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Prediction of improper operation of microprocessor relay protection devices during geomagnetic storms

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Abstract. The authors described a model for predicting the improper operation of microprocessor relay protections caused by the flow of geo-induced currents in the secondary circuits during geomagnetic storms. The model is based on the mathematical method of Takagi-Sugeno. The simulation was performed using an adaptive neural fuzzy network. The ANFIS-editor of the Fuzzy Logic Toolbox extension package in Matlab was used. Since the parameters under study are probabilistic in nature, Gaussian functions were used in the prediction. Input parameters are the date, time and variations of the components of the geomagnetic field. The output data are predictions of malfunctioning microprocessor relay protection in the power system. Using the model, the dependencies between the studied parameters were revealed, the influence of these parameters on each other was evaluated.

1. Introduction

With the increase in the number of electrical equipment the problem of the influence of geomagnetic field variations is very urgent. Some works studied geomagnetic field influence on microprocessor-based relay protection devices (MPD) [1,2,3]. The connection between incorrect MPD triggers and variations of the geomagnetic field has been confirmed. According to the data of the Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation named after N.V. Pushkov of the Russian Academy of Science, the influence of variations of the main components of the geomagnetic field was studied: H (horizontal component of intensity), D (magnetic declination) and Z (vertical component of intensity), as well as the calculated components X and Y (horizontal components of the vector H) and the full vector tensions H_t. It was confirmed that a significant proportion of incorrect MPD triggers occur during geomagnetic storms, with a sharp change in one or several components of the geomagnetic field. At the same time, the rate of change of the components of the geomagnetic field, i.e. their first time derivative (dH/dt, dX/dt, dY/dt, dZ/dt, dD/dt и dH_t/dt) has a decisive influence. It was established that short-term (less than 10 minutes in duration) variations of the geomagnetic field with respect to its components do not affect the incorrect operation of the MPD.

The works [2, 3] give a mathematical description of the conditions of the MEP3 malfunction and an algorithm for predicting the possibility of the MPD malfunctioning. However, such an algorithm requires the development of special software and is quite time-consuming.

We have proposed to use the ANFIS-editor of the Fuzzy Logic Toolbox extension package in Matlab to solve the forecasting problem. For the compilation of fuzzy inference systems when evaluating the influence of geomagnetic parameters, as well as further predicting accidents associated with variations of the geomagnetic field, the Tagaki-Sugeno method was chosen.

2. Evaluation of Takagi-Sugeno fuzzy output system

Fuzzy inference by the algorithm is performed on a fuzzy knowledge base [4,5]:

$$\bigcup_{p=1}^{k_i}\left(\bigcap_{i=1}^{n} x_i = a_{i,jp} \text{ с весом } w_{jp}\right) \to y = b_{j,0} + b_{j,1}\cdot x_1 + \dots + b_{j,n}\cdot x_n$$
$$j = \overline{(1,m)} \quad (1)$$

where b_{jn} – some figures.

In the knowledge base, the rules d_j are given by a linear function of the inputs by the formula:

$$d_j = b_{j,0} + \sum_{i=\overline{(1,n)}}\left(b_{j,i}\cdot x_i\right) \quad (2)$$

The rules in the knowledge base are a kind of switches from one linear law “inputs-output” to another, which is also linear. The boundaries of the subdomains are blurred; consequently, several linear laws can be simultaneously fulfilled, but with different degrees. The degree of belonging of the input vector X * to the values d_j is calculated as follows:

$$\mu_{d_j}(X^*) = \vee_{p=\overline{(1,k_i)}} w_{jp} \ \wedge_{i=\overline{(1,n)}}\left[\mu_{jp}\left(x_j^*\right)\right], j = \overline{(1,m)} \quad (3)$$

where где $\vee(\wedge)$ is an operation from the s-norm (t-norm), i.e. of the many implementations of the logical operation OR (AND).

In Sugeno's fuzzy logical deduction, the following triangular norm implementations are often used: probabilistic OR as the s-norm and the composition as the t-norm.

