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APPLICATION OF FUZZY LOGIC FOR AUTOMATED FAULT-FINDING IN THE POWER SUPPLY NETWORK

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Abstract. *In case of damage, the switching device at the transformer substation disconnects the voltage along the entire line where the damage occurred. Then there is the problem of finding the location of the damage. Existing technical means of locating places of damage in the conditions of great length and branching of distribution networks of Ukraine are quite expensive. Therefore, the task of finding damage by other, less expensive, methods is currently relevant.*

One of the best ways to reduce the negative impact of damage is to reduce the total time of their search and elimination over a period of operation. A particularly important role in this is played by the means of determining the location of the damage (VMP). In the conditions of rough terrain, weak development of a road network, in the presence of power lines of considerable length successful VMP allows to reduce time of search of damage several times. The work is devoted to the topical problem of reducing losses from damage to power grids.

To achieve this goal, two tasks have been solved: the development of methods to support decision-making to determine the location of damage to the grid, the practical implementation of the method.

The first problem is solved on the basis of the theory of fuzzy sets, fuzzy inference. It is proposed to divide each power transmission line into sections. Determine the degree of risk of damage for each site using a fuzzy inference. In the system of fuzzy logical inference, both constant factors of influence (topological, anthropogenic) and variables (climatic conditions) in fuzzy form are used. As a result, in case of damage to the network according to certain degrees of risk, the route of movement of the operational - exit team is formed on the principle of "from the area with the highest to the area with less risk of damage."

The second problem is solved with the help of the MatLab package. The method was tested on the example of its application to a specific 10 kV power grid. The developed technique does not replace expensive means of detecting damage, but is a fairly cheap way to obtain additional information for the network manager. The technique is open to improvement and training during operation.

Key words*: logical control, network damage, mathematical model, software implementation, power line.*

I. INTRODUCTION

In the conditions of market relations between suppliers and consumers of electricity, one of the consequences of emergency power outages is compensation for losses to consumers. Ukrainian legislation provides for the material liability of suppliers to consumers, including the liability of electricity supply organizations. In judicial practice, there have been several cases of satisfaction of consumer claims for damages from the lack of electricity supply from the electricity supply organization.

The main causes of damage to power grids, as well as insufficient level of safety, both humans and animals in contact with them, are [1]:

- imperfection of power supply schemes;
- imperfection of operating rules and their proper implementation;
- practical absence of protection and alarm systems for single-phase earth faults;
- practical lack of systems for diagnosing the state of isolation;
- high level of internal overvoltages;
- use of equipment that has exhausted its regulatory resources.

The most vulnerable in Ukraine are 10 kV distribution networks.

In case of damage, the switching device at the transformer substation disconnects the voltage along the entire line where the damage occurred. Then there is the problem of finding the location of the damage. Existing technical means of locating places of damage in the conditions of great length and branching of distribution networks of Ukraine are quite expensive. Therefore, the task of finding damage by other, less expensive, methods is currently relevant.

One of the best ways to reduce the negative impact of damage is to reduce the total time of their search and elimination over a period of operation. A particularly important role in this is played by the means of determining the location of the damage (VMP). In the conditions of rough terrain, weak development of a road network, in the presence of power lines of considerable length successful VMP allows to reduce time of search of damage several times.

II. ANALYTICAL REVIEW OF THE LITERATURE

In the years since the creation of the first means of remote VMP, many domestic and foreign scientists have conducted research in this area.

Most devices based on insulation control [1-7] signal that there is a decrease in resistance in the network and are not able to selectively detect damage. Such methods can determine the distance to the place of damage, but in the conditions of an extensive distribution network it is not enough. Sometimes the task of locating the site of insulation damage is solved by sequential electrical disconnection of system elements with subsequent control of the insulation resistance of the disconnected element. With this method of searching for a damaged element there is a danger of failure of relay protection devices and automation, as well as the high cost of time of highly qualified personnel [2].

