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Application of Fuzzy Algorithms for Controlling the Modes of Solar Panels in Technological Monitoring at Peak Load

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Abstract

The functional structure of geoecological and technological monitoring systems is analyzed. It is shown that the complication of the multifunctional automated system of geoecological and technological monitoring (MF AS) and the increase in its dynamics aggravates uncertainty of its condition estimation. An uncertainty model of the state of a multifunctional automated system of geoecological and technological monitoring has been developed. To implement the model, fuzzy sets of linguistic estimates fluctuating in time are obtained. The application of fuzzy algorithms to control the modes of solar panels and the detection of failures in thermoelectric systems has been carried out. As a result of the simulation, an increase in the efficiency of the thermoelectric system was revealed by reducing peak loads by 28% and, accordingly, reducing the probability of failures by almost 2 times.

Keywords: solar battery, thermoelectric system, geoecological monitoring, technological monitoring, Temporary Hesitant Fuzzy Linguistic Term Sets.

Introduction

Geoecological and technological monitoring is the most important aspect in ensuring the normal functioning of natural and technical facilities in conditions of increased natural and anthropogenic influence. The structure of individual dedicated monitoring systems is shown in Figure 1 [1-3]. In accordance with [4], four variants of the organization of monitoring systems are distinguished: private and integrated monitoring solutions, systems with the functions of integrated monitoring of the natural environment and sources of impacts, integrated technological systems included in the management circuit of organizations. In general, monitoring provides analysis of: sources of natural and man-made impacts, impact factors and the natural environment itself (geophysical, environmental and climate monitoring) [5]. For the design of such systems, a service-oriented approach is widely used, which allows building the architecture of a monitoring system as a set of functional services [6,7].

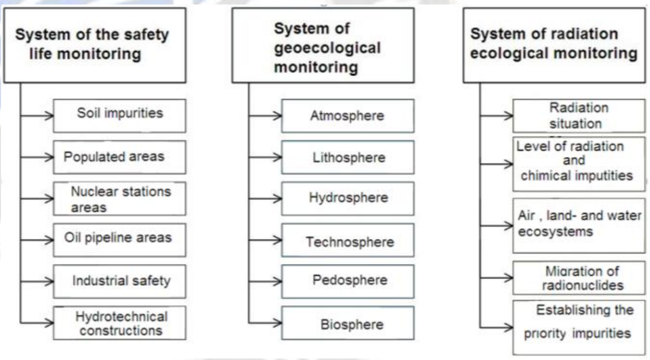

Figure 1 – Functional composition of geoecological and technological monitoring systems

Monitoring systems for the prevention of emergencies are designed to collect, assess and predict natural hazards and emergencies [8-10]: seismic processes, floods, fires, avalanches, etc. The basis for the development of monitoring systems of this class is the approach [11,12], which proposes the use of automated cyber-physical systems technology in the tasks of three-level ground, air and remote monitoring of the Earth in order to provide operational information about the development of an emergency situation for the detection and maintenance of natural and man-made emergencies. Multi-agent systems are used [13], combining data from ground, air and remote sensing of the Earth in conditions of uncertainty [14].

Ensuring the functioning of automated systems of the class under consideration requires additional control of the processes of changing the monitoring object in real time, error handling, detection and elimination of malfunctions and functional degradation of the system [15]. Due to the large scale and complexity of these processes, as well as the emergence of new requirements for functions, the occurrence of malfunctions and failures is the normal mode of operation of geoecological monitoring systems. Advanced monitoring of the requirements of the appointment, the state of the MF AS, including proactive and predictive, allows you to move to sustainable development management. The stochastic nature of the functioning of the MF AS [15] shows the need of mechanisms for observing the state of an object in conditions of uncertainty. There is a close relationship between the effectiveness of monitoring and the effectiveness of the implementation of management of both the functional suitability and the technical serviceability of the functional components (FC) [16,17]. The main requirements for the MF AS monitoring process are: timeliness, efficiency, the degree of elimination of data uncertainty, customer satisfaction, compliance of the process with the requirements [18]. The following requirements are imposed on the monitoring results: the degree of actual use, the credibility of the data (including from distortion), the degree of consistency of the data, the understandability of the monitoring results.

