APPLICATION OF THE FUZZY-SET THEORY TO THE TASKS OF AZERBAIJAN ELECTROENERGETICS SECURITY FOR SHORT-TERM PERIODS

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ABSTRACT

Electric power industry for short-term tasks of security is presented by the combination of four subsystems, namely: fueling subsystem, electricity production subsystem, transmission and distribution of electricity subsystem, export and import of electricity. To evaluate the security of each subsystem the linguistic variables, rules and membership functions have been defined. The resultant level of short-term security of Azerbaijan republic's electric power industry is determined on the basis of each subsystem's security by developed table.

Energy security is a component of power trilemma both for estimation of power industry functioning efficiency and for estimation of its stability. The continuously growing complexity of power engineering systems, their mutual influence and interconnectivity makes it difficult to estimate definitely the energy security level, and therefore it has to decompose the energy security problem by considering it at different time and space levels of power engineering systems. In this process it often has to handle the fuzzy and incomplete information, which doesn't define clearly the condition of power engineering [1].

This article deals with the application of fuzzy-set theory to electric power industry tasks for short-term periods. As it has been shown in [2], when studying the tasks of electroenergetics security for short-term periods the electric power industry is presented in the form of four interconnected subsystems: fueling subsystem, electricity production subsystem, electric power transmission and distribution subsystem and connections with the neighboring power systems and electricity import subsystem. Electroenergetics security is understood as the immunity of state, society and individual citizens from the threats of deficit when providing their needs with economically affordable electricity of acceptable quality and the threats of disturbance of continuous power supply. The most characteristic indexes (indicators) are selected for each subsystem, and external and internal risks and stabilities are separately grouped.

According to the classification of International Energy Agency the letter symbols from A to *E* can be used when estimating the energy security, as it is shown in Fig. 1, where *A* corresponds to the lowest risks and maximum stability, and *E* to the highest risks and lowest stability [3]. Applying the linguistic variables to subsystems' security classification, the following compliances can be obtained: *A* - "excellent", *B* - "normal", *C* - "not bad", *D* -"bad" and *E* -"very bad". The selected indexes of each subsystem take one of the three values: low, medium and high.

Studies show, that the limited by stroke lines areas appear because of both fuzziness of security indexes' values and their dynamics' change, as it is shown in Fig. 1. Different quantities of estimate layers and indicators are used for the estimation of security of above-named subsystems. The indicators often take the range of values with crossing borders, and sometimes they are distant from each other, that makes an ambiguity when determining the security on them.

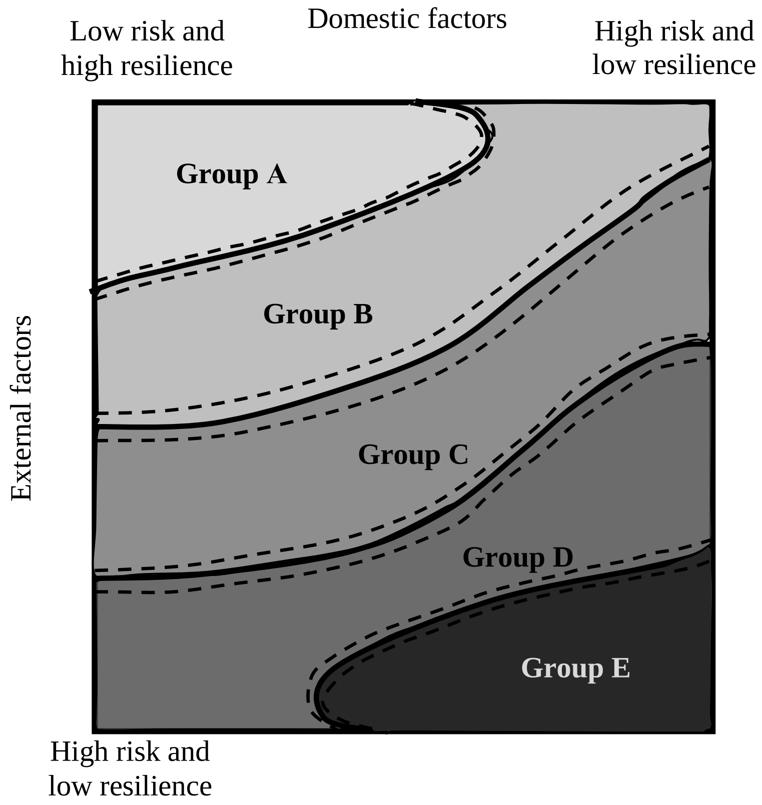

Figure 1.

When determining the security on Fig.1, the obtained result turns out to be sooner qualitative, than quantitative. For example, receiving an estimate of *C* - "not bad", it is difficult to judge, whether this result is closer to the border of B - "normal" or to the border of D - "bad", or it applies strictly to C. Reducing area of each state can be achieved by increasing the number of states with "almost perfect", "almost normal", "not so bad" and so on. But in this case by reducing the inaccuracy of estimate, the scheme of adequate response complicates many times, and subjectivism increases when making a decision about matching the indicators' values to one or another range.

To solve the problem of fuzziness of indicators values, take into account their dynamics' changes and obtain the quantitative value of security on the basis of linguistic information, the clauses of fuzzy-set theory and fuzzy logic can be used.

