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APPLICATION OF THE FUZZY-SET THEORY TO ASSESS THE KNOWLEDGE OF ELECTRIC POWER INDUSTRY SPECIALISTS

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Abstract

In most cases, the assessment of the knowledge of electric power industry workers is carried out according to a test scheme, where the correct answer is selected from the list of answers. All questions have the same difficulty and only the single correct answer gives a certain score [1]. The article developed a universal model for assessing the knowledge of electric power industry workers, where using the theory of fuzzy logic and fuzzy inference, both the complexity of questions and the possibility of a partial correct answer are taken into account.

Keywords: Knowledge Assessment, Training, Fuzzy Knowledge Base

I. Introduction

Articles Personnel training, advanced training of electric power industry workers is a necessary task to improve the efficiency and safety of the operation of electric power facilities. Refresher courses for employees, which should be held at least once every 3-5 years, are necessary for employees and the head of energy enterprises in the electric power industry. Terms should be determined by the internal regulations of the enterprise, as well as the requirements of standards. Refresher courses are held; electricians, technologists, power engineers and heads of departments. Upon completion of advanced training courses, knowledge is tested by conducting an appropriate exam, where a test scheme of answers to the questions posed is mainly implemented. Only one correct answer is selected from the submitted answers, all other answers are considered incorrect. With this approach to testing knowledge, the complexity of the questions is not taken into account, and the possibility of a partial correct answer is also excluded.

The need to take into account the complexity of questions and a partial correct answer makes it possible to use the theory of fuzzy sets and fuzzy inference to assess the level of preparedness of electric power industry workers [2].

II. Knowledge assessment

To account for the complexity of the questions, the questions are divided into four groups: relatively easy questions, normal questions, questions of medium difficulty and difficult questions. The weight coefficients of correct answers are ranked according to the level of difficulty of the questions. The partial correct answer for groups of normal and questions of average difficulty has a smaller total in the resulting assessment of knowledge than the partial correct answer for complex questions. To obtain a quantitative value of knowledge assessment based on linguistic information, one can use the provisions of the theory of fuzzy sets and fuzzy logic [3].

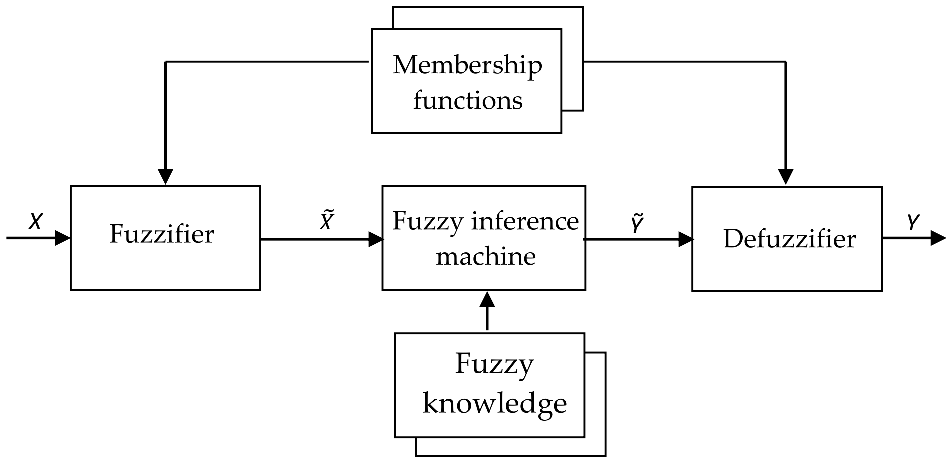

Figure 1: *Fuzzy inference circuit*

The fuzzy model contains the following blocks: a fuzzifier that converts a fixed vector of influencing factors X into a vector of fuzzy sets X˜required to perform fuzzy inference;

$$Y = f(X)$$

fuzzy knowledge base containing information about dependence in the form of linguistic rules of the "IF-THEN" type;

a fuzzy inference machine that, based on the rules of the knowledge base, determines the value of the output variable in the form of a fuzzy set Ỹ corresponding to the fuzzy values of the input variables $\tilde{X}$;

a defuzzifier that converts the output fuzzy set Ỹ into a clear number Y. The Mathlab program contains the Fuzzy Logic Toolbox package, which implements two types of fuzzy models, the Mamdani and Sugeno types. For our case, a Mamdani-type fuzzy model is preferable.