When solving the problem of protection of networks from single-phase short circuits, one of the main tasks is to optimize the neutral mode, as the method of neutral grounding not only determines the operating conditions of network insulation, but also affects the operation of automation and relay protection devices. which in turn create specific structures and schemes of earth fault protection devices. The lowest level of operational reliability corresponds to networks with completely isolated neutral [2]. For such networks in [2] the switching method is offered. The device, based on its use, allows you to continuously monitor the basic parameters of insulation and in the case of gradual deterioration of the latter (for example, with aging insulation) it becomes possible to predict that developing single-phase earth faults,

According to the Rules of technical operation of consumers' electrical installations, the operation of the network with a grounded phase is allowed until the damage is eliminated [8], and the operating personnel must find and eliminate the damage as soon as possible.

New information technologies can significantly speed up the process of finding the location of damage, if you use locking devices with the function of transmitting coded information and identifying the location and type of short circuit on the map-scheme of the dispatcher [9]. The use of such devices reduces the time of emergency mode and shortage of electricity, reduces costs by optimizing the route of the repair crew, reduces the environmental hazard of the environment from damaged power lines, it is possible to monitor unauthorized disconnection of lines or their sections. But in extensive distribution networks, the implementation of such an approach requires large enough funds. In addition, the methodology for remote determination of the location of damage to power grids is not effective enough because it is focused on ensuring a reliable VMP of a single transmission line. Much more effective is the system approach aimed at ensuring a reliable VMP on the power system complex with the use of additional information.

Therefore, monitoring of emergency parameters of overhead lines and weather conditions in the places of their operation, collection and storage of statistical data, forecast assessment of the technical condition of overhead lines are urgent tasks at the present stage [10 - 12].

Despite the significant amount of research on the issue of determining the location of damage to power lines remains relevant in view of the significant damage caused by emergency shutdown of power lines.

Improving existing and developing new methods and tools to control, detect and eliminate damage in distribution networks will help increase the reliability of power supply systems and improve the electrical safety of service personnel.

Thus, we can conclude that in all the variety of already established methods for detecting damage to power grids, it is still necessary to create more universal, accurate, easily corrected, as well as less expensive methods. This is the method proposed in this paper, based on fuzzy logic and fuzzy set theory.

III. OBJECT, SUBJECT AND RESEARCH METHODS

The purpose of the work is to assess the possibility of applying methods of fuzzy logic control for finding damage in the power supply network.

The object of the study is the process of detecting and locating faults (damages) in the power supply network.

The subject of the study is a mathematical model and software implementation of the method of localization of power grid damage based on fuzzy logic.

Research methods. When solving general and partial scientific tasks, the following are used: elements of the theory of fuzzy sets, the concept of a linguistic variable, a fuzzy logical conclusion, numerical methods of analysis with the use of computer technology.

The peculiarity and practical significance of the obtained results lies in bringing theoretical developments to practical implementation, which can be used by the operating staff of 6-10 kV power lines.

IV. THEORETICAL JUSTIFICATION OF THE METHOD

The task is to develop a certain expert system, which would be implemented in the form of a fuzzy inference system [13 - 15] and would determine the location of damage in the power supply network based on measurement data and additional data of both formal and informal nature.

Factors on which the occurrence of transmission line damage depends can be divided into two categories: constant and variable. Constant factors depend on topological conditions, human influence. Variable factors are mainly the influence of meteorological operating conditions.

It is proposed to divide each of the transmission lines into approximately equal lengths. For each site in the operational mode are determined meteorological parameters that affect the possible break of the transmission line, in the form of fuzzy linguistic variables [13]: "wind speed", "precipitation", "icing", "temperature". Also set the parameters that determine the geophysical and other features of the localization of the grid: "proximity to forests", "proximity to settlements", "proximity to roads", "proximity to water bodies". This list of parameters can be supplemented taking into account the specifics of a particular power supply network. The fuzzy linguistic variable "damage occurrence" is selected as the initial parameter.

The following terms have been introduced for each of the linguistic variables: "low", "medium", "high". The type of membership functions is trapezoidal (Fig. 1).

