

A few categories of electromagnetic field problems treated through Fuzzy Logic

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Abstract. The paper deals with the problems of fuzzy logic applied in the field of electromagnetism. In the first part, there are presented some theoretical aspects regarding the characteristics and the application of the fuzzy logic in the general case. Are presented then, some categories of electromagnetic field problems treated by fuzzy logic. The accent is on the effects of exposure to the electromagnetic field on the human body. For this approach is dedicated a paragraph at the end of the paper. There is an application on how to treat by fuzzy logic the effects of electric field exposure. For this purpose, the fuzzy toolbox existing in the Matlab software and the results of some electric field strength measurements into a power substation are used. The results of the study and its conclusions are analyzed and exposed at the end of the paper.

1. Introduction

Practical research on the impact of electromagnetic field with technical systems is very numerous and has significant results. The study of the impact of the electromagnetic field on living organisms has led to more or less accurate results, and those related to human effects have generated great controversy.. This is due to the need for extensive time extension of research or the impossibility of direct exposure of humans to the electromagnetic field for scientific laboratory analysis due to legal and obviously ethical or spiritual constraints. In order to eliminate this shortcoming, it is necessary either to extrapolate animal results or to statistically - probabilistic analyzes or to create physic - mathematical models that will present reality as faithfully as possible.

In Romania, studies related to the influence of the electromagnetic field on living organisms are not numerous. The exact cause cannot be ascertained, but perhaps the subject has not raised much interest amongst the specialists. An almost generalized interest is manifested in other countries, such as in the northern European continent or in the USA.

There have been results that highlight the damaging effects of the electromagnetic field, linked of course, to certain factors or characteristic parameters of field quantities or generating sources.

Among the diseases caused by electromagnetic field exposure, we mention [1-4]: dizziness, loss of memory or lack of concentration, anxiety, sleep disturbance, infertility and impotence, decreased vitality, brain tumors or other forms of cancer etc. Many other studies in the light of the results obtained do not certify the harmful effects of the electromagnetic field. However, in our country, as in other countries, it was not possible to impose on the general population certainty about the harmful effects of exposure to electromagnetic fields.



2. Fuzzy logic. A short presentation

The fuzzy logic was enunciated in 1965 by L. Zadeh, putting its mathematical foundations. Modeling through fuzzy logic allows for the formalization of imprecisions due to the global knowledge of a very complex system and the expressions of its behavior by a word system. It also allows the standardization of a system description and the treatment of numerical data as if it were expressed in linguistic data [5-8].

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 vector resulting in a scalar output. Fuzzy systems are considered a particular case of expert systems [6]. A fuzzy or vague crowd is a lot about which too many exact things are not known. There are several types of fuzzy systems according to the type of reasoning used [7], [9]: Mamdani, Larsen, Sugeno - Takagi, Tsukamoto etc. In fuzzy logic the domains correspond to the concepts of linguistic variables. The theory of fuzzy sets helps to transform qualitative human judgments into quantitative, discrete and deterministic numerical expressions.

The typical structure of fuzzy inference systems is a model that performs a certain correspondence: firm input value - input membership functions - inference rules - output characteristics - output membership functions - firm output 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 [5], [7], [9], [10]. On the model, x_i are the input sizes and Y_i , the output ones.

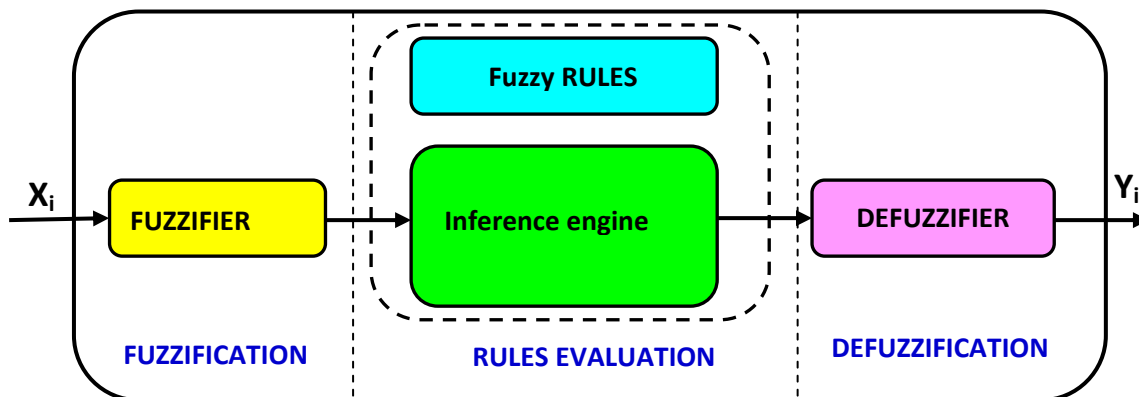


Figure 1. The structure of a fuzzy system and inference process [6]

Fuzzifier has the role of translating numerical expressions into fuzzy sets necessary for activating rules based on language variables and connectors.

