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Assessing the Level of Electromagnetic Pollution through Statistical-probabilistic Methods and Fuzzy Logic

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This paper is dedicated to the analysis of the possibilities of assessing the level of electromagnetic pollution in the public spaces and the lucrative areas on the application of some statistical and probabilistic methods and by fuzzy modeling. The proposed models are applied to several components of the electrical grids located in Oradea or Bihor County.The first part of the paper ishows the statistic-probabilistic methods. There are presented models for calculating the level of electromagnetic pollution based on the probability of exceeding the dangerous threshold values of the characteristic magnitudes of the electromagnetic field. The second part is allocated to assessing the level of electromagnetic pollution by using fuzzy logic. There are elaborated models for fitting the values of electromagnetic field values into the risk levels given by the exposure of the organism in the electromagnetic field. By using the fuzzy toolbox from the Matlab software, the rules of inference for the specific conditions of electromagnetic field exposure and exposure, applied in power plants in Bihor County, are applied.

Keywords: *electromagnetic pollution effects, statistical-probabilistic, fuzzy logic*

1. Introduction

Many of the electromagnetic processes are random events whose characteristic quantities cannot be accurately determined. These processes include the production of over-voltages and short-circuit due to deterioration of electrical grids insulation. Other uncertain events are the negative effects of exposure to living organisms into electromagnetic field. The electromagnetic field (EMF) has a double effect on the human body given by beneficial or useful actions such as medical implications or harmful actions of atomic particles in motion or electromagnetic waves of high energy leading to destruction of body cells. The paper treats the effects of non-ionizing electromagnetic waves. Global research leads to two conclusions about the negative effects of non-ionizing electromagnetic field exposure. Exposure does not have adverse effects on health and contrary, it produces unpleasant to very serious actions on the human body [9].

Due to the fact that there is no consensus on the results of the research and the existing data are influenced by several characteristic quantities of the electromagnetic field and the generating sources, which in some cases show a high degree of uncertainty, it results that the effects of biological systems exposure in electric and magnetic field can treat through statistical-probabilistic methods and fuzzy logic.

However, minimum values of the electric and magnetic fields are considered as dangerous for health and are given by international laws adopted in many countries [12] - [17]. They are in line with the principles of electromagnetic compatibility and prevention. Compared to these normed values, is set in the paper the level of electromagnetic pollution. Among the electromagnetic field exposure affections are included [7][9]: dizziness, fear, trembling, metabolic disorder, nervousness, headache, heart rhythm disorders, impotence, sterility, chronic diseases etc. The electromagnetic field actions may be of the thermal and non-thermal nature. These depend on exposure parameters such as: frequency of the electromagnetic field, exposure time, distance to the source, the values of electric and magnetic fields characteristic quantities(CQ), E – electric field strength (V/m), B – magnetic field density(T), etc. Electromagnetic pollution sources are natural, as is our planet with its own magnetic field or receiving electromagnetic waves from the cosmos and anthropology given by human creativity, as is the case with electronic and telecommunication equipment, household electric devices or power grids.

2. Description of the categories of methods used

According to the recognized principles, the adopted analytical models must be fairly true of the real case because after the simulation with PC support, the results are credible [10]. Thus, the method errors will be minimal.

The values of the electromagnetic field quantities for which the actions on health are dangerous and against which the level of the electromagnetic pollution is assessed are given in the regulations for the general population and the employees from the field sources work spaces, such as the case of the generation, transmission and distribution of the electricity domain. In the paper we use the electric field strength (E) and the magnetic field density (B), because these parameters are measured more easily with dedicated devices. Thus, for the general population the admissible values are [14]: E_a = 5000 V / m, B_a = 100 μT. For lucrative personnel [13]: E_a = 10000 V / m, B_a = 500 μT.

In the applied methods we use the stabilized field of electromagnetic field with 50 Hz frequency, which is the permanent normal state of alternating current within the electric networks.