In the Mamdani-type model, the relationship between inputs X=(x1, x2, ... xn) and output Y is determined by a fuzzy knowledge base of the following format:

if $(x_1 = a_{1,j1})$ and $(x_2 = a_{2,j1})$ and…and $(x_n = a_{n,j1})$

or $(x_1 = a_{1,j2})$ and $(x_2 = a_{2,j2})$ and…and $(x_n = a_{n,j2})$

or $(x_1 = a_{1,jk_j})$ and $(x_2 = a_{2,jk_j})$ and…and $(x_n = a_{n,jk_j})$

That

$y = d_j$, $i = 1, m$,

Where

$a_{i,jp}$ – linguistic term, which evaluates the variable X_i in the line with the number

$jp\ (p = \overline{1, k_j})$

k_j– number of rows – conjunctions in which the output y evaluated by linguistic term d_j;

m– the number of terms used for the linguistic evaluation of the output variable y.

All linguistic terms in the knowledge base are represented as fuzzy sets defined by the corresponding membership functions:

$\mu_{jp}(x_i)$ – input membership function x_i fuzzy term $a_{i,jp}$, $i = \overline{1,n}$, $j = \overline{1,m}$, $p = \overline{1,k_j}$, those.

$$a_{i,jp} = \int_{\underline{x}_i}^{\overline{x}_i} \mu_{jp}(x_i)/x_i,\ \ x_i \in \left[\underline{x}_i, \overline{x}_i\right]$$

$\mu_{d_j}(y)$ – output membership function y fuzzy term d_j, $j = \overline{1,m}$, those.

$$d_i = \int_{\underline{y}}^{\overline{y}} \mu_{d_j}(y)/y,\ \ y \in \left[\underline{y}, \overline{y}\right]$$

Degree input vector accessories $X^* = (x_1^*, x_2^*, \dots x_n^*)$ fuzzy terms d_j from the fuzzy knowledge base is determined by the following system of fuzzy logical equations:

$$\mu_{d_j}\left(X^*\right) = \bigvee_{p=\overline{1,k_j}} \bigwedge_{i=\overline{1,n}} \left[\mu_{jp}(x_i^*)\right],\ \ j = \overline{1,m},$$

Where V (Λ) –operation from the s-norm (t-norm), i.e. from a set of implementations of logical operations OR (AND). The following implementations are most often used: for the OR operation - finding the maximum, for the AND operation - finding the minimum.

The fuzzy set $\tilde{y}$ corresponding input vector X^*, is defined as follows:

$$\tilde{y} = \underset{j=\overline{1,m}}{agg}\left(\int_{\underline{y}}^{\overline{y}} imp\left(\mu_{d_j}\left(X^*\right), \mu_{d_j}(y)\right)/y\right),$$

Where

imp – implication, usually implemented as a minimum finding operation;

agg – aggregation of fuzzy sets, which is most often implemented by the operation of finding the maximum.

III. Fuzzy inference models

Clear output value y, corresponding to the input vector X^*, is determined as a result of defuzzification of the fuzzy set $\tilde{y}$. The most commonly used defuzzification is the center of gravity method:

The choice of the membership function affects the accuracy of the fuzzy inference model. Figures 2-9 show various membership functions for input and output variables [4-6].

Figure 2 shows the function of input variables (answers to all four groups of questions by complexity) in the form of a triangle. The optimal output membership function is shown in Figure 3, in which the adequacy of the result to the rules corresponds to 88.3%.