The inference engine applies a transformation of the set of rules into fuzzy sets.

The defuzzifier executes the assignment of a real numerical value corresponding to a membership function(MF).

A fuzzy set is completely defined by the universe of values X and the function of belonging (MF) that describes the value / degree of belonging μ to the class of elements in the universe. Let X be the universe of the discourse, with elements notated x . A fuzzy set A of the discourse universe X is characterized by a membership function $A(x)$ which associates each element x with a degree of belonging $\mu_A(x)$ to the set A [7-10]:

$$\mu_A(x): X \rightarrow [0,1] \quad (1)$$

To represent a fuzzy set, the function of membership must first be defined. In this case, a fuzzy set A , is completely defined by the set of doublets:

$$A = \{[x, \mu_A(x)] \mid x \in A\} \quad (2)$$

The membership function(MF) μ_A thus, assigns to each element x the degree of belonging to the fuzzy set A and the degree of belonging μ , expresses the extent to which one element belongs to a fuzzy set. There are several types of distinct membership functions: singleton, triangle, gamma, "S", " π ", trapezoid, Gaussian etc. [5-7], [10].

Because it will be used in application from paragraph 5, here it's shown a MF by triangular type(trimf). This is defined by three parameters a, b, c , as follows:

$$\mu_A(x) = \text{triangle}(x;a,b,c) = \begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \quad (3)$$

Or, using the functions „mic” and „max”max, result:

$$\text{Triangle}(x;a,b,c) = \max\left\{\min\left(\frac{x-a}{b-a}, 1, \frac{c-x}{c-b}\right), 0\right\}, \quad (4)$$

with x being the element of the fuzzy set A with the center of the membership function in point c .

The discourse (speech) universe is marked on the abscissa (axis X) of the orthogonal system, which is the range of all possible values applicable to a variable. On the order (Y -axis), the degree of belonging is represented. Like other types of functions on it, dilators and concentrators can be applied. Concentration of a fuzzy set results in a reduction of the membership by square-up of the membership function values. Fuzzy dilatation increases the degree of belonging of a value to the fuzzy set by applying the square root extractor. The phrases of the two operators are [10]:

$$\text{a. Fuzzy concentrator:} \quad \mu_{\text{CON}(A)}(x) = (\mu_A(x))^2 \quad (5)$$

$$\text{b. Fuzzy dilator :} \quad \mu_{\text{DIL}(A)}(x) = \sqrt{\mu_A(x)} \quad (6)$$

Figure 2 shows the graph of a normal or Gauss MF, and in Figure 3 a graph of a triangular MF.

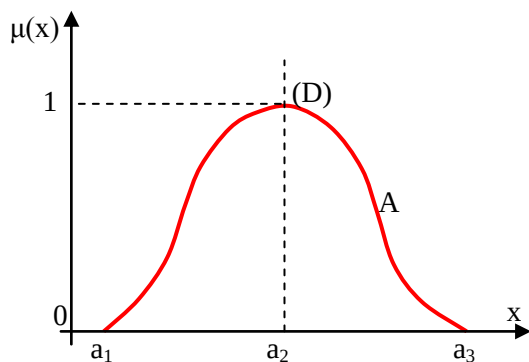


Figure 2. Gaussian MF, (D) – symmetry axis

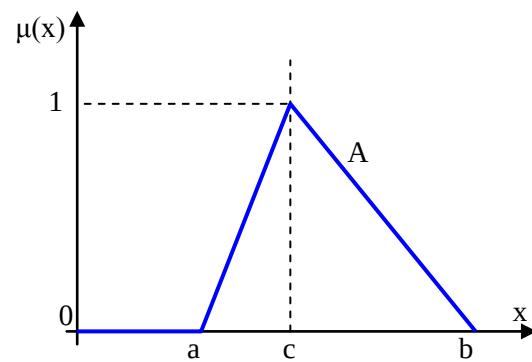


Figure 3. Triangular MF, (c) – set centre

In the paper application, an input variable in the fuzzy system is the age of man. Using this parameter will explain the difference between its treatment by fuzzy logic versus classical logic. In classical logic, the separation of levels is made after a fixed, deterministic value. Thus, a breakdown of age cycles and values in the years that define them are: childhood (0-14 years), adolescence (15-18 years), youth (18-35 years), maturity (36-60 years), old age > 60 years). Each of this range may have subdivisions with specific names [11].