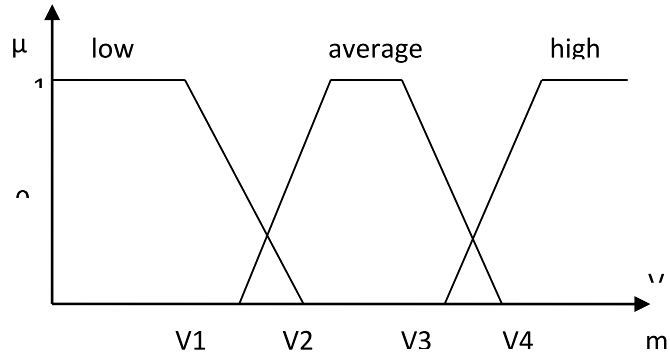


Fig.1. Functions of belonging to the fuzzy linguistic variable "wind"

The membership function of the terms "low", "medium" and "high" variable "wind speed" is calculated as follows:

$$\mu_{V\text{н}} = \max\left(\min\left(1;\frac{V_2 - V}{V_2 - V_1}\right),0\right). \tag{1}$$

$$\mu_{V\text{ср}} = \max\left(\min\left(\frac{V - V_1}{V_2 - V_1};\frac{V_3 - V}{V_4 - V_3};1\right),0\right). \tag{2}$$

$$\mu_{V\text{в}} = \max\left(\min\left(\frac{V - V_3}{V_4 - V_3};1\right),0\right). \tag{3}$$

The values of the parameters of the membership functions are determined by experts. The membership functions of terms of other linguistic variables are constructed similarly.

For "ice":

$$\mu_{\text{Обн}} = \max\left(\min\left(1;\frac{\text{Об}_2 - \text{Об}}{\text{Об}_2 - \text{Об}_1}\right),0\right). \tag{4}$$

$$\mu_{\text{Обср}} = \max\left(\min\left(\frac{\text{Об} - \text{Об}_1}{\text{Об}_2 - \text{Об}_1};\frac{\text{Об}_3 - \text{Об}}{\text{Об}_4 - \text{Об}_3};1\right),0\right). \tag{5}$$

$$\mu_{\text{Обв}} = \max\left(\min\left(\frac{\text{Об} - \text{Об}_3}{\text{Об}_4 - \text{Об}_3};1\right),0\right). \tag{6}$$

For "air temperature":

$$\mu_{T\text{н}} = \max\left(\min\left(1;\frac{T_2 - T}{T_2 - T_1}\right),0\right). \tag{7}$$

$$\mu_{T\text{ср}} = \max\left(\min\left(\frac{T - T_1}{T_2 - T_1};\frac{T_3 - T}{T_4 - T_3};1\right),0\right). \tag{8}$$

$$\mu_{\text{Тв}} = \max\left(\min\left(\frac{\text{T} - \text{T}_3}{\text{T}_4 - \text{T}_3};1\right),0\right). \tag{9}$$

For "precipitation":

$$\mu_{\text{Он}} = \max\left(\min\left(1;\frac{\text{O}_2 - \text{O}}{\text{O}_2 - \text{O}_1}\right),0\right). \tag{10}$$

$$\mu_{\text{Оср}} = \max\left(\min\left(\frac{\text{O} - \text{O}_1}{\text{O}_2 - \text{O}_1};\frac{\text{O}_3 - \text{O}}{\text{O}_4 - \text{O}_3};1\right),0\right). \tag{11}$$

$$\mu_{\text{Ов}} = \max\left(\min\left(\frac{\text{O} - \text{O}_3}{\text{O}_4 - \text{O}_3};1\right),0\right). \tag{12}$$

The values of the functions of belonging to permanent factors, such as "proximity to forest areas", "proximity to settlements", "proximity to roads", "proximity to water bodies" are determined expertly once based on analysis of the topological scheme of the grid.

The presence of a high level of the variable "occurrence of damage" is important for the task of identifying the location of damage, so you can ignore the values of the terms "low" or "medium".

