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# Determination of Azerbaijan Electric Power Industry Security for Long-Term Periods on the Basis of Fuzzy Deduction

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***Abstract*—The paper developed a method for assessing the electric power industry security of Azerbaijan. With the application of fuzzy set theory to the problems of electric power industry security, the values of security for seven subsystems, components of power energy, and to determine the resultant level of electric power industry security for long–term periods.**

***Keywords—energy security, indicators, membership function***

## I. INTRODUCTION

Energy security is one of the major components of economic and national security. Study of energy security threats, estimation of their implementation possibilities represents the important source information on the determination of energy security level [3].

To solve the energy security tasks we have validated the approach to energy security study at the level of individual power industry's systems-oil branch, gas industry and electric power industry. It is caused by the fact that continuously growing complexity of power industry systems requires studying of the energy security problem at the level of individual branch systems of power industry [4,7].

The security of such power industry's systems as oil and gas industries is considerably secured for Azerbaijan Republic, as Azerbaijan Republic is the exporter of oil and natural gas to world markets and therefore when energy security study the attention is basically paid to electric power industry security.

The method for study of electric power industry security of Azerbaijan Republic is worked out in [4]. For short-term tasks of security the system is presented by the collection of 4 blocks, namely the block of fuel supply, block of electric power production, block of electric power transmission and distribution, block of the connections with neighboring power systems and import of electric power. For each block relevant risks and stability are estimated, and as well the degree of vulnerability according to qualification of the "International Energy Agency" (IEA) [1]. All this allows evaluating as a whole the resulting level of short-term security of studied system-electric power industry of Azerbaijan.

The method for using of the fuzzy-set theory to electric power industry's tasks for short-term periods has been validated in [2]. Here, as well as in [2] the electric power industry for short-term tasks of security is presented by the collection of 4 subsystems.

To evaluate the security of each subsystem the linguistic variables, rules and membership functions have been determined.

On the basis of each subsystem's security the quantitative value of short-term security of Azerbaijan Republic's electric power industry is determined on the developed transition table.

In [5] the method, using for study of security of Azerbaijani power system for short-term periods, has been developed for using for medium-term periods. For medium-term tasks of security the system is presented by the collection of 5 blocks, the block of power consumption is added to four ones.

Here the method of application of fuzzy-set theory to the tasks of electric power industry security is presented for evaluation of electric power industry security for long-term periods.

In this paper as well as in [2] and [5], the letter symbols from A to E for setting the security level of electric power industry are used, as it is shown in "Fig. 1". Applying the linguistic variables for classification of security, the following compliances can be obtained: *A*–"excellent", *B*–"normal", *C*–"not bad", *D*–"bad" and *E*– "very bad". When study the electric power industry security for long-term periods the electric power industry is presented by the collection of 7 subsystems: electric power industry fuelling, electric power production, transmission and distribution of electric power, connections with the neighboring power systems and import of electric power, electric power consumption, reproduction of the fixed assets and the subsystem of perspective development. For each subsystem the most responsible indicators are selected, which take one of three values- low, medium and high. As it was shown in [2,5], when evaluating the security of electric power industry subsystems on "Fig. 1" a qualitative assessment has basically obtained rather than quantitative one. For example, the condition of security *C*–"not bad" borders on one hand upon the condition of *B*–"normal" and on the other hand upon *D*–"bad". It is important to determine more precisely the condition of " not bad", because often the situation occurs when the security assessment is in the limited by stroke lines area, owing to the fact that indicators often take the range of values with crossing boundaries, and sometimes they are distant from each other, which leads to ambiguity when determining the security on them. To obtain a quantitative assessment here as well as in [2] and [5] the theory of fuzzy deduction is used on the basis of fuzzy sets.