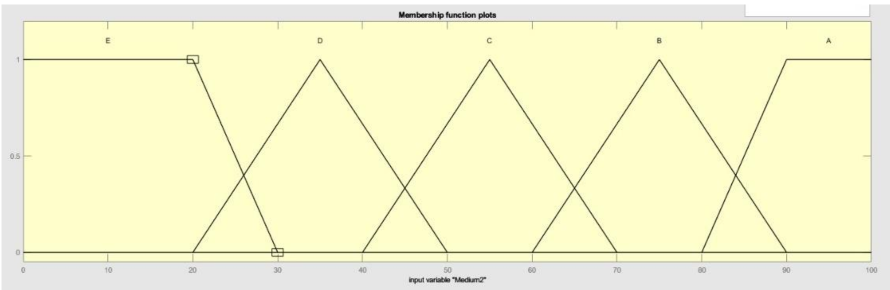

Figure 2: *Linear membership function for the input*

According to the rules (Rules), the program compared the data with the forms of relations and received the results. The triangular membership function results were compared with the rules and it was observed that the result was about 88.3% correct.

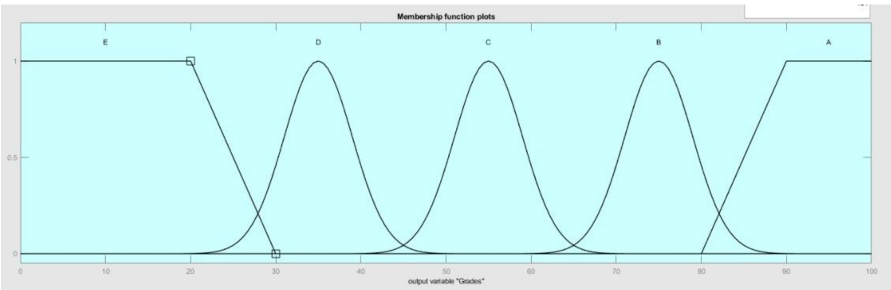

Figure 3: *Linear membership function for the output*

Figure 4 shows the membership function of the inputs in the form of a trapezoid, and Figure 5 corresponds to the membership function of the output in the form of a triangle. Such a choice of the output membership function leads to a high indicator of the adequacy of the output to the rules - 91%.

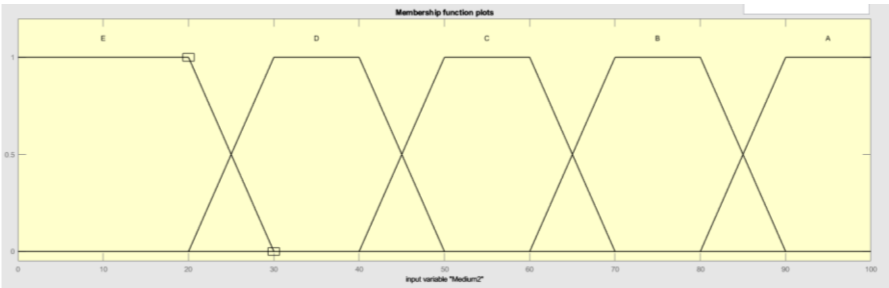

Figure 4: *Trapezoidal membership function for the input*

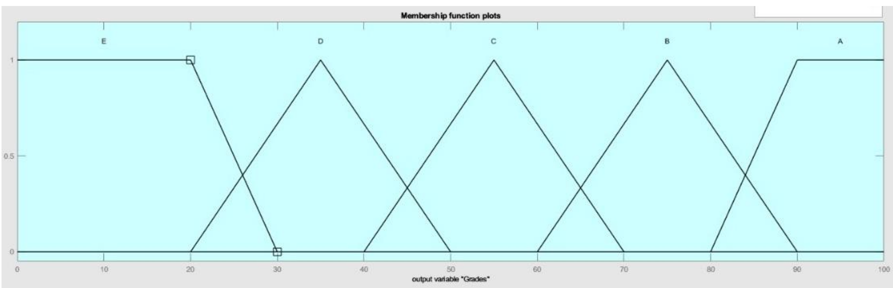

Figure 5: *Trapezoidal membership function for the output*

One of the most commonly used membership functions is the Gbell function (a Gaussian type function). The graphs of the membership functions for the inputs and for the output are shown in Figures 6 and 7, respectively, the result is 88.1% adequate.