By looking at the graphs of normal distributions in figure 1 (a, b) one can appreciate the risk generated by producing an unwanted event by leaving the chosen significance range [11].

The relationship between the significance range and the level of significance is given by the formula [11]:

$$P(\theta < \theta_\alpha) = 1 - \alpha \quad (1)$$

For an unilateral riskl, or by relation:

$$P(\theta_{1-\frac{\alpha}{2}} < \theta < \theta_{\frac{\alpha}{2}}) \quad (2)$$

For a bilateral risk.

where: 1- α is the level of significance;

θ_a - θ_b = range of significance; α – risk

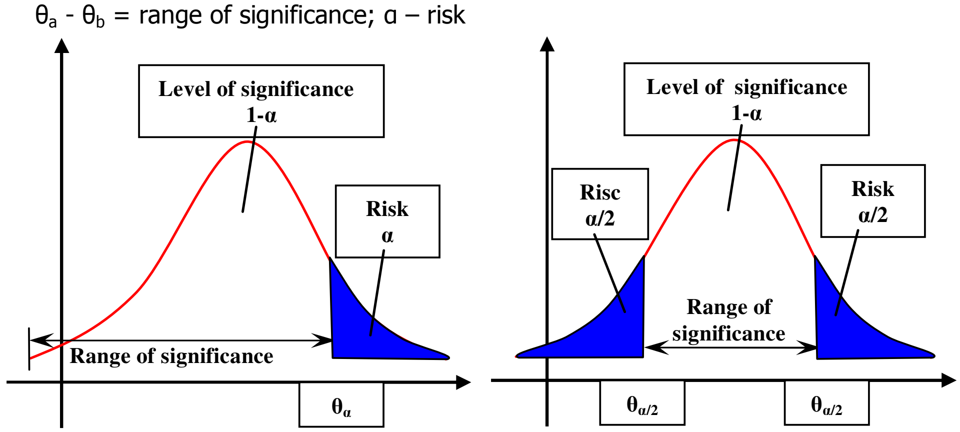

Figure 1. Relationship beetwen range of significance and probability for an unilateral risk[a]and a bilateral risk(b)

The effects of stabilized EMF against the persons which interferes with it, can be estimated by the cumulative total value of the consequence:

$$C = \sum_{j=1}^{M} p_{EV_j} \times c_j \quad (3)$$

where:

p_{EV} – the probability of occurrence of the unwanted event (EVN);

c – unitary severity of the consequence;

j = 1...M – number of persons exposed in dangerous EMF(EMFd) into a time analysis interval (TA).By EMFd is meant that EMF whose characteristic sizes B (magnetic induction) and / or E (field strength) exceeds the admissible values (B_a, E_a).

The unitary severity of the consequence (c) materializes by the degree of damage to the health of a person exposed to EMFd, which is in direct relation to the power Specific Absorption Rate SAR [12]-[18]. If we work with a mean (non-personalized) value of the consequence, according to current norms [19], it can be written:

$$C = c_{med} \sum_{j=1}^{M} p_{EV_j} \tag{4}$$

In this case, the unit gravity of the consequence is considered a deterministic size and the analysis will focus on the random variable (p_{EV}), which can be expressed with the relation:

$$p_{EV} = p \cdot p_p \tag{5}$$

Where, p – probability of simple event (EVS_1):"existence of EMFd in point M";

p_p – probability of simple event (EVS_2): "the human presence in area of EMFd"

For a certain person (j), the value (p_{pj}) will be estimated with relation:

$$p_{pj} = \sum_{j=1}^{k} \frac{t_{jk}}{T_A} \tag{6}$$

Where t_{jk} – time domain in which it is realizing EVS_2 with reference to person "j".