Reconfiguration management in automated systems is carried out on the basis of control object models. The improvement of models in control systems is coordinated with the methods of managing configuration units. The implementation of such management requires improvement of the models of the managed object. In the infocommunication subsystem, SNMP-like technologies are widely used, which allow collecting primary data about management objects (SNMP objects) and accumulating them in a MIB database [19]. The complexity of the control object causes the transition to multilevel tunable models, for example, automatic [20], requiring the integration of synthesis mechanisms, maintenance and support in the process of use. At the same time, models and mechanisms of their formation must meet the requirements of informativeness, accuracy and reliability. Reducing the uncertainty of the monitoring results is achieved by using approaches based on the provisions of the theory of fuzzy sets, for example [21].

The objects of monitoring in the AU are all levels and layers of the system. In accordance with the architectural model [22], monitoring should be carried out according to the functional representations of the system (functional, informational, resource-based and organizational). The main factors of changes in the functional requirements for the monitoring system are [23,24]: changes in external conditions (market and regulatory requirements, the object under control itself); changes in the automated process or the enterprise as a whole (organizational, staff, regulatory changes); reconsidering automation processes (changing technological processes, boundaries of a multifunctional system); clarifying requirements (reconsidering requirements and clarifying them, bringing them into line with the real state of affairs); changing the possibilities and limitations of automation activities (the impact of technical and technological solutions).

The uncertainty model of the state of a multifunctional automated system of geoecological and technological monitoring

The complication of the multifunctional automated system of geoecological and technological monitoring (MF AS) and the increase in its dynamics lead to an increased uncertainty in the assessments of its condition. At the same time, the state of technical components and their functioning processes is determined by measuring instruments, then the characteristics of automation processes and requirements for their functionality are determined primarily on the basis of expert assessments (from persons interested in the development of an automated system).

The uncertainty of the assessment of the state in general and the requirements of the appointment in particular, from an objective point of view, can be divided into linguistic (uncertainty and fuzziness of estimates) and physical (inaccuracy due to imperfection of measuring instruments and randomness of the observed parameters due to the stochastic nature of the functioning processes) [25]. In practical cases, unreliable (including purposeful distortion), inaccurate, incomplete (partial observation) and contradictory information is used in the management process [26].

To assess the uncertainty of the state and purpose in this work, a model is used according to which functional suitability is determined based on a system of indicators of the importance and functional suitability of the components of its components $s_i = \langle k_i, \alpha_i \rangle$ (Figure 2). In this case, all observation noises are classified into three groups:

– uncertainty of the significance of FC ε_α;

– uncertainty of the suitability of FC ε_k;

– incompleteness of management criteria (decision-making) ε_r.

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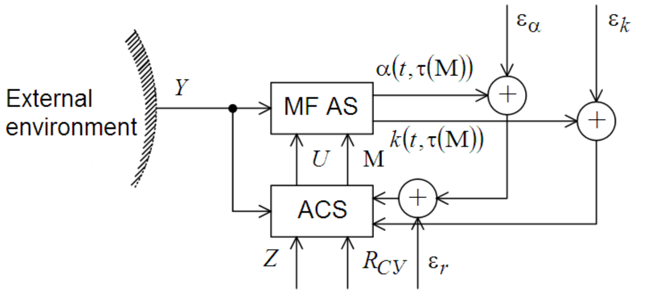

Figure 2 – Functional suitability monitoring model with uncertainty of initial data on the state of MF AS

According to the model, the functional components (FC) are monitored, the result is the values of the importance of α(t,τ(M)) and the suitability of $k(t,\tau(M))$ FC. Monitoring and diagnostics are implemented with interference ε_α and ε_k, respectively. When making decisions, the incompleteness (change) of the decision-making criteria ε_r. also interferes. Thus, the control U is implemented taking into account the noise of all three classes.