Estimation of the level of "high" variable "occurrence of damage" for the j-th section of the i-th transmission line is as follows:

$$L_{i,j} = АЗ_i \wedge \begin{pmatrix} Об_{нi,j} \wedge V_{вi,j} \vee Об_{ci,j} \wedge \left(V_{ci,j} \vee V_{вi,j}\right) \vee Об_{вi,j} \wedge \\ \left(V_{ci,j} \vee V_{вi,j} \vee V_{нi,j}\right) \vee O_{вi,j} \vee T_{нi,j} \vee T_{вi,j} \vee \\ Л_{i,j} \vee P_{i,j} \vee H_{i,j} \vee Д_{i,j} \end{pmatrix}$$

$$\mu_{Li,j} = \min\left(\mu_{АЗi}, \begin{pmatrix} \max(\min(\mu_{Обнi,j}, \mu_{Vвв,j}), \min(\mu_{Обсi,j}, \\ \max(\mu_{Vcc,j}, \mu_{Vвв,j}); \min(\mu_{Обвi,j}, \\ \max(\mu_{Vнн,j}, \mu_{Vвв,j}, \mu_{Vcc,j})); \\ \max(\mu_{Oвi,j}, \mu_{Тнi,j}, \mu_{Твi,j}, \mu_{Лi,j}, \mu_{Pi,j}, \\ \mu_{Hi,j}, \mu_{Дi,j}) \end{pmatrix} \right) \tag{13}$$

$$i = 1,\ldots,m; \quad j = 1,\ldots,n.$$

where Li, j - linguistic variable "damage" j - th section of the i-th transmission line, $\mu_{Li,j}$- degree of belonging of the linguistic variable "damage occurrence" of the j-th section of the i-th transmission line, m - number of transmission lines in the network, n - number of allocated sections on each transmission line, AZi - operation of protection equipment (clear logical value the membership function of which takes the value of 0.1), Ob is the level of icing, O is the level of precipitation, T is the level of air temperature, L is the proximity to the forest area, P is the proximity to the reservoir, H is the proximity to settlements, D is the proximity to roads, μ- membership functions, indices n, c, c - terms low, medium, high.

After conducting the above analysis of each section of each transmission line of the power supply network, we obtain the values of the membership functions of the high level of the variable "damage". The value of these membership functions reflects the degree of risk of damage to the site. This information can be used by the dispatcher when developing the route of the operational and exit team.

4.1. Practical implementation of the proposed technique in MatLab

The research of the developed technique was carried out on the example of the electric network, the scheme of which is shown in fig. 2. Each of the three 10 kV transmission lines is divided into approximately equal sections, the numbers of which are shown in this figure 2.