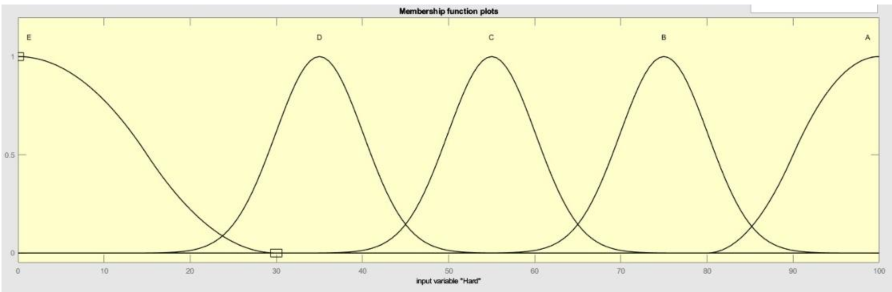

Figure 6: *Gaussian membership function for the input*

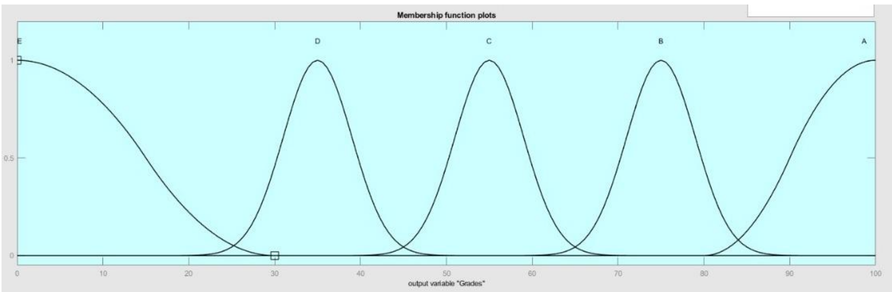

Figure 7: *Gaussian membership function for the output*

Numerous studies on the choice of membership functions for inputs and outputs have shown that the maximum adequacy is achieved when using Gauss-Linear functions, which is formed by combining the Gauss and limf functions (Gauss and limf), which are shown in Figure 7 and 8. For these membership functions, the adequacy of the output to the rules is 97.7%.

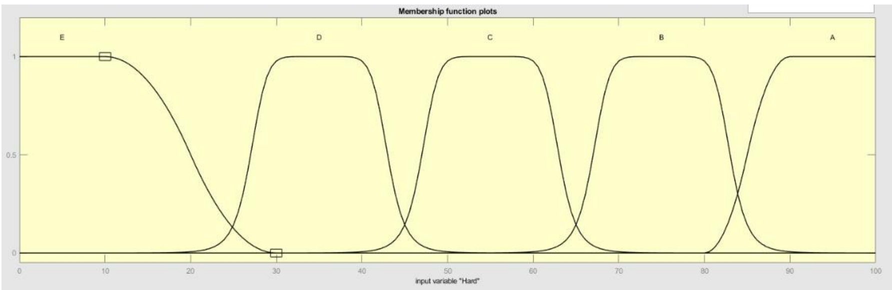

Figure 8: *Gauss-Linear membership function for the input*

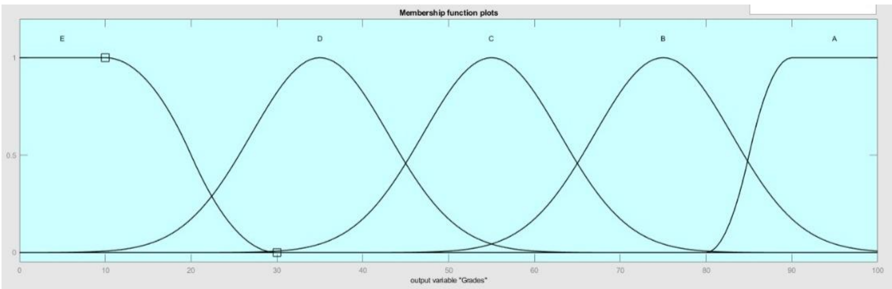

Figure 9: *Gauss-Linear membership function for the output*

Table 1 shows a comparison of the adequacy of the output to the rules for various membership functions. As can be seen from Table 1, the maximum adequacy of the model is achieved when using membership functions of the Gauss-Linear type [7-9].