Under these conditions, the analysis will focus on size "p". Given the character (p, c) - random and imprecise levels - the subject can be treated by applying probabilistic modeling. With reference to the EVS_1 probability calculation, for one of the characteristic sizes of the EMF (B or E), where appropriate with one of the relations [4][5]:

$$p_{nx} = \frac{1}{\sqrt{2\pi} \cdot \sigma_{Xm}} \int_{X_a}^{\infty} e^{-\frac{(X_m - m_{Xm})^2}{2 \cdot \sigma_{Xm}^2}} dX_m, \quad X=\{E,B\} \tag{7}$$

where, X_m – the measured values of the characteristic sizes;

X_a – the admissible values of the characteristic sizes;

X_i – the coordinate of the intersection point of the two distributions (admissible values, measured values).

We considered that the measured values of CQ varied according to a normal distribution low. The admissible values are fixed, indicated in a normative for case 1 and the admissible values are the mean values of some (E, B), random variables in case 2(n = 1,2).

The two relationships are expressions of probability (p), with reference to each size (B, E). In fact, the two characteristic sizes coexist in EMF formation. In this paper we will evaluate the probability EVS_1 in real conditions: „ B or/and E exceed the admissible / supportable values"(B_a, E_a). So:

$$\begin{cases} p_1 = p_{1B} + p_{1E} - p_{1B}p_{1E} \\ p_2 = p_{2B} + p_{2E} - p_{2B}p_{2E} \\ p_{EV1} = p_1 \cdot p_p \\ p_{EV2} = p_2 \cdot p_p \end{cases} \tag{8}$$

The fuzzy logic was enunciated in 1965 by L. Zadeh, who put its mathematical bases in a first form [10]. Fuzzy logic allows the formalization of impurities due to the global knowledge of a very complex system and the expressions of system behavior in a word system. It allows the standardization of a system description and the processing of numerical data as if it were expressed in linguistic data [10].

The specificity of a fuzzy system is that it can simultaneously control numerical data and lexical knowledge. In a fuzzy system executes a non-linear transformation on the input data stream resulting in a scalar output. Fuzzy systems are considered a particular case of expert systems [6]. A fuzzy set or a vague one is a set about which do not know to much exact things.A Fuzzy Set is completely defined by the universe of values X and by membership function (MF) ce descrie valoarea/ gradul de apartenenţă μ la clasa elementelor din univers.

Let X be the universe of discourse, with elements noted x. A fuzzy set A of universe of discourse X is characterized by a membership function A(x) which associated to each element x an membership degree $\mu_A(x)$ at the set A[10]:

$$\mu_A(x): X \rightarrow [0,1] \tag{9}$$

To represent a fuzzy set, must define the first his membership function. In this case, a fuzzy set A is complete define by lot of doublets:

$$A = \{[x, \mu_A(x)] \mid x \in A\} \tag{10}$$

Membership function μ*A* thus associates each element *x* mambership degree to the fuzzy set *A* and membership degree μ express the extent to which one element belongs to a fuzzy set. There are several types of membership functions or fuzzy numbers: singleton, triangular, gamma, "S", „ п", trapezoidal, gaussian, etc [2][10].

The typical structure of fuzzy inference systems is a pattern that performs a certain correspondence: firm entry value - membership functions of entrance – inference rules – output characteristics – memebrship functions of exit – firm exit value. The structure of a fuzzy system is shown in Figure 3, having the form in which it is found or described in other specialized papers [1] [2] [10]. On the model, X_i is the input sizes and Y_i, the output ones. Each block and link have specific functions [8][10].