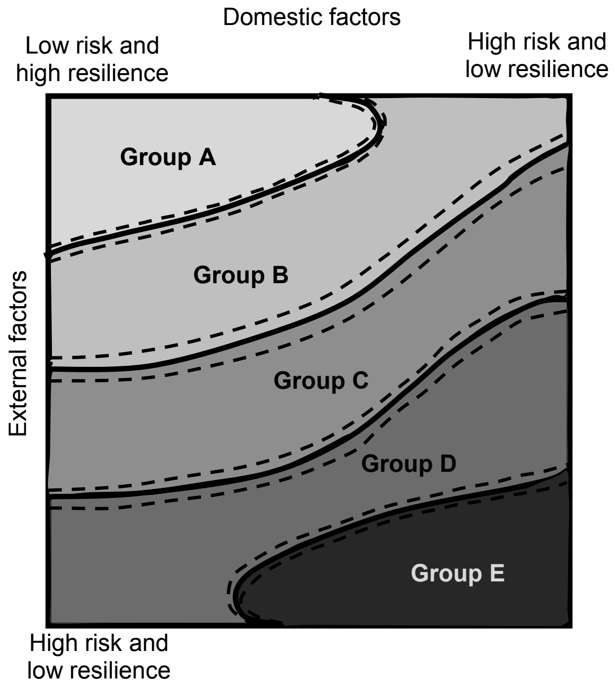



Fig. 1. *Diagram of energy security study*

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" [5].

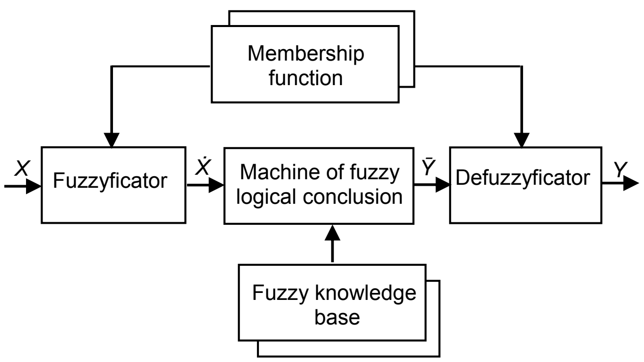



Fig. 2. *Scheme of fuzzy logic conclusion*

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:

$$\text{IF } (x_1=a_{1,j1}) \text{ AND } (x_2=a_{2,j1}) \text{ AND...AND } (x_n=a_{n,j1})$$
$$\text{OR } (x_1=a_{1,j2}) \text{ AND } (x_2=a_{2,j2}) \text{ AND...AND } (x_n=a_{n,j2})$$
.....
$$\text{OR } (x_1=a_{1,jk_j}) \text{ AND } (x_2=a_{2,jk_j}) \text{ AND...AND } (x_n=a_{n,jk_j})$$

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.

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

$\mu_{d_j}(y)$ - 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:

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

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:

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

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.

In Azerbaijan Republic a natural gas is basically burned at the power plants. As a whole to evaluate a security of natural gas supply of the country the following risks and resiliencies are considered, as it is shown in "Table 1".

TABLE 1. Indicators for evaluation of security of "natural gas supply"

| Risks | | Resilience |
|---|---|---|
| **External** | • Dependence on import<br>• Political stability of suppliers | • Number of ports of liquefied natural gas input.<br>• Number of pipelines<br>• Diversity of suppliers |
| **Domestic** | • Seabed mining | • Delivery volume of gas from the storage<br>• Intensity of gas consumption |

The most important indicator from the point of view of gas supply security is the dependence on import. According to this indicator the country are divided into three categories: low dependence on import (<10%) and the exporting countries, moderate dependence on import (30-40%) and high dependence (>70%).

In "Fig. 3" the study diagram of security of country gas supply, proposed by IEA, is shown, the output of this subsystem is one of the inputs for subsystem of "electric power industry fuelling".

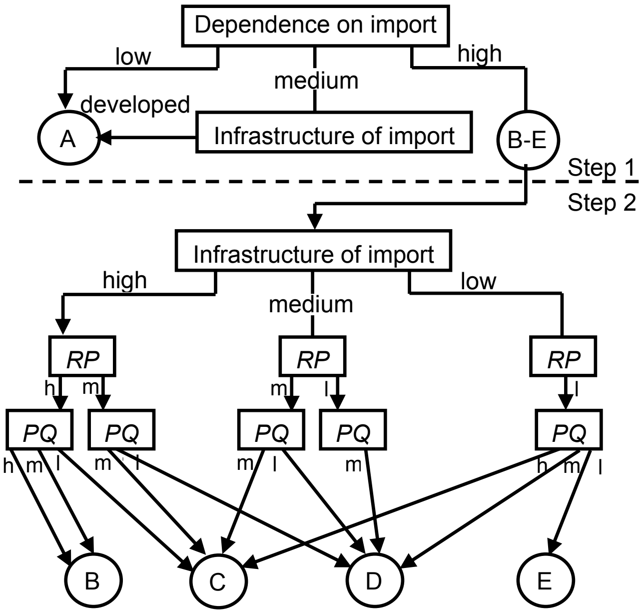



Fig. 3. *Security of "natural gas supply"*

For this subsystem the input parameters of subsystem and their turndowns are given in "Table 2".