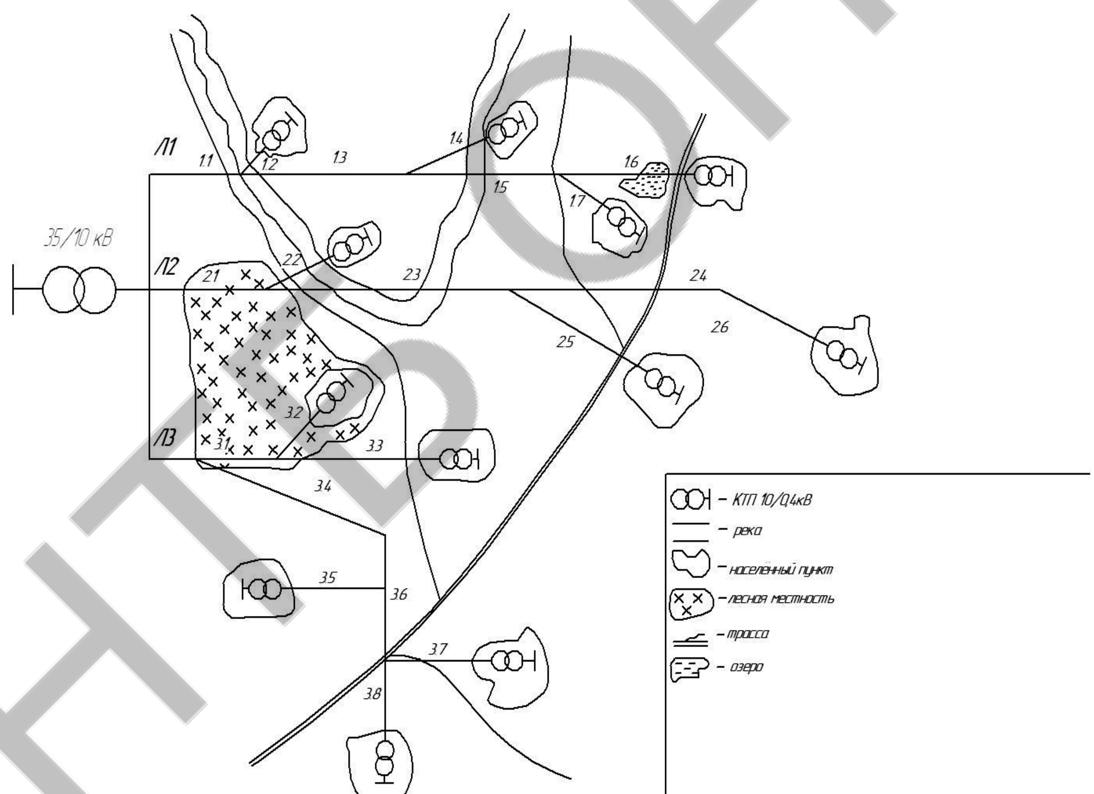


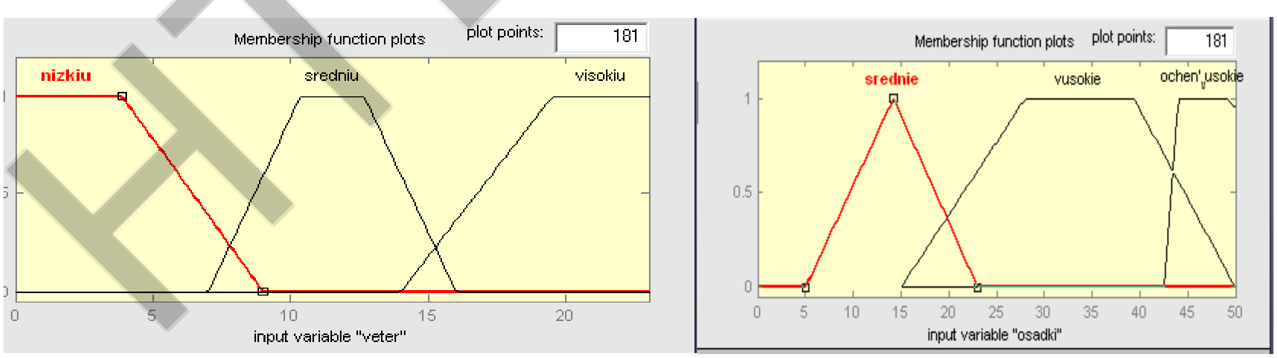
Fig. 2. Diagram of the power line

In the table. 1 shows expert estimates of fuzzy non-meteorological parameters.

Table. 1. The degree of risk of failure at each section of the transmission line on the relief features

	Relief features			
Power line sections	Proximity to forest areas JL	Proximity to water bodies µR	Proximity to settlements Mr.	Proximity to roads Ed
1.1	0.1	0.1	0.05	0.1
1.2	0	0.5	0.5	0.5
1.3	0	0.4	0.2	0.4
1.4	0	0.5	0.5	0
1.5	0	0.5	0.5	0.5
1.6	0	0.5	0.5	0.5
1.7	0	0.3	0.2	0.5
2.1	0.5	0	0.1	0.05
2.2	0.5	0.5	0.5	0.5
2.3	0.45	0.5	0.3	0.5
2.4	0	0.5	0.2	0.5
2.5	0	0	0.5	0.5
2.6	0	0	0.5	0
3.1	0.5	0	0	0
3.2	0.5	0	0.5	0
3.3	0.4	0	0.5	0.5
3.4	0.5	0	0.1	0.1
3.5	0.1	0	0.5	0.1
3.6	0	0	0.1	0.5
3.7	0	0	0.5	0.5
3.8	0	0	0.5	0.1

We model the process of assessing the risk of damage to the grid in the MatLab package [15, 16]. Fasification of meteorological parameters is presented in fig. 3.