Fuzzy logical conclusion is carried out on the basis of fuzzy knowledge base, expressed by the linguistic statements of "if-then" type and the operation with fuzzy sets, as it is shown in Fig.2 [4].

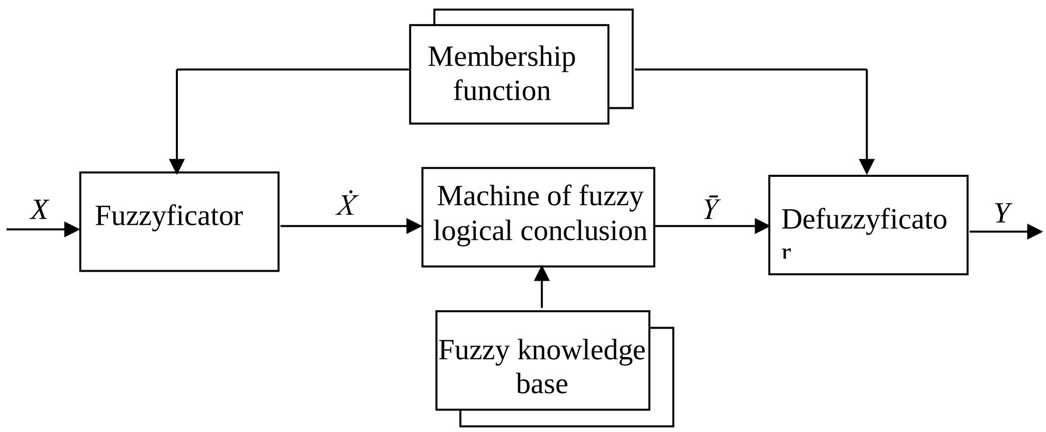

Figure 2.

Fuzzy model contains the following blocks:

- *fuzzyficator,* which transforms a fixed vector of influencing factors X into the vector of fuzzy sets $\tilde{X}$, required for performing the fuzzy logical conclusion;
- fuzzy knowledge base, containing the information about dependence $Y = f(X)$ in the form of a linguistic rules of "*FI- THEN*" type;
- machine of fuzzy logical conclusion, which on the basis of knowledge base rules defines a value of output variable in the form of a fuzzy set $\tilde{Y}$, corresponding to fuzzy values of input variables $\tilde{X}$;
- *defuzzyficator*, transforming the output fuzzy set $\tilde{Y}$ into a clear number Y.

Mathlab program has the package of Fuzzy Logic Toolbox, in which two types of fuzzy models of Mamdany and Sygeno type are realized. For our case the fuzzy model of Mamdany type is preferable.

The relationship between inputs $X = (x_1, x_2, ...x_n)$ and output y in the model of Mamdany type is determined by the fuzzy knowledge base of 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 $(x_n = a_{n,jk_j})$

THEN $y = d_j$, $i = \overline{1,m},$

where $a_{i,jp}$ is linguistic term by which the variable x_i is estimated in the line with jp $(p = \overline{1,k_j})$ number; k_j -is a number of lines-conjunction, in which the output y is estimated by linguistic term d_j; m - is the number of terms, used for linguistic estimation of output variable y.

All linguistic terms in the knowledge base are presented as the fuzzy sets, specified by the relevant membership functions, as it is shown in Fig. 2:

$\mu_{jp}(x_i)$ - membership function of input x_i to a fuzzy term $a_{i,jp}$, $i = \overline{1,n},$ $j = \overline{1,m},$ $p = \overline{1,k_j},$
i.e.

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

$\mu_{d_j}(y)$ - membership function of output y to a fuzzy term d_j, $j = \overline{1,m},$ i.e.

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

The membership degree of input vector $X^* = (x_1^*, x_2^*, ...x_n^*)$ to fuzzy terms d_j from fuzzy knowledge base is determined by the following system of fuzzy logical equations:

$$\mu_{d_j}(X^*) = \bigvee_{p=\overline{1,k_j}} \bigwedge_{i=\overline{1,n}} [\mu_{jp}(x_i^*)], \; j = \overline{1,m}, \qquad (2)$$

where $\vee$ ($\wedge$) - is the operation of s -norm (t -norm), i.e. from a variety of implementation of *OR (AND)* logical operations. The following implementations are used most often: for *OR* operation - finding a maximum, for *AND* operation - finding a minimum.

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

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

Where *imp* -is an implication, usually implemented as the operation of minimum finding; *agg* - is an aggregation of fuzzy sets, which is most often implemented by the operation of maximum finding.

A clear value of output y, corresponding to input vector X^*, is defined as a result of defuzzyfication of fuzzy set $\tilde{y}$. A defuzzyfication by the method of centre of gravity is most often used:

$$y = \frac{\int_{\underline{y}}^{\overline{y}} y \cdot \mu_{\tilde{y}}(y) dy}{\int_{\underline{y}}^{\overline{y}} \mu_{\tilde{y}}(y) dy}$$

In our model the defuzzyfication is also carried out by this method.

Using the above, the model of fuzzy conclusion for evaluation of each subsystem's security of electric power industry separately is drawn. To evaluate the fueling level of electric power industry, it needs to evaluate the fueling of country, the fuzzy output of which is one of inputs of electric power industry fuelling subsystem.

