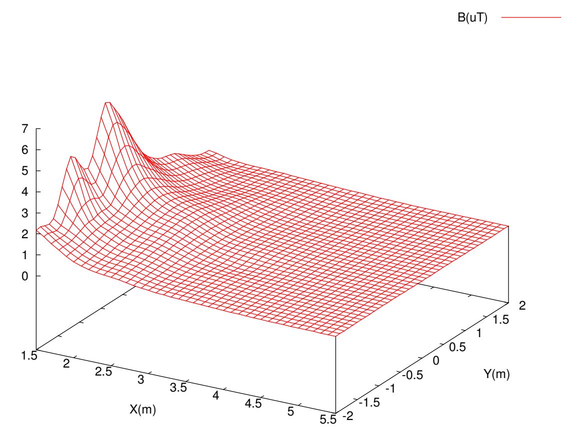

Figure 15: Section of the flux density approximation – Substation Podi 9 - Eastern side

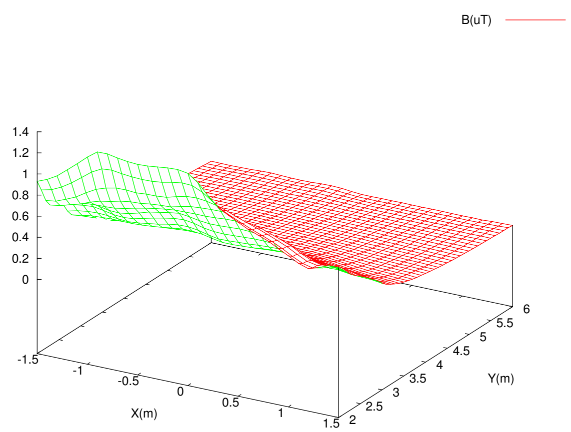

Figure 16: Section of the flux density approximation – Substation Podi 9 - Northern side

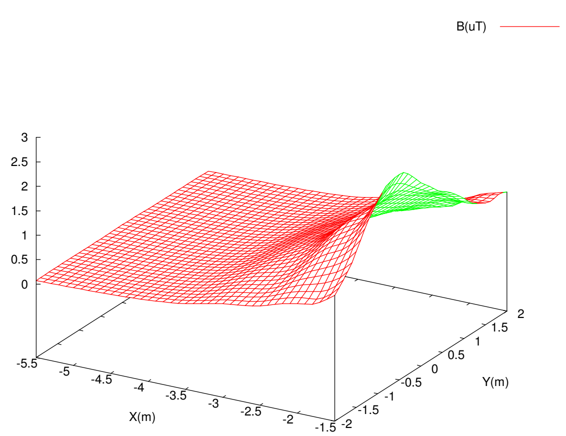

Figure 17: Section of the flux density approximation – Substation Podi 9 - Western side

Minimizing the negative approximation (9), the “maximum vectors”;$P_{max1}=[0.3679\ \ -2\ \ 1]^t$, yielding the maximal flux density $B_{max\ 1}=18.76\mu T$ for substation *10/0,4 kV Škrape 10* and $P_{max2}=[0.2702\ -2\ 1]^t$, yielding the maximal flux density $B_{max\ 2}=7.93\mu T$ for substation*10/0,4 kV Podi 9*, are obtained.

As can be seen, the approximation section associated with the southern side *(Figure 10)* of substation *Škrape10* contains the maximal value point $B_{max1}=18.76\mu T$. A low-voltage switchboard attached to a southern wall with outgoing cables down below affect the resultant magnetic field significantly as a result of higher current levels on low voltage side of the transformer compared to the medium voltage side and large clearance between cables and conductors. A transformer, a medium-voltage switchbox and an underground cable network also contribute to the resultant magnetic field but to a lesser extent. The value of the magnetic flux density approximation associated with the eastern side of the substation *(Figure 11)* does not exceed $3\mu T$ since there is no equipment in close proximity of the wall. The medium voltage cables, the low-voltage switchboard, the medium-voltage switchbox and the underground power network around the substation affect the magnetic field distribution in the approximation section associated with the northern side of the substation. However, the magnetic flux density does not exceed $3.5\mu T$ as a result of considerably lower current values at medium voltage side of the transformer *(Figure 12)*. On the western side of the substation *(Figure 13)*, the incoming cable that supplies the medium-voltage bus is attached to a western wall and it increases the value of the magnetic field significantly. The magnetic flux density reaches $9\ \mu T$. The transformer, the low-voltage switchbox and the underground cable network contribute less to the resultant magnetic field. No flux density value exceeds $2\mu T$ as long as the distance from the nearest substation wall is 4m at least, falling steeply off by going away from the substation.