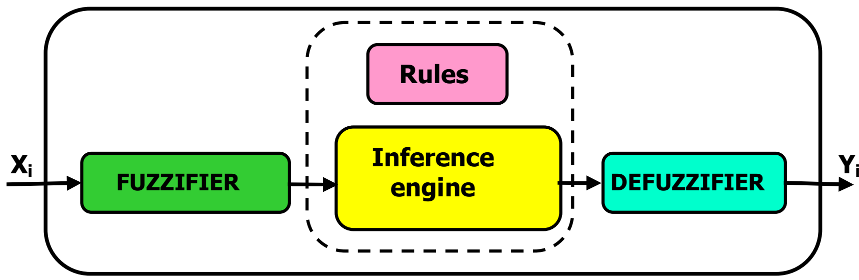

Figure 2. General scheme of a fuzzy system

To generate correlations between the exposure parameters and the level of health damage, different input sizes of the type [2] can be established: electromagnetic field frequency, magnetic induction and field strength, distance to source, exposure duration, age, gender, type of source, etc

The application of fuzzy logic can be done in other electromagnetic field issues, either singly or in combination with genetic algorithms, binary logic or neural networks, such as [1][3][6]: controlling the speed of an electric car by modifying electromagnetic parameters, the evolution of the electromagnetic compatibility of an electrical device according to the electrical and magnetic stresses occurring during the operation, identification of short circuits in the electrical circuits of industrial power networks, control of reactive power reactive and power factor increase etc.

3. Examples

For the first method, are calculated the values of the probabilities expressed with the relations (8) and the values of the EMF characteristic quantities assumed by means of dedicated measuring devices. In case of fuzzy analyze there will be degrees of influence on health which give the level of electromagnetic pollution (PEM) inside considered area. The example given in the second case comes from a more extensive study by authors on the high voltage level of 14 power substations (PS) belonging to the Bihor Power System. Was used Fuzzy Toolbox from the Matlab software, with input data as the E and B values, and as the output parameters are the effects of EMP on the human body.

In Table 1 are given the results obtained for the probability of exceeding the admissible values, with reference at the two characteristic quantities(CQ) E and B under the conditions of the two working hypotheses. The model presented applies for 9 PS from city of Oradea.

Table 1. Obtained values of probability of EMFd existence

No	PS	p_{1E}	p_{1B}	p_1	p_{2E}	p_{2B}	p_2
1	Velenţa	0,0346	0,0154	0,049	0,0646	0,0258	0,089
2	Oradea Centre	0,0252	0,0169	0,042	0,0552	0,0254	0.079
3	Crişuri	0,1034	0,0225	0,124	0,1205	0,0326	0,149
4	Oradea South	0,2076	0,0145	0.219	0,3195	0,0284	0,339
5	Oradea West	0,1175	0,0265	0,141	0,1815	0,0372	0,212
6	Eurobussines	0,0465	0,0154	0,061	0,0525	0,0263	0,077
7	Ioşia	0,0567	0,0264	0,082	0,0867	0,0387	0,122
8	Mecanica	0,0784	0,0165	0,094	0,0684	0,0255	0,092
9	Era park	0,0196	0,0126	0,032	0,0319	0,0194	0,051

The data processing process generates the situation in Figure 3. Data analysis allows for the storing of electrical stamps according to the value of probabilities of reaching the admissible values of the EMF characteristic quantities.

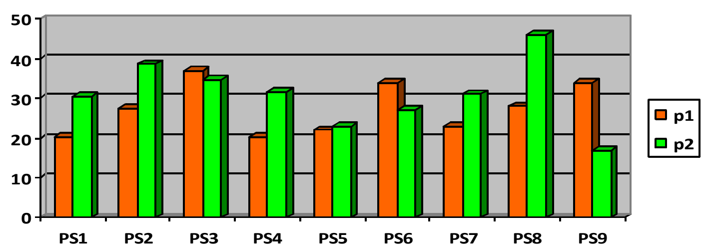

Figure 3. Statistical analysys results

For fuzzy modeling of EMP effects, the five Fuzzy Toolbox modules, each with specific functions [8], are used. The measured values of E and B are grouped on 4 levels according to the admissible values (Fig.4). The four levels are termed as linguistic expressions as such: level 1 is called „negligible", level 2 called „little", level 3 called „big" and level 4 called „very big". The individual levels of E and B have four degrees of influence (significant, high influence, very high influence). These levels combine in doublets, random, but consistent with other results reported in the literature and in the normative, forming five types of consequences against human health, framed as follows: very small, small, medium, high, very high. Measured values of CQ of EMF are grouped according to the number of appearances for each set level. From software will be generate automatically the effects on basis of inference rules established by authors which are entered into the software too, according to figure 5.