TABLE 2. Input parameters of "natural gas supply" subsystem

| **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% |

The membership functions of input parameters of "natural gas supply" subsystem correspond to the membership functions as it is shown in "Fig. 4". If for short-term and medium-term periods the membership function of subsystem of "natural gas supply" corresponded more with the trapezoidal function, then for the long-term periods the membership function corresponds more to the Gaussian function. It links with a relatively more uncertainty of subsystem condition of "natural gas supply" for the long-term periods in comparison with the short-term and medium-term periods.

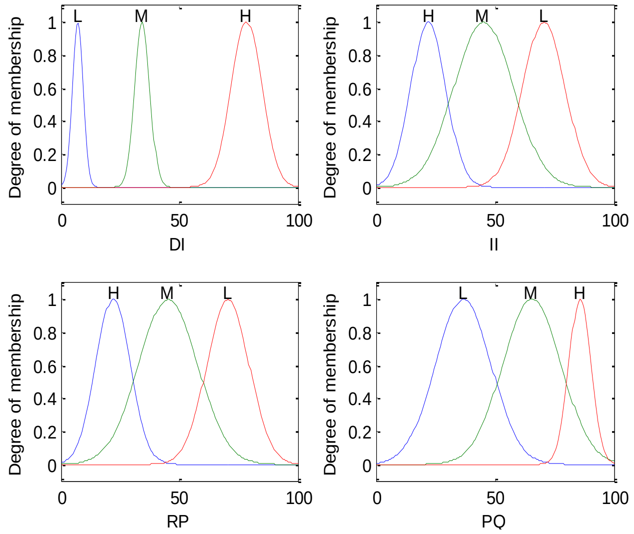



Fig. 4. *Membership functions of input parameters for subsystem of "natural gas supply"*

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 3.

| 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".

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

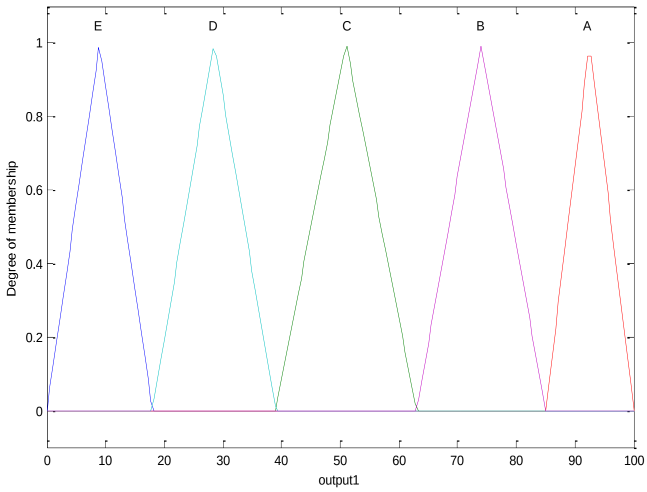



Fig. 5. *Membership function of output parameter for the subsystem of "natural gas supply"*

For Azerbaijan the security of "Natural gas supply of the country" subsystem after defuzzification of output value for long-term periods as well as for medium-term and short-term periods is equal to 92.5%, which clear corresponds to *A* level.

## Electric power industry fuelling

One of the input values of "Electric power industry fuelling" 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" [6].

TABLE 4. Input parameters of "electric power industry fuelling" subsystem

| **Electric power industry fuelling - *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% |
| *SOP*– share of seabed mining | <30% | 40-60% | >80% |
| *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. 6".