In the graphs from Figure 4, the appreciation is random as intervals and was made by the authors. Age division has been conceived, however, in accordance with the active period of the man in which he is involved in the process of work in an organized form, in an economic institution.

In fuzzy modeling, the boundaries of each level will be merged by overlapping, because there is a different perception of people on them. For example, a 35-year-old person can be considered a young by a 50-year-old one, as well the same person, is considered old by a 19-year-old one. Age is an input variable in Matlab's fuzzy model that participates in assessing the effects of exposure, and the explanation for its perception is justified. Since every human being is unique in his own way, electromagnetic behavior can be considered different from person to person. This also suggests a different sensitivity to electromagnetic field exposure. So, the need to use fuzzy logic in the analytical and deliberative process is due to the assumption that the human perception is imprecise. For these reasons, the inference rules from the proposed application have also been formed.

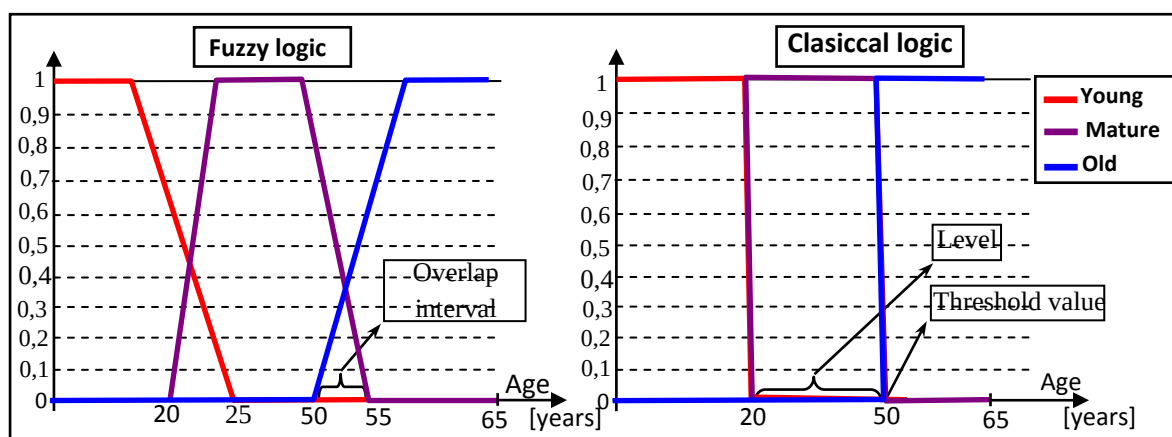


Figure 4. Active professional cycles of life in fuzzy logic and classical logic

3. Fuzzy Logic Toolbox from Matlab

For fuzzy modeling of applications in different fields, implicitly for electromagnetic field problems, it can use the dedicated toolbox, existing in the Matlab computer program.

This Toolbox has five components and functions as follows [5], [12], [13]:

- a). The Editor of the fuzzy system, named „FIS Editor” (Fuzzy Inference System), allows the creation of inputs and outputs in the system;
- b). The editor of the membership functions, i.e. fuzzy sets over the universes of the speech inputs and output variables of the system with fuzzy logic, named „Membership Function Editor”(MFE);
- c). The fuzzy rule editor, which allows the formulation of the set of rules of the fuzzy system, named „Rule Editor”;
- d). Rule view window, where you can see the degree of activation of each rule and the result or effects of each rule, generating exit from the system for a certain pass-through value of the user-defined entry (Rule Viewer);
- e). The Fuzzy Logic System Output Surface Viewing window, which graphically shows the dependence of the tangled output of the system with fuzzy logic on the fuzzy logic system inputs, determined by the fuzzy logic system operation; this dependence is generally known as the "system control surface," and the window appears under the name “Surface Viewer”.

Toolbox components are dynamically coupled to each other, so a modification of the parameter on a work page automatically generates the modification of the other component components, provided they are connected to the set of rules. The graphical presentation of the working windows for each component of a fuzzy module is presented in point 5 of the paper, in which a case study will be presented.