In substation *Podi 9*, the low-voltage equipment is placed in the centre of the room. Therefore, its contribution to the resultant magnetic field is lower. Incoming and outgoing cables are coming from the deep cable duct and do not increase the level of the field significantly. The approximation section associated with the southern side of the substation (Figure 14) contains the maximal value point $B_{max2}=7.9327\mu T$, where the main field sources are low-voltage switchboard and transformer. Partial contribution of incoming and outgoing cables to the resultant magnetic field distribution can be seen on the approximation section associated with the eastern side of the substation shown in *Figure 15*, where the magnetic flux density reaches $6\mu T$. On the northern side of the substation (*Figure 16*), the magnetic flux density approximation does not exceed a value of $1.3\mu T$ since the main source of the field is the medium-voltage switchboard. There is no underground network or feeder cable contribution in the western side of the substation. From the section of the flux density approximation shown in *Figure 17*, it is easy to infer that the low-voltage switchboard is the greatest source of magnetic field, while the transformer contributes to a lower extent compared to the medium-voltage switchboard. No flux density value exceeds $0.2\mu T$ as long as the distance from the nearest substation wall is 4m. Generally, the magnetic field levels from *TS Podi 9* are lower although the measured values of phase currents show considerably greater values compared to the measured values of phase currents from *TS Škrape 10.* The low-voltage switchboard produces the greater density levels comparing to the distribution transformer. Hence, the corresponding rearrangement of the substation equipment can reduce the density levels.

G. Comparison Of Computed Results With Safety Standard

Results of maximal flux densities obtained are presented in Table 2 while reference levels values for *general public exposure of ICNIRP* [24] and *Croatian EMF protection regulation* [25] are given in *Table 3*. The limits presented in the table are for the general public exposure, since the area around substation is normally occupied by public.

Table 2: Maximal flux densities from power substations

Substation	B_{max} [μT]
Substation Škrape 10	18.76
Substation Podi 9	7.93

Table 3: Reference levels values for the general public

Standard	B_{max} [μT]
ICNIRP guidelines (1998)	100
Croatian EMF protection regulation (2003)	40

Comparison of the computed results with safety standards shows that the results of maximal flux densities are shown to be well below safety limits.

IV. Concluding Remarks

The measurement of discrete electromagnetic field quantity values generated by power substation in order to accurately find a global maximum would require rather high effort. To solve this problem, this paper introduces an assessment technique of the maximal field value based on a limited number of measured values, thus reducing the required measurement effort. The field function may have a number of local extremes arising from the fact that the substation represents a complex concentration of magnetic field sources (power cables, busbars, transformers, overhead lines, capacitor banks, etc.). The procedure includes the multiquadric approximation of field quantity obtained using the discrete measured data set. The approximation is capable to handle multidimensional multiextreme functions by interpolating their discrete values accurately. Subsequently, the maximal value of field quantity is assessed by minimizing the negative multiquadric approximation via a stochastic optimization method – differential evolution.

To improve understanding of ELF magnetic field characteristics in AC power substations and to determine which pieces of equipment within a substation are the main sources of magnetic fields, ELF magnetic fields generated by a typical distribution substation were measured and calculated.

The results indicate that magnetic field distribution is significantly influenced by the substations layout. The low-voltage switchboard produces the greater density levels compared to the distribution transformer and medium-voltage equipment, thus having the greater influence on the ambient magnetic fields. In power substation *Podi 9*, where low-voltage equipment is placed in the centre of the room, the ambient magnetic field is significantly lower than the magnetic of substation *Škrape 10* where the part of the equipment is attached to the wall. The magnetic field levels fall off rapidly away from the substation.

The computed results have been checked against international safety guidelines. The relevant results show that the magnitudes of the measured field values are within recognized guidelines, suggesting that the fields are not dangerous and, therefore, are no cause for concern for the public.

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