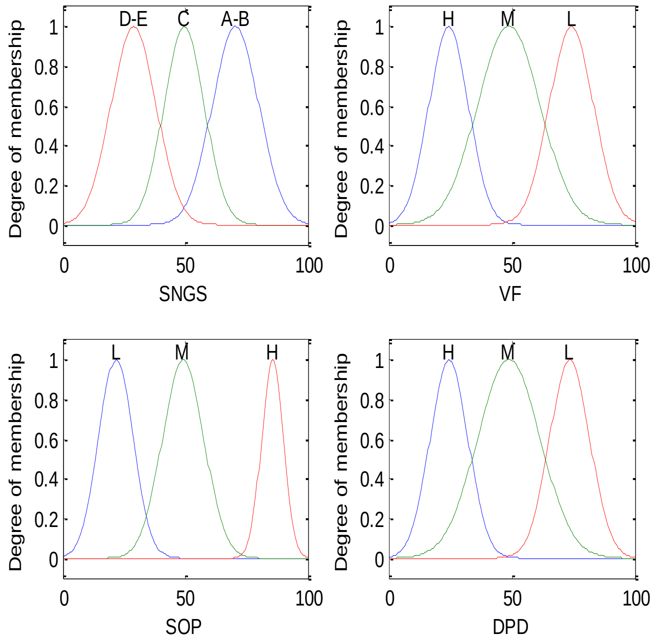



Fig. 6. *Membership functions of input parameters for subsystem of "electric power industry fuelling"*

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

TABLE 5. The fragment of fuzzy knowledge base for subsystem of "electric power industry fuelling"

| **№** | **SNGS** | **VF** | **SOP** | **DPD** | **O** |
|---|---|---|---|---|---|

| | L–60-100%<br>M–40-60%<br>H–0-40% | H<0,33<br>M–0,33-0,64<br>L>0,64 | H>80%<br>M–40-60%<br>L<30% | H<0,33<br>M–0,33-0,64<br>L>0,64 | |
|---|---|---|---|---|---|
| 1 | H | H | H | H | C |
| 2 | H | H | H | M | D |
| 3 | H | H | H | L | D |
| 4 | H | H | M | H | C |
| 5 | H | H | M | M | C |
| 6 | H | H | M | L | D |
| 7 | H | H | L | H | C |
| 8 | H | H | L | M | C |
| 9 | M | L | L | L | D |
| 10 | L | H | H | H | B |
| 11 | L | H | H | M | B |
| 12 | L | H | H | L | C |
| 13 | L | H | M | H | A |
| 14 | L | H | M | M | B |
| 15 | L | H | M | L | C |

It should be noted that the values of input parameters of majority of subsystems as opposed to the short-term and part of medium-term periods are obtained not in a view of specific values but as some ranges of values. If to use the long-term values of input parameters of Azerbaijan "Electric power industry fuelling" subsystem, expressed by the ranges of values (SNGS-92.5, VF-0.55-0.45, SOP-82-80, DPD-0.55-0.48) and knowledge base, the security of this subsystem will be in the range of 51.3-58.8%, which corresponds to *C*- "not bad".

### Electric power production

To evaluate a security of electric power production subsystem for long-term periods the most important indicators and their ranges of values are presented in "Table 6".

TABLE 6. Input parameters of " electric power production " subsystem

| **Electric power 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% | 20-25% | >30% |
| *CI*– wear degree of capital equipment | <15% | 15-30% | >40% |

The functions of input parameters' belonging of "electric power production" subsystem are shown in "Fig. 7".

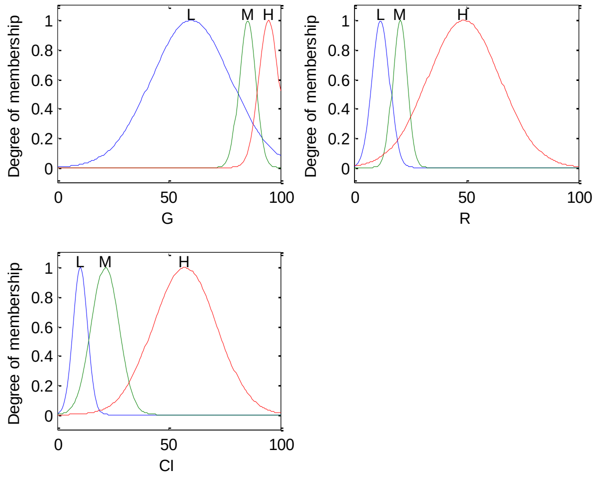



Fig. 7. *Membership functions of input parameters for subsystem of "*electric power production*"*

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

TABLE 7. The fragment of fuzzy knowledge base for subsystem of "electric power industry fuelling"

| **№** | **G** | **R** | **CI** | **O** |
|---|---|---|---|---|
| | H>90%<br>M–80-90%<br>L<80% | H>30%<br>M–20-25%<br>L<15% | H>40%<br>M–15-30%<br>L<15% | |
| 1 | H | H | H | B |
| 2 | H | H | M | B |
| 3 | H | H | L | A |
| 4 | H | M | H | C |
| 5 | H | M | M | B |
| 6 | H | M | L | B |
| 7 | H | L | H | C |
| 8 | H | L | M | C |
| 9 | H | L | L | B |
| 10 | M | H | H | C |
| 11 | M | H | M | C |
| 12 | M | H | L | B |
| 13 | M | M | H | D |
| 14 | M | M | M | C |
| 15 | M | M | L | B |

Output parameter of "electric power production" subsystem as well as the outputs of all subsystems is estimated in accordance with "Table 3". After defuzzification of output parameter the security of this subsystem for long-term periods in Azerbaijan with the adoption of input parameters' values *G*–100%, *R*–23-27%, *CI*–25-21% will be in the range of 62.9-64.3%, which nearly corresponds to "normal" level.