The diagnostic assessment of the technical condition of the MF AS affects the value of the fitness coefficients k_i. Assessments of changes in assignment requirements, in turn, adjust the values of the importance of FC α_i, the regulatory requirements for FC, which changes the fitness index, as well as the decision-making criteria Rl.

The reduction of uncertainty in well-known studies is achieved by: identifying implicit cause-effect relationships based on the theory of fuzzy sets and the theory of experimental planning [26]; correcting goals based on agent technologies under uncertainty conditions [27]; introducing formal domain models that take into account the dynamic qualities of the domain based on category theory [25]. However, the well-known works do not take into account the simultaneous nature of both changes in the requirements of the assignment (correction of the goal) and the incompleteness of the system of decision-making criteria (uncertainty of the preferred states of the MF AS). The study of the method of active monitoring and diagnostics of suitability in order to take into account these features of modern MF AS is the purpose of this work.

Time-fluctuating fuzzy sets of linguistic assessments

Time–fluctuating fuzzy sets of linguistic assessments - Temporal Hesitant Fuzzy Linguistic Term Sets. It is a development of fluctuating fuzzy sets of linguistic estimates of HFLTS [28], characterized by the ability to set time-varying estimates in cluster analysis algorithms.

For the HFLTS algorithm, H_s is an ordered finite subset of consecutive linguistic concepts s_i from the set of linguistic concepts $S = \{s_0, \dots, s_g\}$. In this case, the linguistic variable (concept) is given by the set:

$$(H, T(H), U, G, M), \tag{1}$$

where *H* is the name of the variable; *T*(*H*)=*S* is the set of linguistic values of the variable – the term set; *U* is the domain of definition (the universe of the variable); *G* is the syntactic rule for generating values from *H* that are meaningful in the aspect under consideration; *M* is the semantic rule for associating values from *U* with each *T*(*H*).

An example of a linguistic variable when monitoring operating conditions in thermoelectric solar cell systems is $((H_1, T_1(H), U_1, G_1, M_1)$ where H_1 = "brightness"; $T_1(H)$ = {"very dark", "dark", "medium", "bright", "very bright"}; U_1 = [0,50] cd/m2; G_1 – the procedure for forming new terms using the rules "AND", "NOT"; M_1 – mapping $T_1(H)$ into U_1 (Fig. 3).

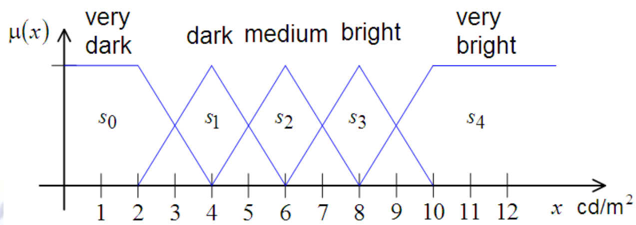

Figure 3 - An example of mapping $T_1(H)$ into U_1 for the variable H_1

In the case of the THFLTS algorithm, H_{sT} is the set of ordered finite subsets $H_{s,t}$ of consecutive linguistic concepts s_i from the set of linguistic concepts $S = \{s_0, \dots, s_g\}$. THFLTS is given by the pair $H_{sT} = (\{H_{s,t}\}, T)$ where $\{H_{s,t}\}$ is the set of HFLTS H_s in the time intervals between time points $t \in T$; T is the set defining discrete time. When $T = \{t_0\}$, $H_{sT} = (\{H_{s,t_0}\}, T = \{t_0\}) = H_{s,t_0} | t \in (t_0, t_{max}())|$ where t_{max} is the maximum possible value of the moment of time, as applied to the object under consideration.