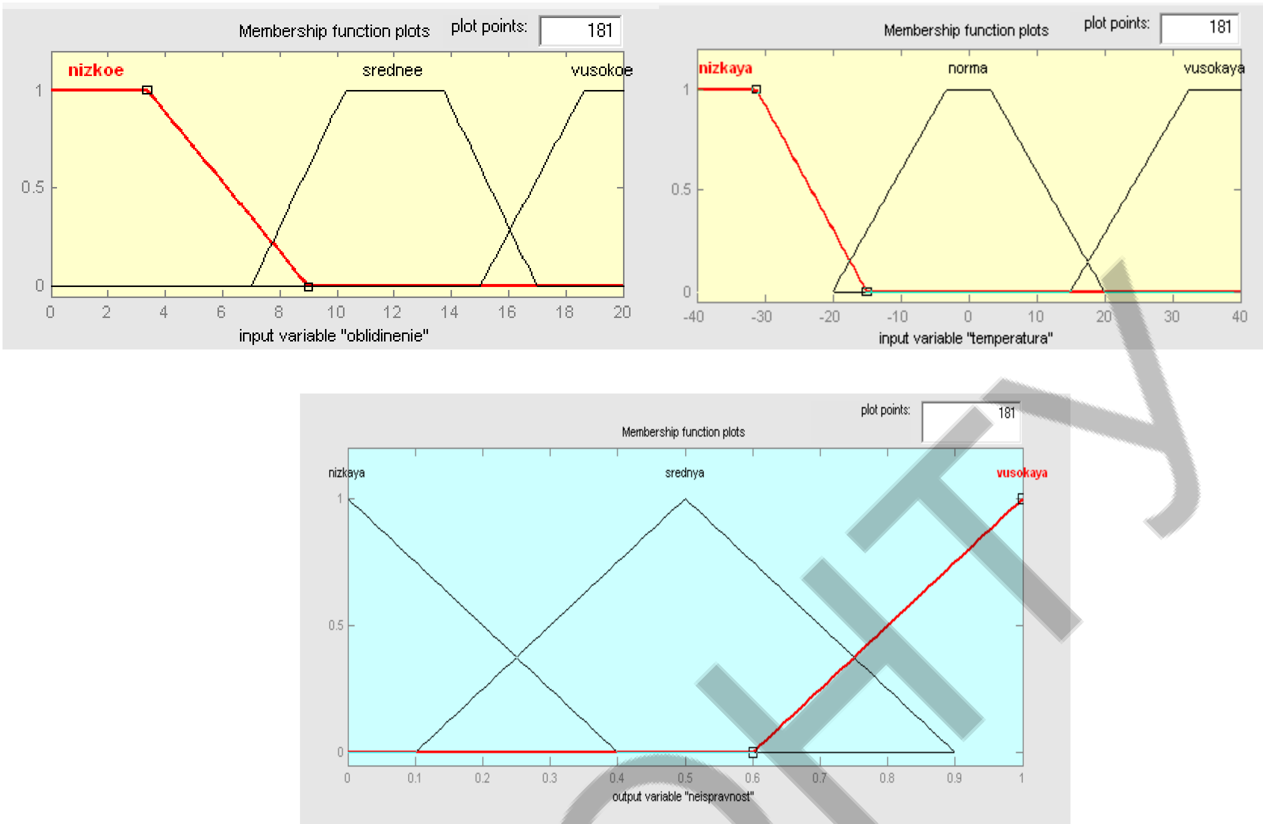


Fig. 3. Functions of belonging to the variables "wind", "precipitation", "icing", "temperature", "fault"

Then, according to (13), we determine the rules of fuzzy inference for each Fig. 4.