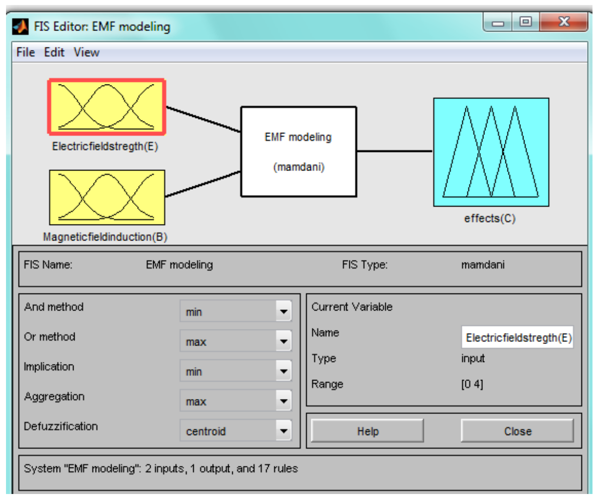

Figure 4. Inputs interface in Fuzzy Toolbox

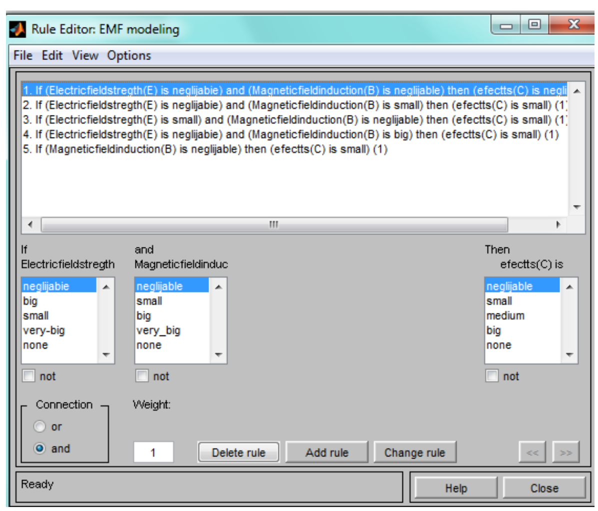

Figure 5. Interface for the inference rules establishment

Tables 2 and 3 present the results of applying the fuzzy model for Tileagd Power Substation (PS) for E and b at the high voltage level (HV). Table 4 summarizes the cumulative effects of E and B for all analyzed substations.

Table 2. Obtained values of levels of E

Code	Level	Signification of effects	Value ranges	No. of presences
1	Negligible	Insignificant	$E \leq 1/2\ E_a$	142
2	Little	Significant	$1/2\ E_a < E \leq E_a$	40
3	Big	High signification	$E_a < E \leq 2E_a$	15
4	Very big	Very high signification	$E > 2E_a$	3

Table 3. Obtained values of of levels of B

Code	Level	Signification of effects	Value ranges	No. of presences
1	Negligible	Insignificant	$E \leq 1/2\ E_a$	161
2	Little	Significant	$1/2\ E_a < E \leq E_a$	36
3	Big	High signification	$E_a < E \leq 2E_a$	3
4	Very big	Very high signification	$E > 2E_a$	0

Table 4. Total values of cumulative effects for E,B

Code	Signification	Levels of E,B combined	Appearances number
1	Very small	(1,1)	342
2	Small	(1,2); (2,1); (1,3); (3,1)	695
3	Medium	(2,2); (1,4); (4,1); (2,3), (3,2)	414
4	High	(2,4); (4,2); (3,3)	92
5	Very high	(3,4); (4,3); (4,4)	19

The resulting levels for the input sizes are centralized in Figures 6 and 7 for all the stations that were the subject of the study.