Natural gas supply of the country

For this subsystem the input subsystem's parameters and their turndowns are shown in Table 1.

Table 1.

Natural gas supply-*SNGS*			
Input parameters	Terms' meanings		
	L-low	M-medium	H-high
DI -dependence on import	<10%	30–40%	>70%
II -infrastructure of import	>60%	30–60%	<30%
RP -variety of suppliers	>60%	30–60%	<30%
PQ -power of delivery from gas storage	<50%	50–100%	>100%

Given in Table 1 the membership function of input parameters, are shown in Fig. 3.

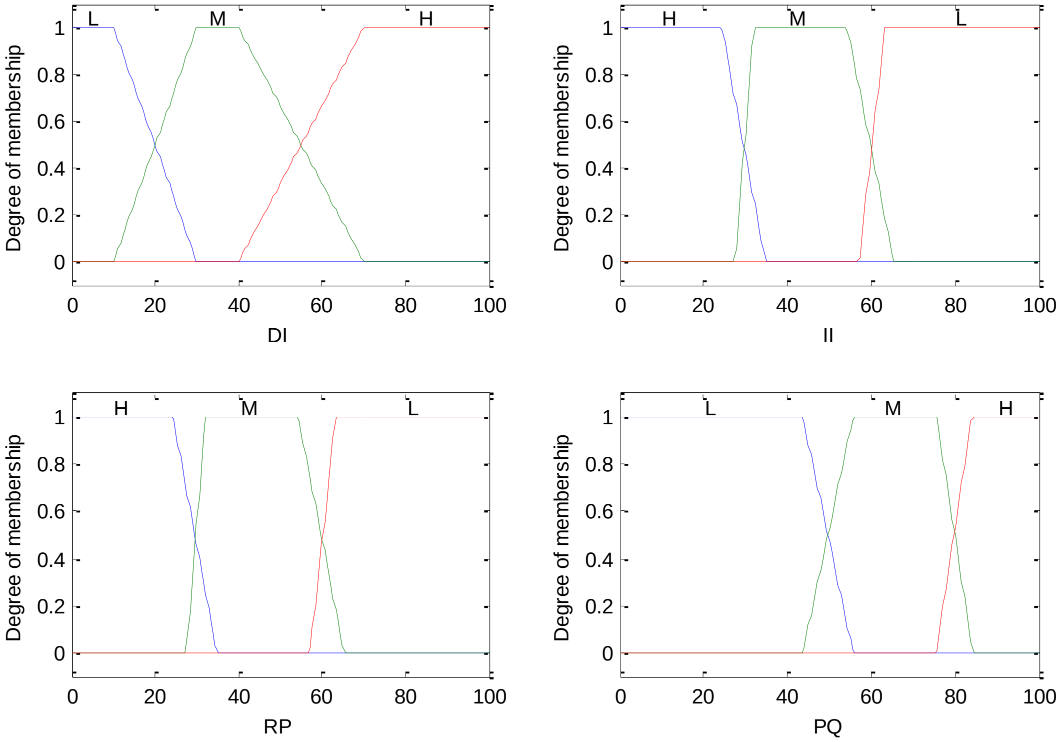

Figure 3.

Security of all subsystems is estimated in Table 2, where the compliances of output value, expressed in percentage terms, with the letter symbols are shown.

Table 2.

Output	*A*	*B*	*C*	*D*	*E*
	85–100	63–85	39–63	18–39	0–18

The membership function of output parameter for "Natural gas supply of the country" subsystem is shown in Fig. 4.

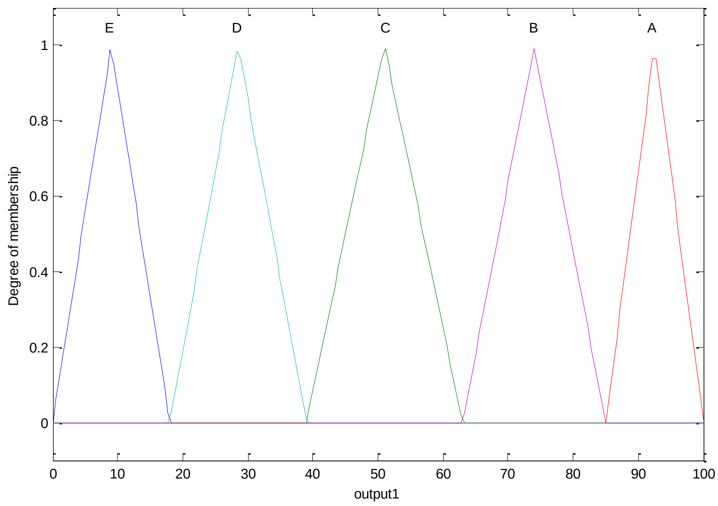

Figure 4.

It needs to note, that the membership function of output parameter for all subsystems is the same.

To estimate the security level of "Natural gas supply of the country" subsystem it needs to use the fuzzy knowledge base, drawing up in the form of table of rules, as it is shown in Table 3.

Table 3.