As a result, we get such a fuzzy set ỹ corresponding to Y^* input vector:

$$\tilde{y} = \frac{\mu_{d_1}\cdot(X^*)}{d_1} + \frac{\mu_{d_2}\cdot(X^*)}{d_2} + .. + \frac{\mu_{d_m}\cdot(X^*)}{d_m} \quad (4)$$

The resulting output value y is defined as the superposition of linear dependencies performed at a given point X^* of an n-dimensional factor space. To do this, we will defuse the fuzzy set ỹ by finding a weighted average or a weighted sum:

$$y = \left(\sum_{j=\overline{(1,m)}} \mu_{d_j}(X^*)\cdot d_j\right) \Big/ \left(\sum_{j=\overline{(1,m)}} \mu_{d_j}(X^*)\right) \quad (5)$$

$$y = \sum_{j=\overline{(1,m)}} \mu_{d_j}(X^*)\cdot d_j \quad (6)$$

We carried out a two-stage procedure of constructing fuzzy models of the Sugeno type. At the first stage, the system with its own rules using subtractive clustering was synthesized using the training data. Through the use of subtractive clustering the rules become object-oriented, thus avoiding a strong increase in the knowledge base. When setting the parameters of the system, the amount of input data and terms in them is specified, the laws of change. For learning the system, the ANFIS-algorithm of the package with the Fuzzy Logic Toolbox extension (adaptive fuzzy neural network) in the Matlab environment [6] was chosen. We used Gaussian functions, since the parameters under study in the prediction are of a probabilistic nature. At the second stage, after training the system, it was tested on independent data, which made it possible to improve the accuracy of the system and draw conclusions on its efficiency.

3. Performing a prediction task by use of a neural fuzzy network

The ANFIS editor allows to synthesize neural fuzzy networks from experimental data automatically. The neural fuzzy network can be considered as one of the varieties of fuzzy inference systems such as Sugeno. At the same time, the membership functions of the synthesized systems are configured (trained) so as to minimize the deviations between the results of fuzzy modelling and experimental data. To execute the ANFIS algorithm, we need to decide on the input data and the output. Date, time and variations of the geomagnetic field components dH/dt, dX/dt, dY/dt, dZ/dt, dD/dt и dH_t/dt were used as input data. As an output, statistical data were used on incorrect operation of the MPD in the power system of the Republic of Khakassia.

As an example, we will consider the execution of the prediction problem for the component of the geomagnetic field H_t. First, an array of input and output data is created. Input values are the date, time and rate of change of the geomagnetic field dHt/dt (given by Gaussian functions). The output value will be the possible failure of the MPD in the investigated period of time. The date will be presented in double format, time in seconds, H_t in nTl.

To train the network, we chose the hybrid method, which gives the smallest error (a hybrid method combining the backpropagation method with the least squares method), which results in the development of the FIS forecasting system presented in figure 1.