At the same time, we set the following linguistic description: "between 8^{00} and 18^{00}, the value of the variable "brightness" is not less than "bright", otherwise not less than "average" (Figure 4.). In this case, the formal model of THFLTS can be represented as follows:

$H_{sT} = (\{H_{s,t}\}, T)$, $T = \{t_0 = 0; t_1 = 8^{00}; t_2 = 18^{00}\}, \{H_{s,t}\} = \{H_{s,t_0}; H_{s,t_1}; H_{s,t_2}\}$: $H_{s,t_0} =$ AT LEAST "average", H_{s,t_1} = AT LEAST «bright»; H_{s,t_2} = AT LEAST «average».

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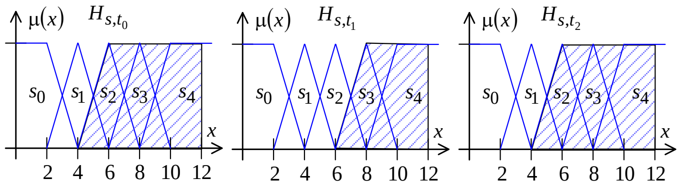

Figure 4 – An example of THFLTS for the variable H_1

Application of THFLTS algorithms to control the modes of solar panels and detect failures in thermoelectric systems

Within the framework of the work, THFLTS algorithms were used to form time-varying requirements for the automation functions of MF AS in the framework of monitoring the energy efficiency of solar panels in thermoelectric systems.

We introduce linguistic variables of the occurrence of a failure in the components of a thermoelectric system with their corresponding sets of basic terms. Let 's imagine them as:

$$\langle x, T, X, G, M\rangle, \quad (2)$$

where x is the name of the linguistic variable; T is the set of values of the linguistic variable x defined on the set X; G is a syntactic procedure that allows generating new values (terms) of the linguistic variable x; M is a semantic procedure that allows you to specify the type of membership function. For the semantic procedure M, fuzzy connectives and modifiers are often used: “not” $\left(\mu_A * (x) = 1 - \mu_A(x)\right)$, , «and» $(A \cap B)$, «or» $(A \cup B)$, «almost» $\left(\mu_A * (x) = \mu_A^{1/2}(x)\right)$, «very much» $\left(\mu_A * (x) = \mu_A^2(x)\right)$, as well as triangular, Z- and S-linear membership functions.

Input variables (Figure 5):

1. $\langle x_1, T_1, X_1, G_1, M_1\rangle$ where x_1 is the reaction time of the telecommunication diagnostics subsystem; T_1 is {"low", "medium", "high"}; X_1 is [0, 1000] (seconds); G_1 is the syntactic rule for the formation of new terms. For example: "low or medium", "very high"; M_1 is the procedure for specifying fuzzy subsets (A_{11} = "low", A_{12} = "medium", A_{13} ="high".