№	DI	II	RP	PQ	O
1	H	H	H	H	B
2	H	H	H	M	B
3	H	H	H	L	C
4	H	H	M	H	B
5	H	H	M	M	C
6	H	H	M	L	D
7	H	H	L	H	B
8	H	H	L	M	C
9	H	H	L	L	D
10	H	M	H	H	C
11	H	M	H	M	C
12	H	M	H	L	D
13	H	M	M	H	C
14	H	M	M	M	C
15	H	M	M	L	D
16	H	M	L	H	C
17	H	M	L	M	D
18	H	M	L	L	E
19	H	L	–	H	C
20	H	L	–	M	D
21	H	L	–	–	E
22	M	H	–	–	A
23	M	M	H	H	A
24	M	M	H	H	A
25	M	M	H	L	B
26	M	M	M	H	A
27	M	M	M	M	B
28	M	M	M	L	B
29	M	M	L	H	B
30	M	M	L	M	C
31	M	M	L	L	D
32	M	L	–	H	B
33	M	L	–	M	C
34	M	L	–	L	D
35	L	–	–	–	A

Security of "Natural gas supply of the country" subsystem becomes for Azerbaijan after defuzzyfication of the output value equal to 92.5 %, which well corresponds to A level.

Electric power industry fuelling

One of the input values of "Electric power industry fueling" subsystem- *PFE* is the output of "Natural gas supply of the country" subsystem- *SNGS*. Two another inputs are "Variety of fuel types" and "Diversification of delivery ways", as it is shown in Table 4 [5].

Table 4.

Electric power industry fueling - *PFE*			
Input parameters	Terms' meanings		
	L-low	M-medium	H-high
SNGS -output of "Natural gas supply of the country" subsystem	60–100%	40–60%	0–40%
VF -variety of fuel types	>64%	33–64%	<33%
DPD-diversification of delivery ways	>64%	33–64%	<33%

The membership function of input parameters for "Electric power industry fuelling" subsystem are shown in Fig. 5.

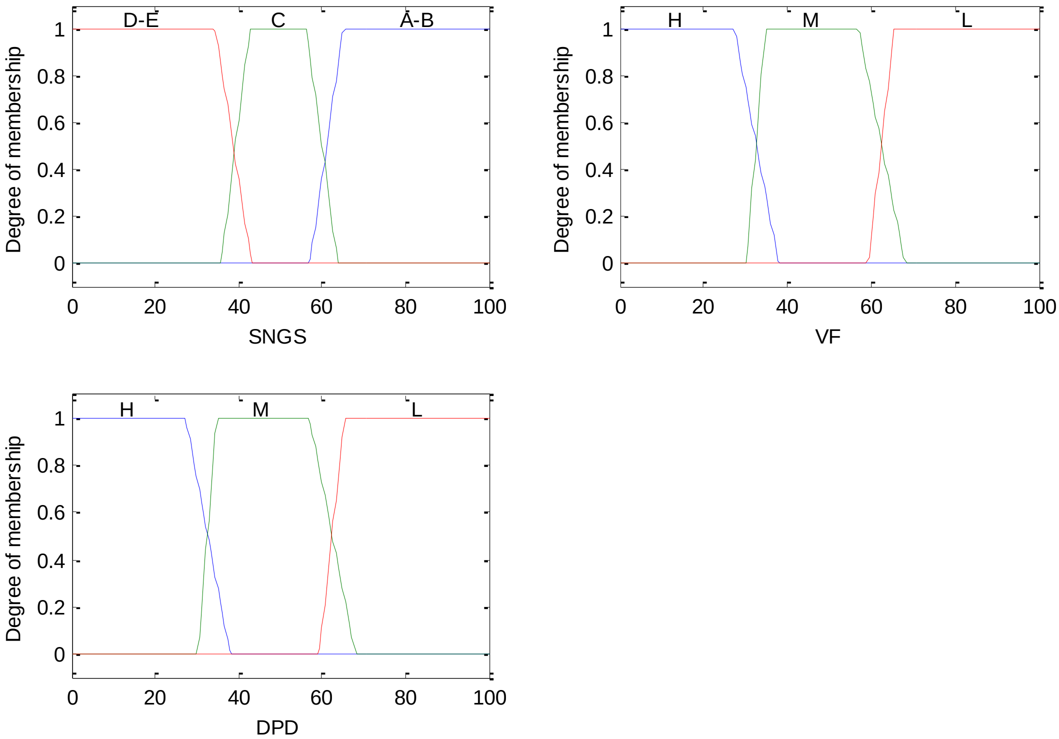

Figure 5.

The fragment of fuzzy knowledge base for evaluation of security of "Electric power industry fueling" subsystem is given in Table 5. It should be noted that, for making the knowledge base the central indicators' values are used.

Table 5.

№	SNGS	VF	DPD	O
1	H	H	H	C
2	H	H	M	C
3	H	H	L	D
4	H	M	H	C
5	H	H	M	D
6	H	H	L	E
7	H	L	H	D
8	H	H	M	E
9	H	H	L	E
10	M	H	H	B

If to use the current values of input parameters of Azerbaijan "Electric power industry fueling" subsystem and the knowledge base, then the security of this subsystem will be 74 %, which corresponds *to B* "normal".

Electricity production

The most important indicators and their ranges for evaluation of this subsystem's security are presented in Table 6.