### Transmission and distribution of electric power

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

TABLE 8. Input parameters of "transmission and distribution of electric power" subsystem

| **Transmission and distribution of electric power–*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 electric power" subsystem are shown in "Fig. 8".

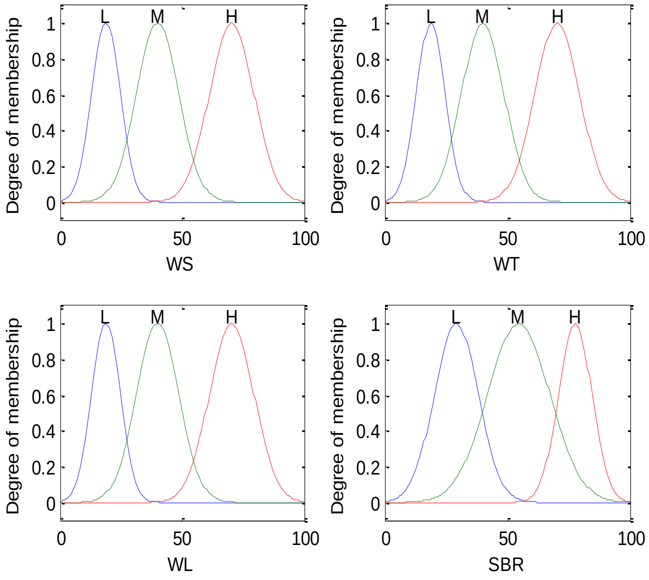



Fig. 8. *Membership functions of input parameters for subsystem of "transmission and distribution of electric power"*

"Table 9" shows a fragment of fuzzy knowledge base for evaluation of security of "transmission and distribution of electric power" subsystem.

TABLE 9. The fragment of fuzzy knowledge base for subsystem of "transmission and distribution of electric power"

| № | WS | WT | WL | SBR | O |
|---|---|---|---|---|---|
| | L<25%<br>M–30-50%<br>H>60% | H<25%<br>M–30-50%<br>L>60% | H<25%<br>M–30-50%<br>L>60% | H>70%<br>M–40-70%<br>L<40% | |
| 1 | L | H | M | L | D |
| 2 | L | M | H | H | B |
| 3 | L | M | H | M | C |
| 4 | L | M | H | L | C |
| 5 | L | M | M | H | B |
| 6 | L | M | M | M | B |
| 7 | L | M | M | L | B |
| 8 | L | M | L | H | B |
| 9 | L | M | L | M | B |
| 10 | L | M | L | L | B |
| 11 | L | L | H | H | B |
| 12 | L | L | H | M | C |
| 13 | L | L | H | L | C |
| 14 | L | L | M | H | A |
| 15 | L | L | M | M | B |

After calculation of security of "transmission and distribution of electric power" subsystem with the input parameters' values *WS*– 49-45%, *WT*– 47-43%, *WL*– 47-43%, *SBR*–70-75% the range of values will be obtained equal to 66.6-71.8%, which corresponds strictly to security level of B-"normal".

**Connections with the neighboring power systems and import of electric power**

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

TABLE 10. Input parameters of "connections with the neighboring power systems and import of electric power" subsystem

| **Connections with the neighboring power systems and import of electric power–*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% |

The functions of input parameters' membership of "connections with the neighboring power systems and import of electric power" subsystem are shown in "Fig. 9".