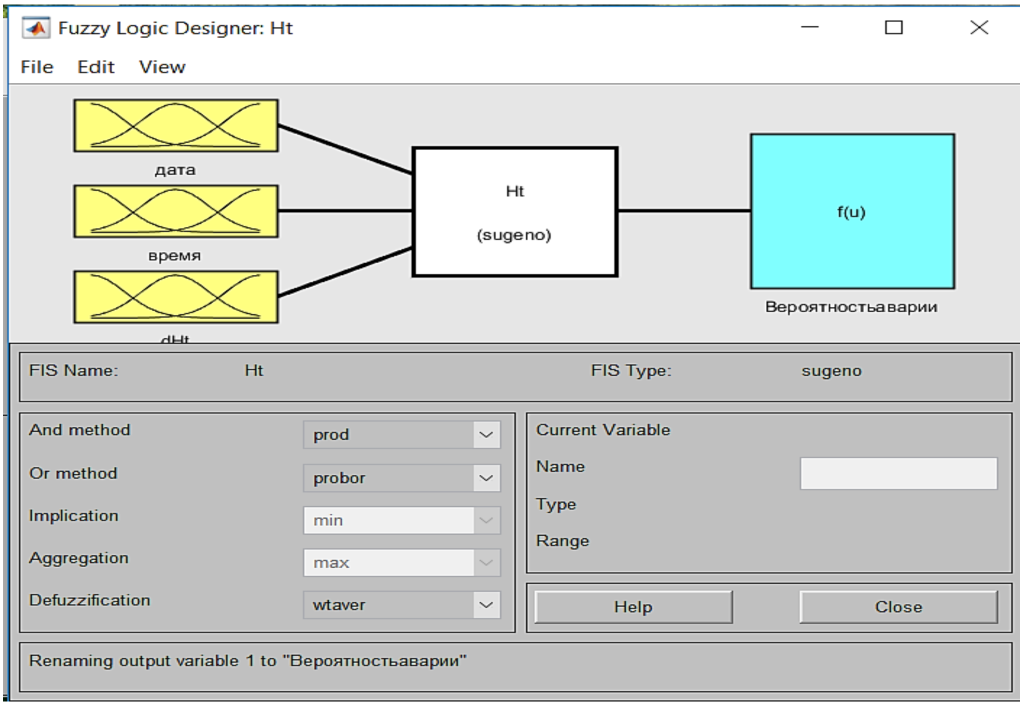

Figure 1. FIS-system for component dH_t.

In this system, a structure is formed that is common to all arrays of the "date-time-parameter" type (figure 2) with its own rules, according to which, by changing the value, we can predict the probability of an accident. Figure 3 shows a graphical image of the surface dependence of the input-output. The dependence of the output dH_t/dt on the date and time is presented in figure 4.

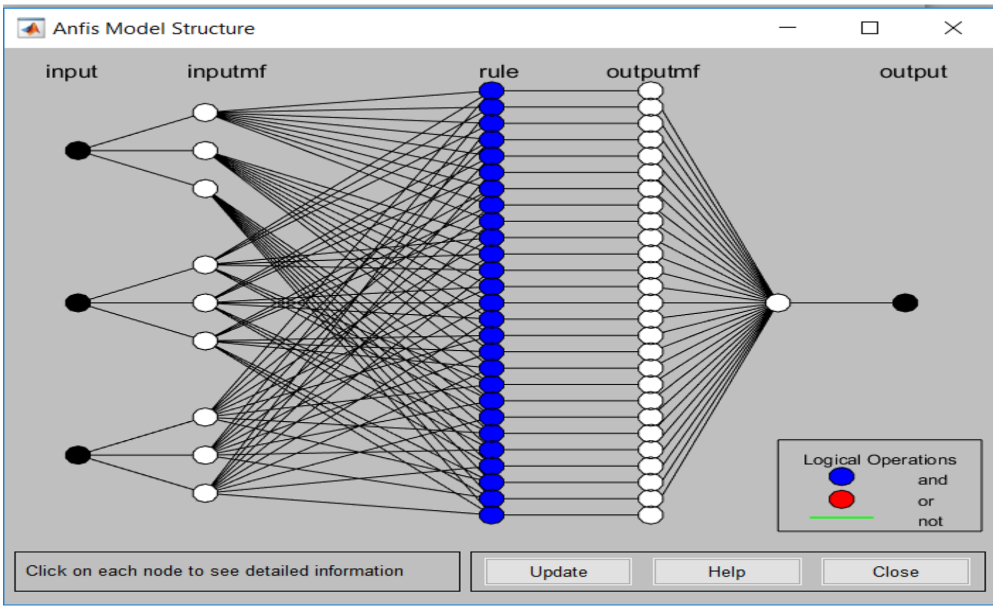

Figure 2. Model structure.