4. Fuzzy approaches of some electromagnetic fields problems

It can be remembered a number of older and established applications of fuzzy logic in various fields of science: automatic control (temperature rules, subway speed control, autofocus of cameras), medicine (control of pacemakers), form recognition (fuzzy classification algorithms), Economy (fuzzy decision methods) or measurements (processing information provided by sensors).

Fuzzy logic is a deduction system that uses the concept of "degree of truth" or "calculus with words". In binary logic a sentence can be "true," with a value of 1 or a "false" value of 0. In fuzzy logic a sentence can be half true and / or half false, or 15% false and 85% true, etc. The human brain efficiently and continuously processes data with a wide uncertainty such as "probable," "almost impossible," "very difficult," "acceptable," situations that can be coupled by fuzzy logic modeling [9].

Due to the nonlinear and unpredictable character of electromagnetic field characteristics and the uncertainty of the effects produced by the impact with the technical and biological systems it is suitable to analyze these manifestations and phenomena by using fuzzy logic modeling. The main problem addressed in the paper is to determine the degree of health damage due to exposure of workers in the electromagnetic field.

For the correlation between the exposure parameters and the health damage level, different input sizes such as [14]: electromagnetic field frequency, electric field strength and magnetic induction, distance to source, exposure duration, age, gender, type of the source etc.

The application of fuzzy logic can be applied to other electromagnetic field problems, either solely or in combination with the technique of genetic algorithms, neural networks or binary logic. Examples of applications are [8], [15 -17]: estimation of the magnetic and magnetic field outside high and very high voltage overhead lines under normal and short-circuit conditions, electromagnetic influence produced by damaged power transmission lines on neighboring regions and induced tensions in pipelines, controlling the speed of an electric car by modifying electromagnetic parameters, the electromagnetic compatibility of an electrical device depending on the electrical and magnetic stresses occurring in the process, the identification of the short circuits in the electrical circuits of the industrial networks, the reactive power control and improving power factor etc.

For example, this latest approach is needed to establish the electromagnetic compatibility reduction of the apparatus since, after entering domestic or industrial use, the electromagnetic compatibility check is no longer carried out by users, although at least the degradation of the physico-chemical characteristics of the materials From the structure of the device seems obvious and does not survive over time.

5. Application

The application refers to fuzzy modeling of the effects of electric field exposure of personnel within an Power Substation(P.S.)

For the electric field strength, are used the values obtained by measurements at different distances from sources from the Remeți Power Substation(PS), Bihor county, which serves a Hydro power Plant(HPP). The PS image is shown in Figure. 5. The measuring instrument used was SPECTRAN 5035, manufactured by Aaronia, Germany. Its image is shown in Figure 6. The age considered for the simulations is that of the electricians serving the HPP considered. Other input variables, set of rules, and degrees of severity are established based on norms recommendations or procedures used in other specialist papers [14].

Following the principle in paragraph 2, for the design of age classes specific to fuzzy logic, variation ranges for all input sizes are assigned in the Matlab Fuzzy Toolbox. Triangular memberships will be used.



Figure 5. Devices and Bus Bars on H.T. level from Power Substation Remeti, Bihor



Figure 6. Field Detector SPECTRAN

The assignment of linguistic levels and variables is random and belongs to the authors. Similarly, the rules of inference are also formulated. Parameters required for simulation with the assignment of significance levels are presented in the Table 1.

Table 1. Simulation parameters

Input variables				Output variable
Electric field strenghtE[V/m]	Ages [years]	Exposure time [min]	Distance from the source[cm]	Effect
Low	young	short	small	Insignificant
medium	mature	medium	medium	Moderate
high	old	long	large	Significant

The Overlap Intervals(O.I.) of levels of the input parameters and the Allocated Intervals(A.I.) depending on the values of the delimitation thresholds(T.V.) chosen for the input variables, are shown in the following table:

Table 2. Assign intervals for input sizes

Field strenght[kV/m]			Ages[years]			Exposure time[min]			Distance[m]		
O.I.	A.I.	T.V.	O.I.	A.I.	T.V.	O.I.	A.I.	T.V.	O.I.	A.I.	T.V.
3-5	0 - 5	5	20-25	0-25	0	40-60	0-60	0	1-2	0-2	0
8-10	5 - 10	10	50-55	20-55	20	240-300	60-300	60	3-5	2-5	2
10-12	10-15	15	50-55	55-65	50	300-360	300-480	480	5-7	5 - 10	5