Table 1: *Percentages, based on the rules of the membership functions*

Membership Function	Accuracy percentages
Triangular	88.3
Trapezoid	91.0
Gaussian	88.1
Gauss Linear	97.7

Table 2 presents a fragment of the learning rules (knowledge base) of the fuzzy inference model for assessing the level of preparedness of electric power industry workers.

Table 2: *Fragment of model training rules*

Examples	Hard	Medium 2	Medium 1	Easy	Result (with rules)	Result (Gbell-mf)
Examples 1	85	85	75	65	A	A(84.84)
Examples 2	85	75	85	55	A	A(84.84)
Examples 3	75	85	35	45	B	B(64.94)
Examples 4	65	55	65	45	B	B(64.94)
Examples 5	65	35	75	55	C	C(55.06)
Examples 6	15	25	85	65	C	D(37.87)
Examples 7	45	35	25	35	D	D(35.10)
Examples 8	15	25	45	95	D	D(27.86)
Examples 9	15	25	15	55	E	E(13.23)
Examples 10	5	15	65	55	E	E(13.23)

With the selected answers to questions from four blocks, you can get the corresponding score, as shown in Figure 10. Here, the first column shows the score for difficult questions, the fourth for easy questions, and the last column the resulting score.

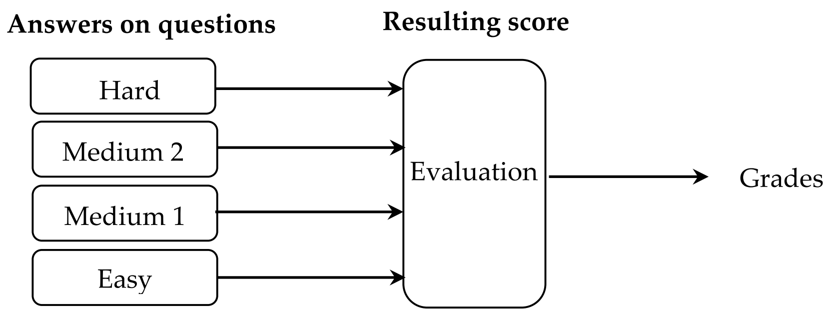

Figure 10: *a) Evaluation by points*

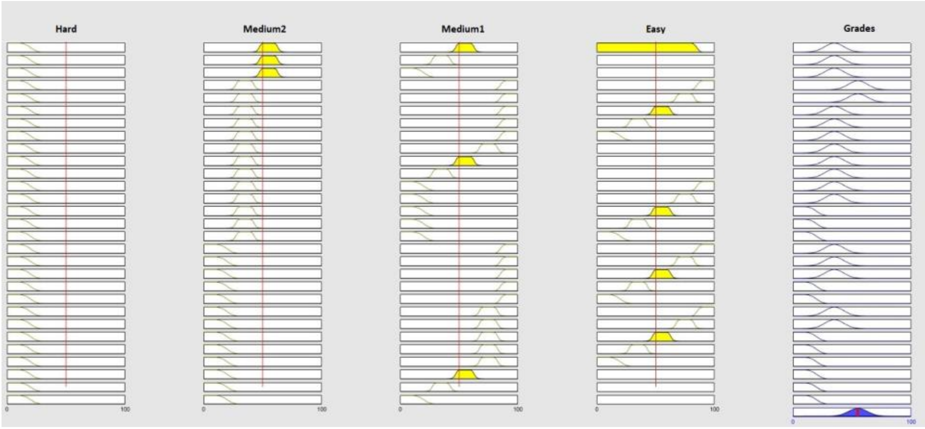

Figure 10: *b) Evaluation by points*

IV. Discussion

1. A universal method for assessing the level of preparedness of electric power industry workers has been developed, where, using the theory of fuzzy logic and fuzzy inference, one can take into account the complexity of questions, as well as the possibility of a partial correct answer.

2. By choosing membership functions for the inputs and outputs of functions of the Gauss-Linear type, you can achieve the maximum adequacy of the fuzzy inference model - 97.7%.

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