Table 6.

Electricity production-*EP*			
Input parameters	Terms' meanings		
	L-low	M-medium	H-high
G -electric power generation by own sources	<80%	80–90%	>90%
R -reserve level	<15%	15–25%	>30%
CI - wear degree of capital equipment	<15%	15–30%	>40%
MP -maneuver and distributed generation	<15%	15–30%	>40%

The functions of input parameters' belonging of "Electricity production" subsystem are shown in Fig. 6.

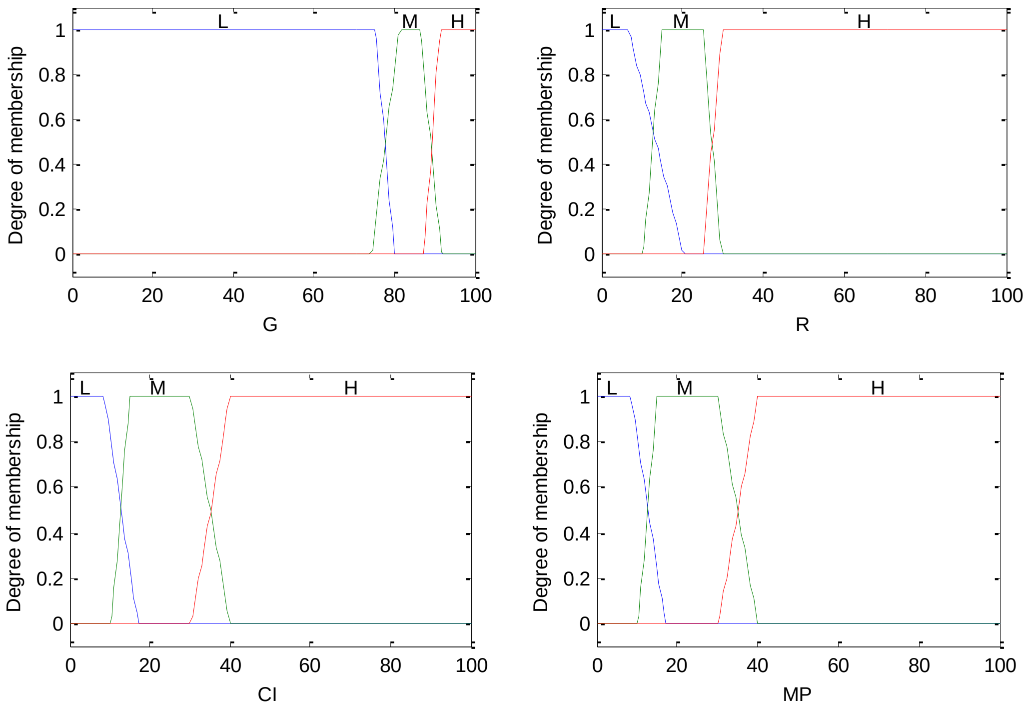

Figure 6.

Table 7 shows a fragment of fuzzy knowledge base for evaluation of security of "Electricity production" subsystem.

Table 7.

№	G	R	S	MP	O
1	H	H	L	L	B
2	H	H	L	M	A
3	H	H	L	H	A
4	H	H	M	L	B
5	H	H	M	M	A
6	H	H	M	H	A
7	H	H	H	L	D
8	H	H	H	M	C
9	H	H	H	H	B
10	H	M	L	L	C

The output parameter of "Electricity production" subsystem just as the outputs of all subsystems is estimated in accordance with Table 2. After defuzzyfication of output parameter, and with taking the input parameters *G*-100 %, *R*-20 %, *CI*-25 %, *MP*–25%, this subsystem's security for Azerbaijan turns out to be 72.8 %, which also corresponds to "normal" level.

Transmission and distribution of electricity

The input parameters for evaluation of this subsystem's security-*TDE* and their values are shown in Table 8.

Table 8.

Transmission and distribution of electricity-*TDE*			
Input parameters	Terms' meanings		
	L-low	M-medium	H-high
WS -wear level of substations	<25%	30–50%	>60%
WT- wear of transformers	<25%	30–50%	>60%
WL -wear of air lines	<25%	30–50%	>60%
SBR - balance degree of regions	<40%	40–70%	>70%

The functions of input parameters' membership of "Transmission and distribution of electricity" subsystem are shown in Fig. 7.