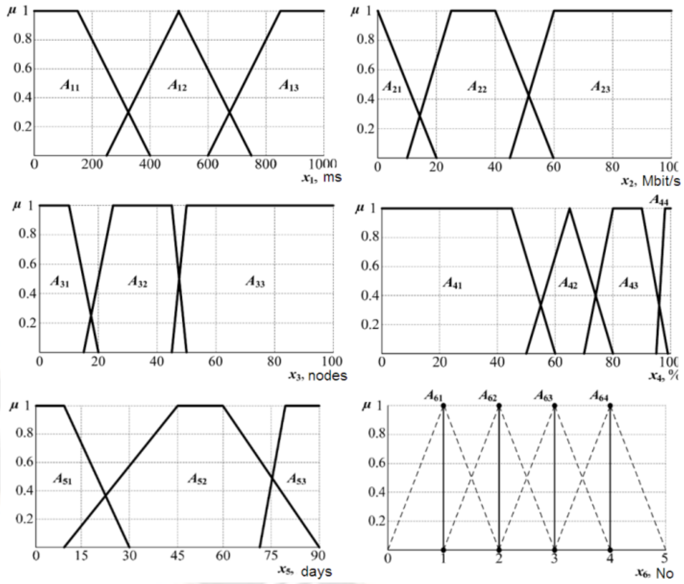

Figure 5 – Formalization of input linguistic variables x_i

2. $\langle x_2, T_2, X_2, G_2, M_2\rangle$ where x_2 is the bandwidth of the telecommunications environment, $T_2$is {"low", "medium", "high"}; X_2 is [0, 100] (Mbit/s); G_2 is the syntactic rule for the formation of new terms; M_2 – a semantic procedure that allows to set the type of membership function (A_{21} = "low", A_{22} = "medium", A_{23} = "high").

3. $\langle x_3, T_3, X_3, G_3, M_3\rangle$ where x_3 is "the number of objects of the thermoelectric system ; T_3 is {"small", "medium", "large"}; X_3 is [3, 10]; v is the syntactic rule for the formation of new terms; M_3 is a semantic procedure, which allows to set the type of membership function of fuzzy subsets (A_{31} = "small", A_{32} = "medium", A_{33} = "large").

4. $\langle x_4, T_4, X_4, G_4, M_4\rangle$ where x_4 is the availability of measuring equipment (which describes the possibility that measuring equipment will be available for use when needed); availability is determined by dividing the time when measuring equipment is actually available by the total time in the year, and then multiplying the result by 100 to express the resulting value as a percentage); T_4 – {"unsatisfactory", "satisfactory", "good", "excellent"}; X_4 – [0, 100] (percent); G_4 – syntactic rule for the formation of new terms; M_4 is a semantic procedure that allows to specify the type of membership function of fuzzy subsets (A_{41} = "unsatisfactory", A_{42} = "satisfactory", A_{43} = "good", A_{44} = "excellent").

5. $\langle x_5, T_5, X_5, G_5, M_5\rangle$ wherex_5 is the possibility of a malfunction at the facilities (this means that the reliability of the elements that make up the system and takes into account seasonal fluctuations in external conditions; measured as the average time between equipment failures); T_5 is {"low", "average", "high"}; X_5 – [1, 90] (days); G_5 – syntactic rule for the formation of new terms; M_5 – semantic

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procedure that allows to set the type of membership function of fuzzy subsets (A_{51} = "low", A_{52} = "medium", A_{53} = "high").

6. < x_6, T_6, X_6, G_6, M_6> where x_6 is the possibility of a failure; X_6 is [1, 4] (number); G_6 is the syntactic rule for the formation of new terms; M_6 is a semantic procedure that allows to specify the type of membership function of fuzzy subsets.

Output variable is <*y*, *Ty*, *Xy*, *Gy*, *My*> where *y* is the possibility of a failure; *Ty* is {"low", "medium", "high"}; *Xy* is [0, 100] (percents); G_y is the syntactic rule for the formation of new terms; *My* is a semantic procedure that allows to set the type of membership function of fuzzy subsets (B_1 = "low", B_2 = "medium", B_3 = "high") (Figure 6).

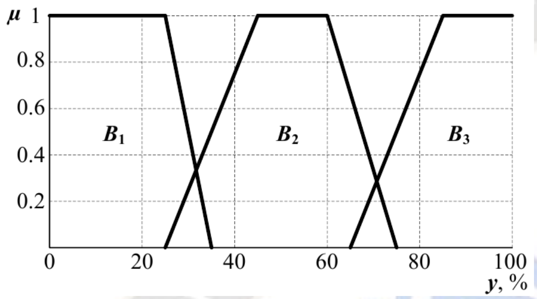

Figure 6 - Formalization of the linguistic variable y "possibility of failure"

To determine a set of fuzzy rules, a priori knowledge and a priori initial data are used, which are determined by specialists and experts, and data obtained as a result of operating experience of components of a thermoelectric system are also used. It should be noted that entering all possible rules into the database can lead to a significant loss of the meaning of logical inference. To verify the rules of fuzzy inference, it is advisable to use test situations with a known result. Optimization of the rules can be achieved by using empirical information from experts, as well as by adapting training sample sets. To do this, all samples of the training sample ($x_1^{(k)}$, $x_2^{(k)}$, $x_3^{(k)}$, $x_4^{(k)}$, $x_5^{(k)}$, $x_6^{(k)}$, $y^{(k)}$) *(k =1, …, K)* are put in accordance with each production rule.