To establish the ranges in Table 2, the reasoning in paragraph 2 of the paper was used. Allocation of age ranges took into account only the active age at work, 65 years being the retirement age, the period after this limit being out of context. For the determination of the electric field intervals, the delimitation thresholds are set according to the admissible value stipulated in the Romanian norms [18]: $E_a = 10000 \text{ V / m}$. The effect or degree of harm refers to the negative influence on health. The inference rules are created with the operator “AND” and also with the conditional statements: “IF - THEN”. All formed fuzzy rules are then inserted into the dedicated section from Toolbox. In order to solve the application, the options set in the fuzzy toolbox on analytics parameters are as follows: *document name*: “Exposure CELM”, *type of fuzzy method*: mamdani; *number of input variables*: 4; *input variables type*: electric field strength, duration(exposute time), distance from the source and age; *inference rules number*: 20; *number of effect levels*: 3; *Types of affecting level*: insignificant, moderate,

significant; operator: „AND”; defuzzification: maximum sampling method (Max); fuzzy number allocated to MF: triangular, by real variables. For input sizes, their values, variation ranges, implications in the set of rules, and the share of the final effects are assigned directly to the toolbox.

The application of the settings and the results obtained from the simulations are shown in Figures 7 ÷ 12. For the initial case of generating the cumulative effects, the operator's age is 30 years, the distance from the source is 200 cm, the field strength is 3000 V / m and exposure time is 120 minutes (Figure 10). To diversify the effects, the input parameters were changed as follows: age → 56 years, distance → 100 cm; duration → 400 min, field strength $E \rightarrow 7500$ V/m (Figure 11). Other modifications are shown in Figure 12. Changes to mention parameters were made by moving the cursor marked with red line in the "Rule Viewer" window of the program, for the options chosen in each case.