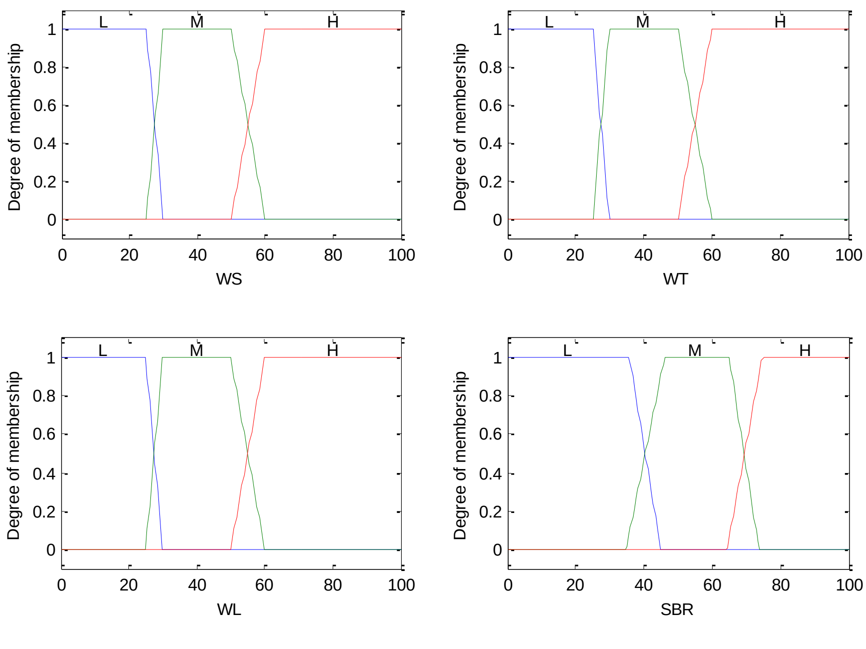

Figure 7.

The fragment of fuzzy knowledge base for evaluation of security of "Transmission and distribution of electricity" subsystem is shown in Table 9.

Table 9.

№	WS	WT	WL	SBR	O
1	H	H	H	H	D
2	H	H	H	M	D
3	H	H	H	L	E
4	H	H	M	H	D
5	H	H	M	M	D
6	H	H	M	L	E
7	H	M	H	H	D
8	H	M	H	M	D
9	H	M	H	L	E
10	H	M	M	H	D

Calculating the security of "Transmission and distribution of electricity" subsystem at input parameters of *WS*-67 %, *WT*-62 %, *WL*-60 %, *SBR*-60 % we shall receive 28.5 %, which corresponds to *D*-"poor" security level.

Connections with the neighboring power systems and electricity import

Input parameters for evaluation of security of this *CEI*-subsystem and their values are shown in Table 10.

Table 10.

Connections with the neighboring power systems and electricity import-*CEI*			
Input parameters	Terms' meanings		
	L-low	M-medium	H-high
LI -level of import	<10%	10–30%	>50%
II-infrastructure of import	>64%	33–64%	<33%
RMC -reserve of transfer capability of intersystem connections	<20%	20–40%	>50%

Fig. 8 shows the functions of input parameters' belonging of "Connections with the neighboring power systems and electricity import" subsystem.

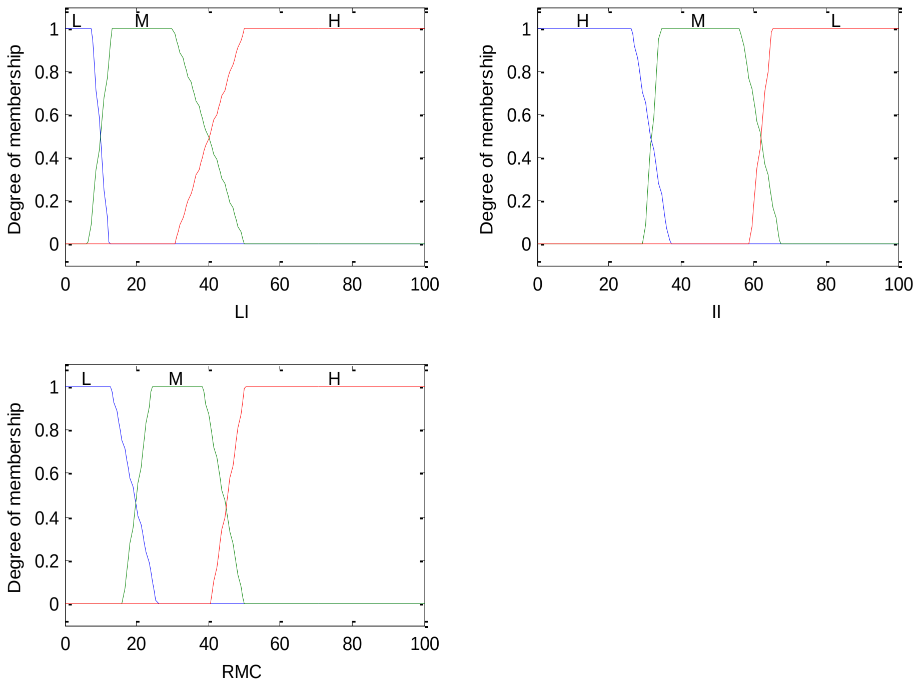

Figure 8.

The fragment of fuzzy knowledge base for evaluation of security of "Connections with neighboring power systems and electricity import" subsystem is shown in Table 11.

Table 11.

№	LI	II	RMC	O
1	H	H	H	C
2	H	H	M	C
3	H	H	L	D
4	H	M	H	C
5	H	M	M	D
6	H	M	L	E
7	H	L	H	D
8	H	L	M	E
9	H	L	L	E
10	M	H	H	B

Security of "Connections with neighboring power systems and electricity import" subsystem with input parameter *LI*-0.5 % turns out to be 92.5 %, which corresponds to *A* -"excellent" security level.

Electroenergetics security of the country

Electroenergetics security of the country is estimated with the help of fuzzy values of subsystems' security, constituting the electric power industry, as it is shown in Fig.9.