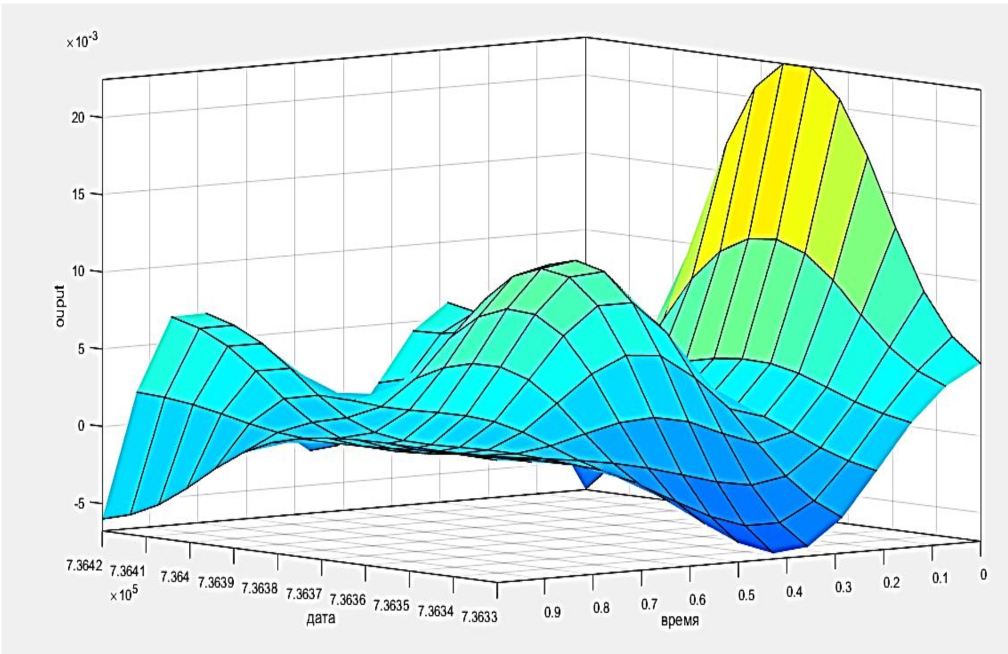

Figure 3. Surface dependence of the output from the date and time.

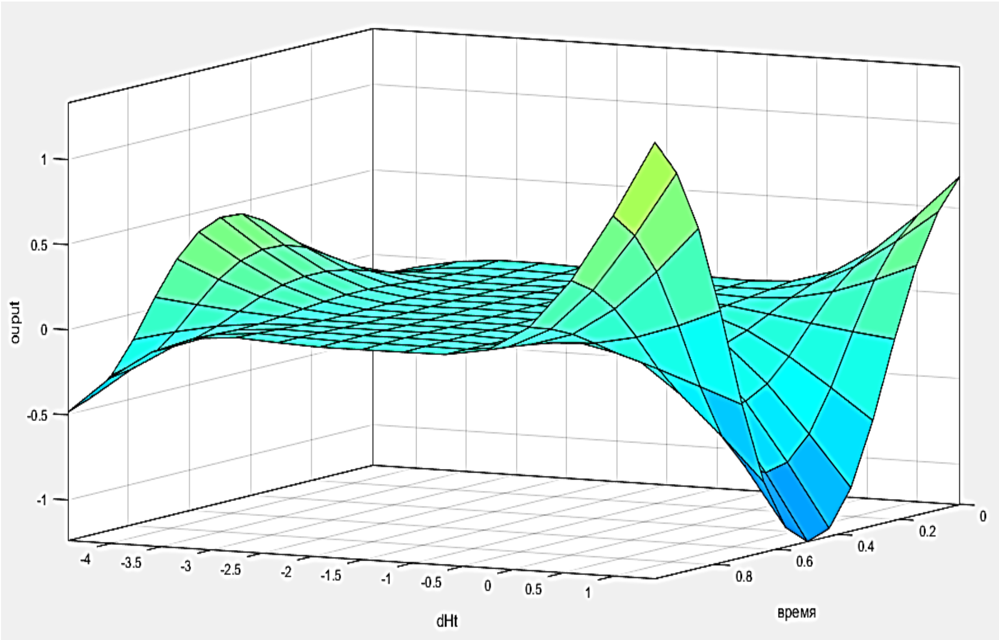

Figure 4. Surface output versus time and dH_t.

The system check was carried out on test data, different from the training sample for each component of the variations of the geomagnetic field. The magnitude of the error in all cases does not exceed 0.11. The test results showed that the values of the test data do not deviate from the values obtained during training, and the presented twin system can be used to predict failures of relay protection devices depending on the predicted values of geomagnetic field variations.

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