The concept of the importance index for each production rule is introduced:

$$r_i = \sum_{k=1}^{K} \mu_{\tilde{A}_{i1}}\left(x_1^{(k)}\right) * \mu_{\tilde{A}_{i2}}\left(x_2^{(k)}\right) \dots \mu_{\tilde{A}_{i7}}\left(x_7^{(k)}\right) * \mu_{\tilde{B}_i}\left(y_1^{(k)}\right) \qquad (3)$$

where $\tilde{A}_i$ for $i = 1..6$ is a fuzzy set of the linguistic variable $x_{1..6}$ defined on the set $X_{1..6}$, with corresponding characteristic functions $\mu_{\tilde{A}_{i(1..6)}}(x_{1..6}) \in [0,1]$ where $\tilde{B}_i$ is a fuzzy set of the linguistic variable *y* defined by X_y, with corresponding characteristic functions $\mu_{\tilde{B}_i}(y) \in [0,1]$.

Taking into account the estimated indicators of importance, the elimination of fuzzy rules from the database with min results r_i occurs. From the set of rules that have passed the test, the final base of fuzzy rules is compiled.

Modeling results of the thermoelectric system operation at peak energy load

Numerical simulation of the control and control system of a thermoelectric air conditioning and ventilation system using solar-powered sources has been carried out. Applications of fuzzy algorithms at peak energy load are considered.

In order to implement peak energy demand modes in a distributed thermoelectric system, it is usually provided with elevated temperatures in the case of heating systems and lowered temperatures in the case of cooling systems, as well as control of thermoelectric devices of the energy network to ensure more intensive heat exchange. When this is not enough, it is necessary to use additional capacities of additional energy sources. As a rule, these sources are either used only in peak load modes, or are attracted from the outside, which is associated with additional capital investments and operating costs. A good approach is to use energy storage modes through the use of solar energy. This mode is obvious due to the irregularity of the receipt of this type of energy. In addition, when using algorithms for intensifying temperature regimes in a distributed thermoelectric system, it may turn out to be a suboptimal solution, since the carrier spreads over the network at a limited speed and forms delays in establishing the necessary temperature regimes.

The data of daily observations of energy consumption *W* of the agro–industrial complex facility - dairy processing shop without the use of modes of accumulation and use of solar energy (curve 1 Figure 7) were used as initial data

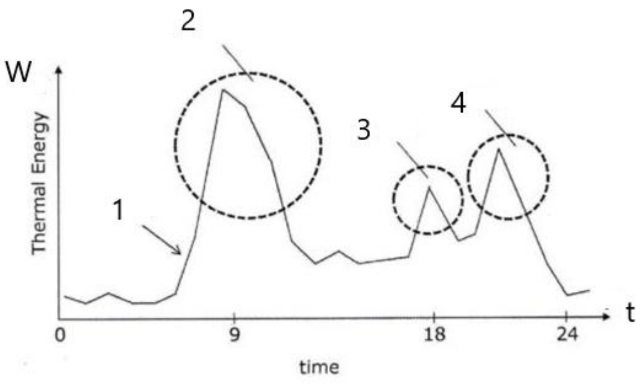

Figure 7 - Daily consumption of energy resources by a thermoelectric system.