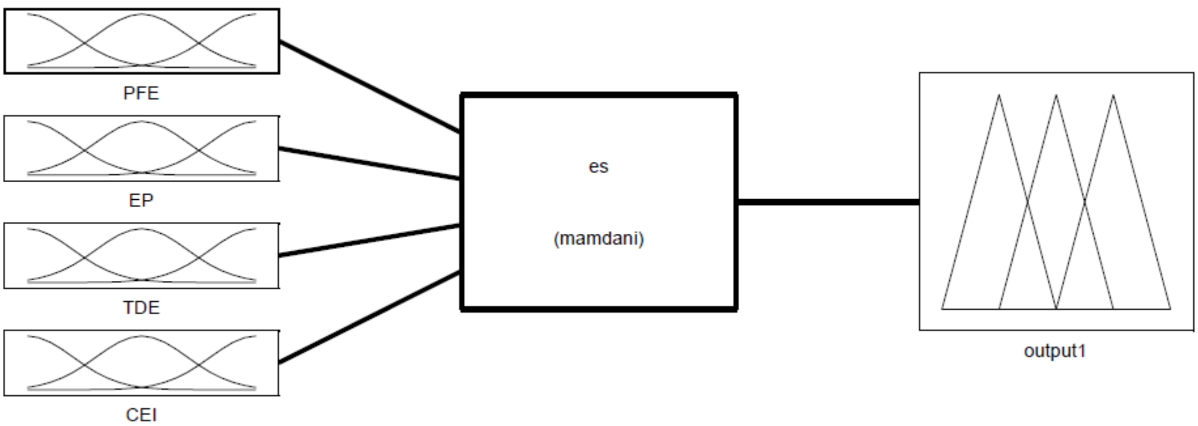

Figure 9.

The Input values of evaluation system of electroenergetics security and their values are shown in Table 12.

Table 12.

Electroenergetics security of the country			
Input parameters	Terms' meanings		
	L-low	M-medium	H-high
PFE-Fueling of electric power industry	0–39%	39–63%	63–100%
EP -Electricity production	0–39%	39–63%	63–100%
TDE- Transmission and distribution of electricity	0–39%	39–63%	63–100%
CEI- Connection with neighboring power systems and electricity import	0–39%	39–63%	63–100%

The membership function of inputs and output for evaluation of electroenergetics security are shown in Fig. 10.

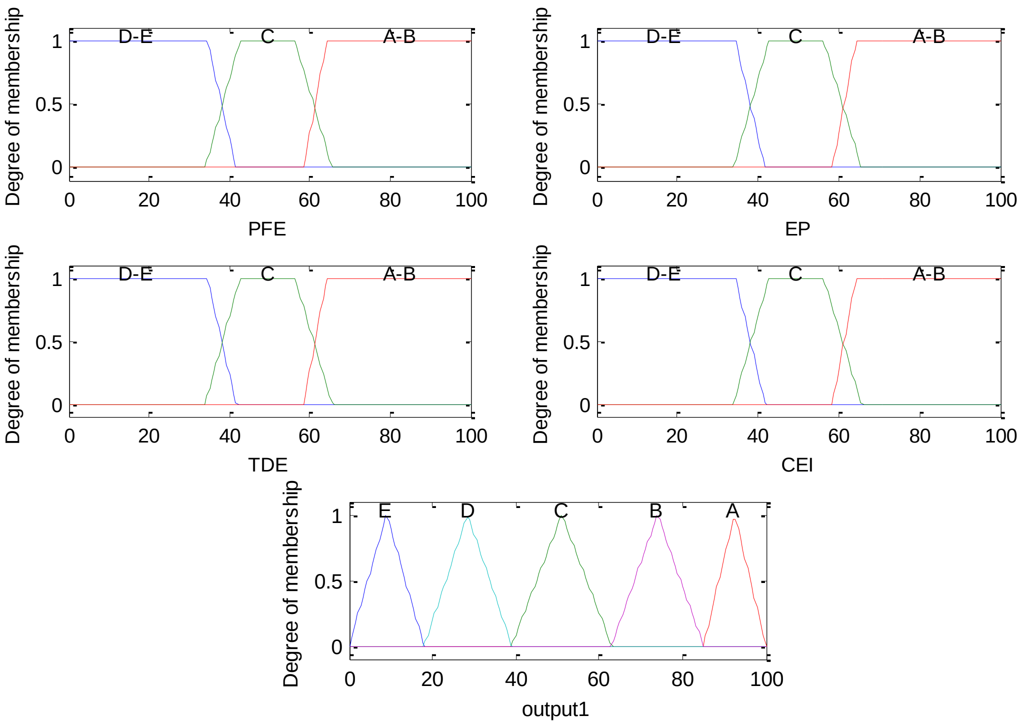

Figure 10.

Table 13 reflects the fragment of fuzzy knowledge base for evaluation of security of "Connection with neighboring power systems and electricity import" subsystem.

Table 13.