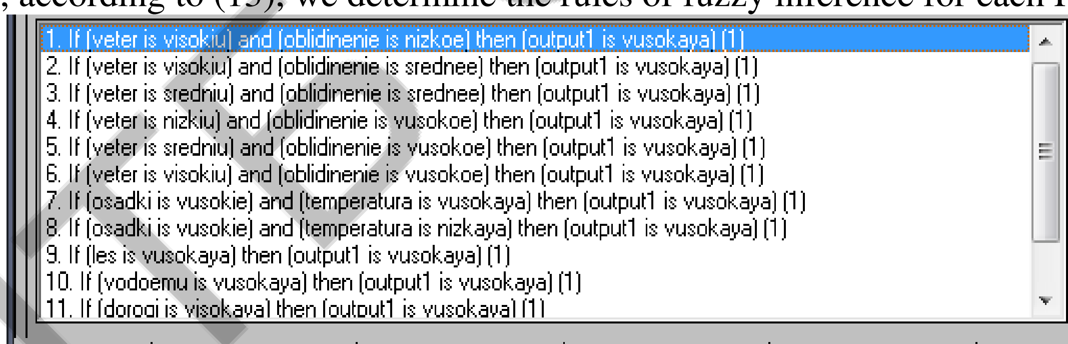


Fig. 4. Knowledge base in RuleEditor

As a result, we obtain the risk of damage to each section of the grid, as shown in Fig. 5.

Fig. 5. Visualization of fuzzy inference in RuleViewer

To visualize the result, you can use the window to view the fuzzy output surface (Fig. 6).

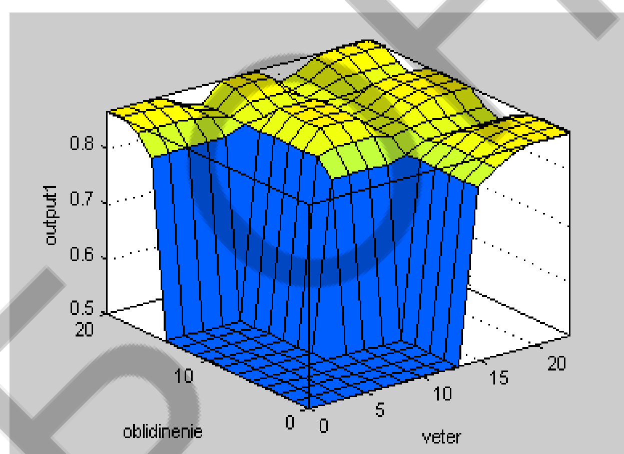


Fig. 6. Input-output surface in the SurfaceViwer window

To view the actual operation of the simulated system, consider a specific example with data obtained from the hydrometeorological service after damage to the power line (Table 2).

Table. 2. Values of input variables for each section of the transmission line

	Values of input variables			
sections of power lines	Wind speed, m / s	The amount of precipitation, mm / 12 h	Freezing on wires, mm	Temperature, 0C
1.1	13	15	2	-5
1.2	14	16	3	-6
1.3	13.5	15	3	-5.5
1.4	14	15.5	3.5	-6
1.5	14	16	4	-7
1.6	15	16	4.5	-7.5

1.7	13.5	14	2.5	-5
2.1	16	16	5	-7
2.2	15	15	4	-6
2.3	15.5	14	6	-10
2.4	14	13	4.5	-6
2.5	13	12	2	-5
2.6	13	12	1.5	-3
3.1	15	16	5	-5
3.2	17	15	2	-4
3.3	14.5	16	2	-5
3.4	17	13	1.5	-4
3.5	16	12	2	-5
3.6	19	10	3	-5
3.7	17	9	1	-4
3.8	16	7	0.5	-3

In this table, the numerical indicators are given according to the section number of the transmission line.

We will enter these values in the window of visualization of a fuzzy logical conclusion already created in advance.

As a result, we obtain the data listed in table 3.

Table 3 - The results of fuzzy inference

section of the transmission line	Degree of belonging of the fault level "high"
1.1	0.5
1.2	0.87
1.3	0.83
1.4	0.87
1.5	0.5
1.6	0.9
1.7	0.6
2.1	0.83
2.2	0.82
2.3	0.828
2.4	0.6
2.5	0.6
2.6	0.55
3.1	0.82
3.2	0.86
3.3	0.812
3.4	0.85
3.5	0.836
3.6	0.9
3.7	0.855
3.8	0.836

From the obtained results it can be concluded that if there is a signal of damage to the transmission line, and often triggers protection equipment that indicates which line is damaged, then entering data from the meteorological center, you can determine approximately where it happened.

In this case, we see that the most likely malfunction occurred on L1: section 1.6, with a slightly smaller possibility on sections 1.2 and 1.4; on L2: 2.1, with a slightly smaller possibility on 2.3 and 2.2; on L3: 3.6, with a slightly lower possibility on 3.2 and 3.7. These data can serve as a basis for development of a route of movement of operatively - exit crew on the principle "from a site with the greatest to a site with less risk of occurrence of damages".