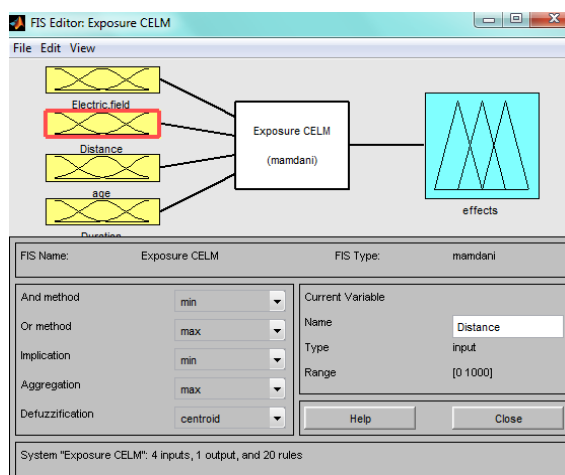


Figure 7. Inputs creation

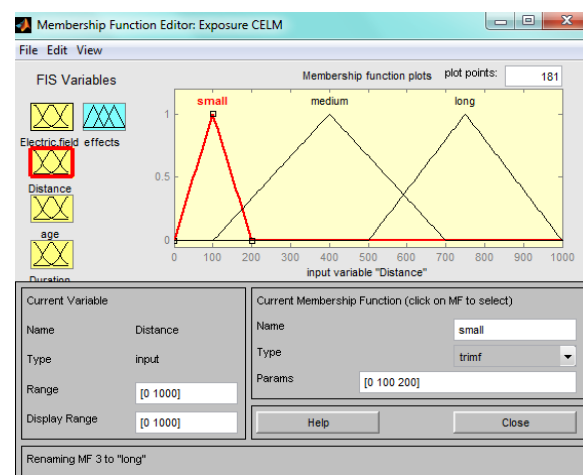


Figure 8. Assing input levels

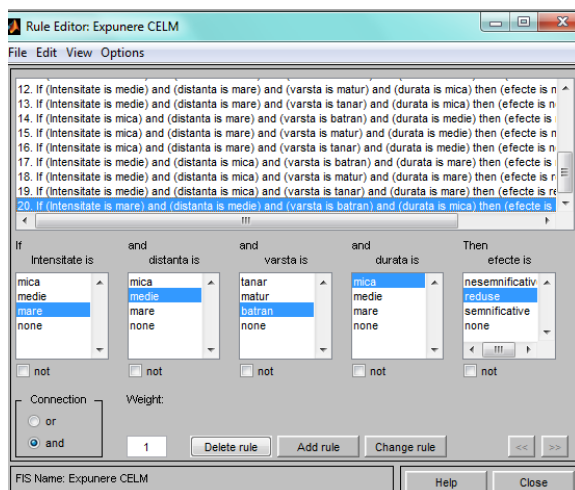


Figure 9. Rules set creating

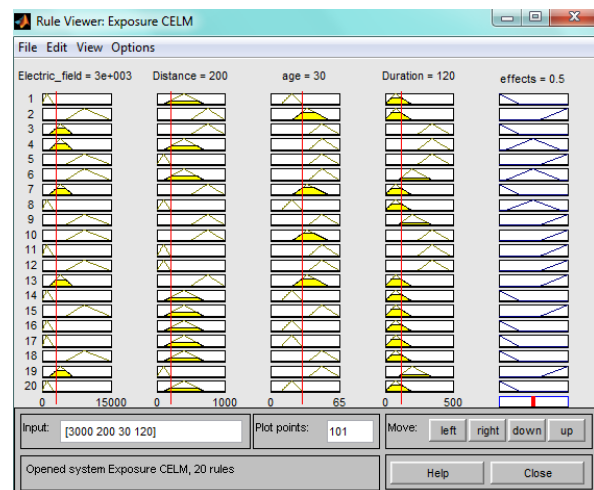


Figure 10. Generating cumulative effects

In Figure 11, all the values of the inputs originally set in Figure 10 have been modified. The change of input parameters, with the results of Figure 12, was performed by keeping the other complementary input parameters constant at the initial values from Figure 10.

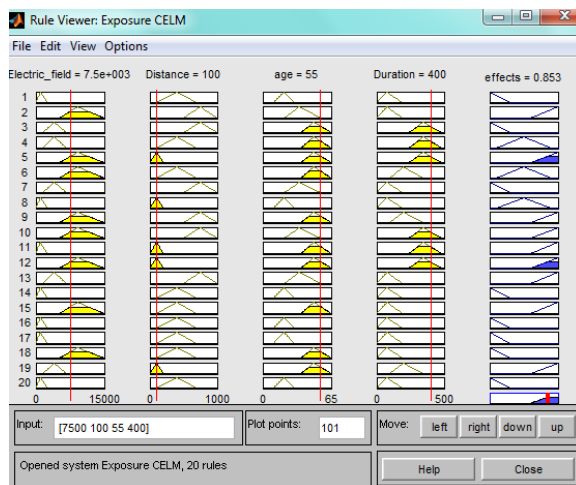


Figure 11. The modification of effects at changing of all input parameters

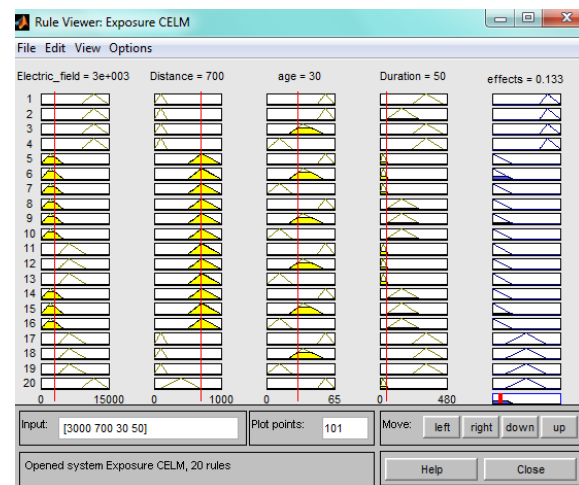


Figure 12. The modification of the effects at changing the length and distance values at the input

6. Conclusions

The implication of input parameters in generating effects can be highlighted in Matlab simulations provided they are comprised in the rules of inference. The biggest share has the "Insignificant" effects that resulted from 12 combinations of input sizes included in the rules of inference. "Significant" and "Moderate" effects hold the same share, each with four occurrences. Of course, the number of possible combinations of variables involved in writing inference rules was not exhausted, but the purpose of the simulation was reached. All three categories of effects were generated and the choice of different variants also took into account the results of other authors or recommendations from the dedicated literature. So, from the simulation results, the most favorable situations can be chosen to prevent the unwanted effects of exposure. This type of simulation is especially useful for workers from power grids.

According to different human perception of man, there are several ways of approach when it comes to defining thresholds. Fuzzy logic modeling uses this approach. The problem of exposure in the electric and magnetic field is to determine as accurately as possible the harmfulness thresholds, but also the magnitude of the harmful interval surrounding the source of electromagnetic pollution. An analysis technique based on the principles of fuzzy logic can lead to a better understanding of the effects of these fields. The precautionary principle must also take into account the future effects. An electromagnetic device sent to a person in the context in which there is the least chance of harming them should be canceled, even if the benefits of using it are obvious.

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