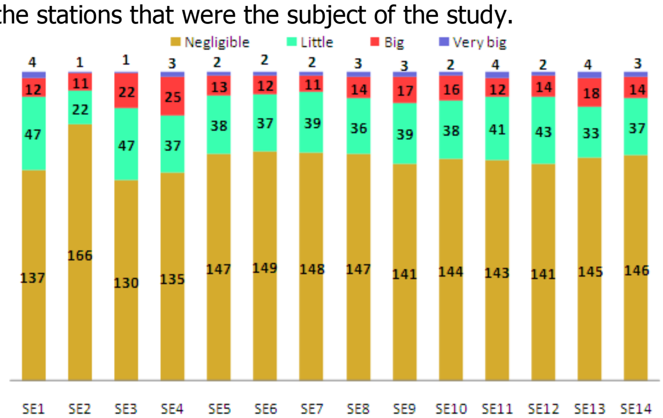

Figure 6. The intake levels of E on the whole PS- HV

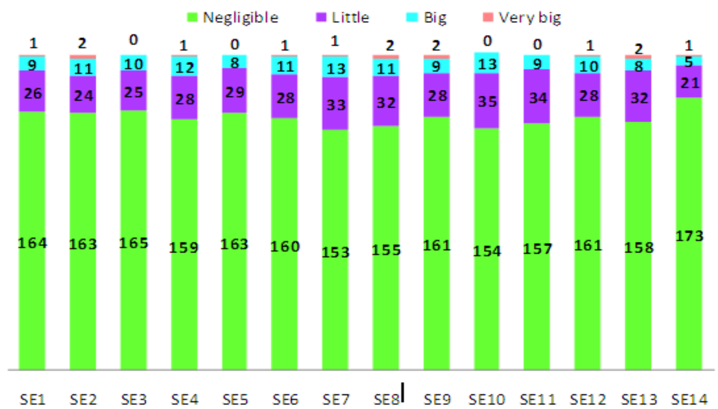

Figure. 7. The intake levels of B on the whole PS – HV

For each PS, were taken through measurements 200 values of electromagnetic field characteristic quantities .From the analysis of Figures 6 and 7 it can be observed that most of the occurrences are the low levels of the field strength of the electric and magnetic fields. As cumulative effects of sizes E and B(table 4), most values are included in small (695) and medium (414).

4. Conclusions

Assessing the probability of exceeding the normative values considered as generating adverse health effects is a step in the exposure risk assessment. The risk in this case can be defined as the product of the probability of exceeding the exposure limit values for E and B and respectively the consequences of these overshoots, the latter being the measure of the impact on human life or health. As the actual consequences cannot be determined deterministically each time especially because of the very high exposure time necessary to produce the unwanted effect will be associated with the effect of a vector of gravity attributing the different consequences.

The statistical methods based on the analysis of the real data obtained by measurements of E and B allow highlighting areas with intensive electromagnetic field, which are dangerous for health, and on the basis of the extrapolations of the results it is possible to draw up statistical forecasts for the future regarding the polluting tendencies of the electric and magnetic field sources the same nature and configuration as those investigated in the paper.

The methods for calculating the electrical and magnetic field characteristics (E, B) for electrical network components are currently well structured, clear, applicable by dedicated software packages. Determination by direct measurement of the characteristic EMF sizes is the safest way to determine the level of EMP that affects workers in installations with electromagnetic field sources and the general population. In addition to the electromagnetic field regime considered in the work can be considered abnormal regimes such as the transient considering events such as short circuits or over voltages. For electrical wiring, these events can generate emergency conditions. At the same time, although these phenomena last a little due to the functioning of the protections, they can generate high intensities of the electric and magnetic fields. Thus, with the input data of the proposed models, it is possible to choose combinations with a type of field parameter in normal mode and the same parameter in the damage mode.

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