V. CONCLUSIONS

In the course of the work was:

1. An analysis of modern methods and tools for detecting damage to the power supply network.
2. A method for determining the location of damage has been developed and researched, which uses additional information in the form of readings recorded by devices installed at substations in order to increase the probability of successful determination of the location of damage.

And also conclusions are made:

1. The system provides additional information on the location of damage to power lines, as well as allows you to determine the optimal route of the operational and exit team, which reduces the time of search for damage and, consequently, the shortfall of electricity to consumers.
2. The system is open to changes and improvements by changing the membership functions for input and output variables, editing the rules of fuzzy inference, as well as introducing informal knowledge of experts, dispatchers working on this transmission line.
3. The system for determining the damage to the power supply network, modeled in the MatLab program, is ready and easy to use.
4. The use of fuzzy logic does not offer to completely abandon the use of expensive tools to determine the location of damage, but allows you to improve and speed up the search process without much expense.

VI. REFERENCES

1. Сабадаш, І. (2017). Нові мікропроцесорні технології експлуатації мереж 6-35 кВ. *Електричні мережі та системи*, (5), 29–32.

2. Булич, А., Гуляєв, А., Міщенко, Д., & Шишигін, С. (2014). Метод контролю стану ізоляції в мережах з компенсованою нейтраллю за даними вимірювань у нейтралі трансформатора. *Вісник Вологодського державного технічного університету*, (4), 37–44.

3. Буличов, А. (2014). Контроль стану ізоляції мережі 6-10 кВ з ізольованою

нейтраллю. *Вісник Вологодського державного технічного університету*, (4), 45–49.

4. Дороніна, О., & Гребченко, Н. (2013). Оперативний контроль стану ізоляції приєднань 6-10 кВ із двигунами. *Автоматизація об'єктів та технологічних процесів*, (6), 40–44.

5. Качесов, В. (2015). Метод визначення зони однофазного замикання у розподільчих мережах під робочою напругою. *Електрика*, (6), 13–15.

6. Шкрабець, Ф. П., Місяць, Є. П., & Кириченко, М. С. (б. д.). Структура системи безперервного контролю параметрів ізоляції у мережах напругою 6 – 10 кВ гірничих підприємств. У *Ефективність та якість електропостачання промислових підприємств* (с. 18–22).

7. Jansen, J. (2006). Hochpannungsfreileitung. *Elektrotechnische Zeitschrift*, *9*(12), 732–733.

8. Правила технічної експлуатації електроустановок споживачів (ПТЕЕС). – 2017.

9. Гребченко, Н., & Сидоренко, О. (2013). Інтелектуальна система для визначення місця та ступеня локальних дефектів ізоляції в мережі із ізольованою нейтраллю. *Релейний захист та автоматика енергосистем*, *3*(21), 10–14.

10. Гребченко, Н. (2014). Математичне моделювання локальних та розподілених дефектів електричної ізоляції у вузлах електричних систем з двигунами. *Електротехніка та енергетика*, (79), 55–62.

11. Лебедєв, Г. (2008). Математичне моделювання локальних дефектів ізоляції силових кабелів 6-10кВ. *Електрика*, (12), 22–27.

12. Турбін, В. (2017). Удосконалення методів вивчення кліматичних навантажень на повітряні лінії з урахуванням топографічних особливостей місцевості. *Енергетика та електрифікація*, (10), 12–17.

13. Заде, Л. (2006). *Поняття лінгвістичної змінної та її застосування до прийняття наближених рішень*.

14. Круглов, В. (2020). *Інтелектуальні інформаційні системи: Комп'ютерна підтримка систем нечіткої логіки та нечіткого виводу*. Фізматліт.

15. Штовба, С. (2013). Ідентифікація нелінійних залежностей за допомогою нечіткого логічного висновку у пакеті MATLAB. *Exponenta Pro: Математика у додатках*, (2), 28–32.

16. Леоненков, А. (2013). *Нечітке моделювання у середовищі MATLAB та fuzzyTECH*.