Figure 7 shows three peak load moments formed by the conditions of technological processes at the enterprise (2-4). In accordance with the method discussed above, the input

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variables were recalculated taking into account the fuzzy control algorithms for accumulated solar energy in the system to reduce peak loads (Figure 8)

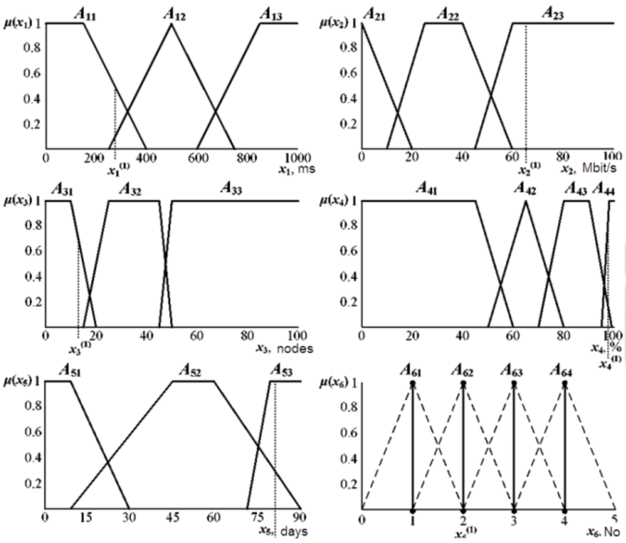

Figure 8 - Formalization of input linguistic variables with fuzzy control

Figure 9 shows the daily consumption of energy resources (curve 5), taking into account the fuzzy algorithms for controlling the accumulation and use of solar energy in the thermoelectric system of the facility, which reduced the peak load on the thermoelectric system.

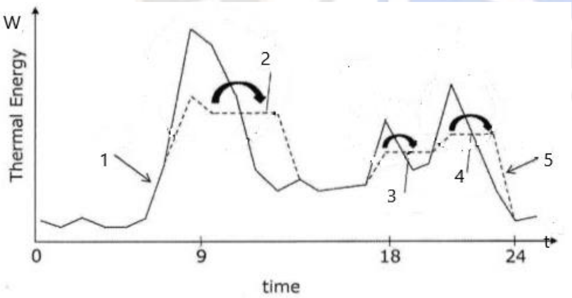

Figure 9 – Daily consumption of energy resources by a thermoelectric system when using fuzzy algorithms for controlling solar panels.

Estimates of the possibility of failure and estimates of the efficiency of providing energy-saving mode over a daily time interval were used as output variables. The evaluation of the use of fuzzy algorithms was carried out using the method of the gravity center (Figure 10).

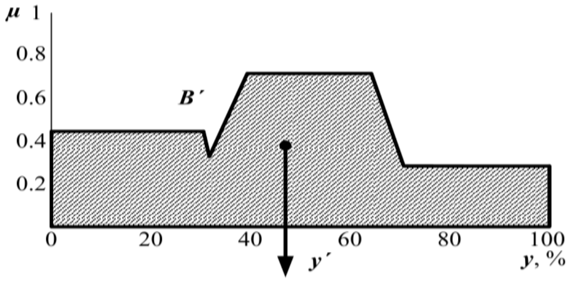

Figure 10 - Graphical representation of the gravity center method

Within the scope of the method y' is defined as the center of gravity for $\mu_{B'}(y)$ as follows

$$y' = \frac{1}{T}\int_0^T \frac{\int_{Y_{min}}^{Y_{max}} y\mu_{B'}(y)dy}{\int_{Y_{min}}^{Y_{max}} \mu_{B'}(y)dy} dt, \qquad (4)$$

where Y_{min}, Y_{max} are the specified boundaries of the interval of the fuzzy set of the output variable y.

As a result of the simulation, an increase in the efficiency of the thermoelectric system was revealed by reducing peak loads by 28% and, accordingly, reducing the probability of failures by almost 2 times. It should be noted that the results obtained are estimated and may take other values in other energy conditions.

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