№	Electric power industry fuelling	Electricity production	Transmission and distribution of electricity	Electricity import	Result
1	A-B	A-B	A-B	A-B	A
2	A-B	A-B	A-B	C	B
3	A-B	A-B	A-B	D-E	B
4	A-B	A-B	C	A-B	B
5	A-B	A-B	C	C	B
6	A-B	A-B	C	D-E	C
7	A-B	A-B	D-E	A-B	B
8	A-B	A-B	D-E	C	C
9	A-B	A-B	D-E	D-E	D
10	A-B	C	A-B	A-B	B

With the obtained calculating values of electroenergetics security of subsystems: electric power industry fueling-74 %, electricity production-72.8 %, transfer and distribution of electricity-28.5 %, connections with neighboring power systems and electricity import - 92.5 %, the electroenergetics security of Azerbaijan will constitute 74 %, which corresponds to firm "normal" value, as it is shown in Fig. 11.

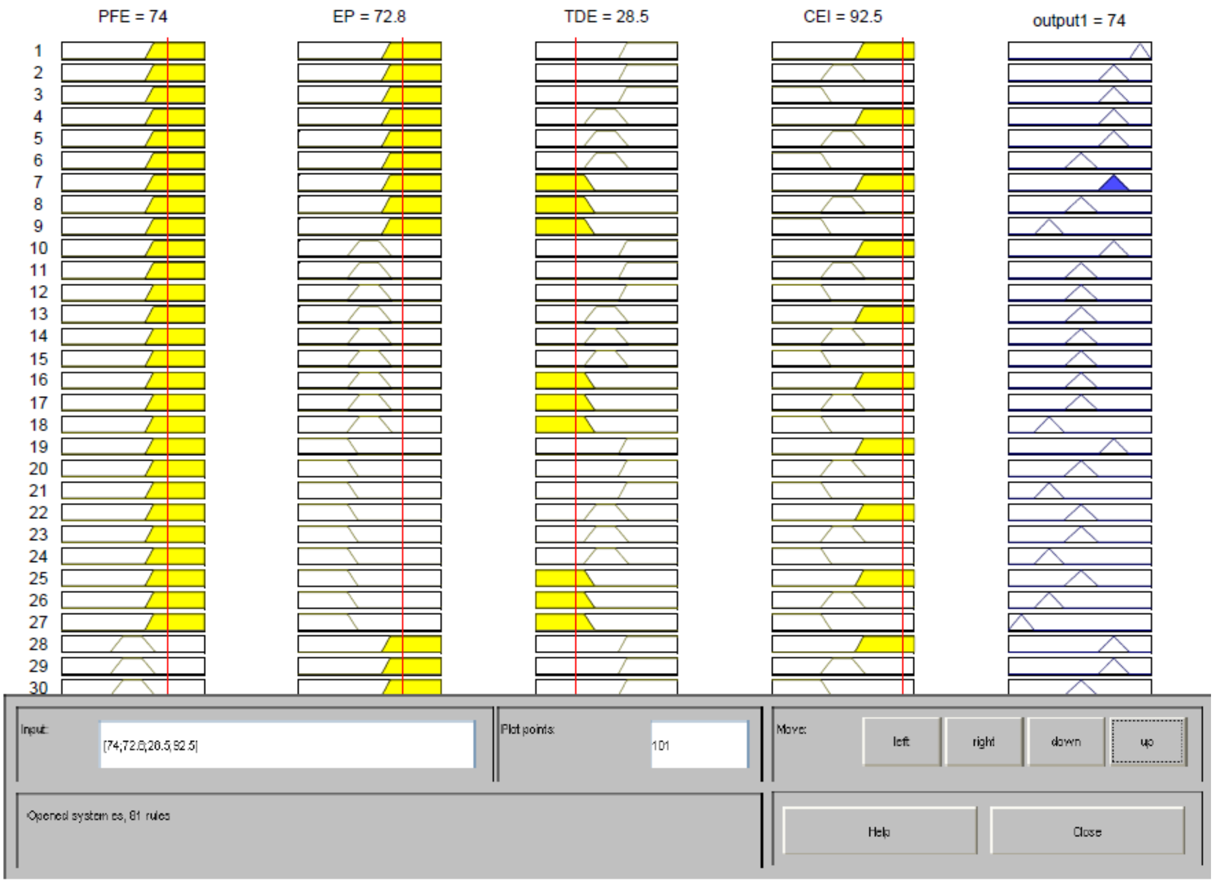

Figure 11.

CONCLUSIONS

1. The fuzziness and incompleteness of indicators' values as well as the dynamics of their change make uncertainty for determining the electroenergetics security.
2. Electroenergetics security for short-term periods can be studied with using 4 interconnected subsystems.
3. Electroenergetics security can be determined by the security of subsystems' components with using the theory of fuzzy sets and fuzzy logic.
4. Applying the fuzzy sets theory the following values have been obtained for electroenergetics security and subsystems' components of Azerbaijan: electric power industry fueling -74 %, which corresponds to *B* security level; production of electricity-72.8 %, the security level-*B;* transmission and distribution of electricity-28.5 %, the level of security-*D*; connections with neighboring power systems and electricity import-92.5 %, the level of security-*A*, the electroenergetics security of Azerbaijan will constitute 74 %, which corresponds to firm "normal" *B*-value.
5. Developed method allows evaluating the security quantitatively, and therefore gives an opportunity to implement the time-based monitoring of energy security level changes of electric power industry and to estimate the effectiveness of policy in electric power industry field in terms of energy security.

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