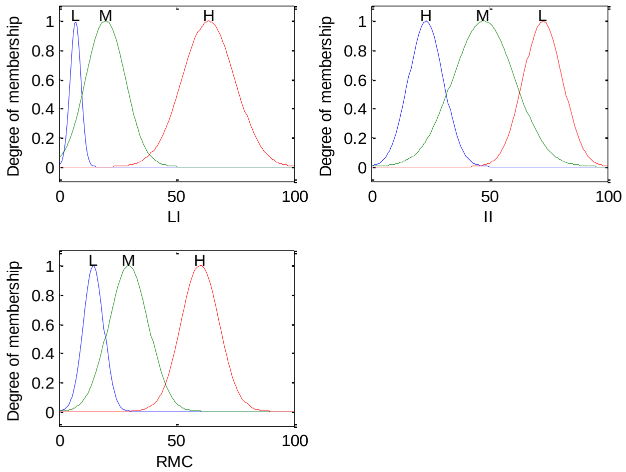



Fig. 9. *Membership functions of input parameters for subsystem of "*connections with the neighboring power systems and import of electric power*"*

"Table 11" shows a fragment of fuzzy knowledge base for evaluation of security of "connections with the neighboring power systems and import of electric power" subsystem.

TABLE 11. The fragment of fuzzy knowledge base for subsystem of "connections with the neighboring power systems and import of electric power"

| № | LI | II | RMC | O |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| | H>50%<br>M–10-30%<br>L<10% | H<33 %<br>M–33-64%<br>L<15% | H>50%<br>M–20-40%<br>L<20 % | |
| 1 | M | H | H | B |
| 2 | M | H | M | B |
| 3 | M | H | L | C |
| 4 | M | M | H | B |
| 5 | M | M | M | C |
| 6 | M | M | L | D |
| 7 | M | L | H | C |
| 8 | M | L | M | D |
| 9 | M | L | L | E |
| 10 | L | H | H | A |
| 11 | L | H | M | A |
| 12 | L | H | L | A |
| 13 | L | M | H | A |
| 14 | L | M | M | A |
| 15 | L | M | L | A |

Taking into account that the connections of Azerbaijani power system with neighboring systems have sufficient potentials the security of "connection with neighboring systems and import of electric power" subsystem with the values of input parameters for long-term periods *LI*– 3-2%, *II*–15-10%, *RMC*–60% will be in the range of 87.4-88%, which corresponds to the level of security *A*– "excellent".

**Electric power consumption**

Input parameters for evaluation of security of this subsystem *EC* and their values are shown in "Table 12".

TABLE 12. Input parameters of “electric power consumption” subsystem

| **Electric power consumption–*EC*** | | | |
|---|---|---|---|
| Input parameters | Terms' meanings | | |
| | L-low | M-medium | H-high |
| *DOO* –duration of switching-offs | <24 h. | 40-80 h. | >100 h. |
| *PAI*– share of average income per capita spent on electric power | <1.5% | 2-4% | >6% |
| *RDE*– relative decline of electric power consumption at the expense of energy saving | <1% | 2-4% | >6% |

The membership functions of input parameters of "electric power consumption" subsystem are shown in "Fig. 10".

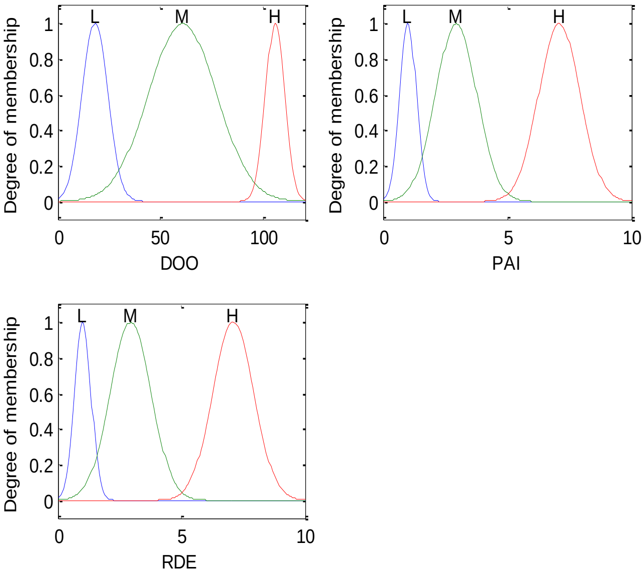



Fig. 10. *Membership functions of input parameters of "electric power consumption" subsystem*

"Table 13" shows a fragment of fuzzy knowledge base for evaluation of security of "electric power consumption" subsystem.

TABLE 13. The fragment of fuzzy knowledge base for subsystem of "*electric power consumption*"

| **№** | **DOO** | **PAI** | **RDE** | **O** |
|---|---|---|---|---|
| | H>100 ч.<br>M–40-80 ч.<br>L<24 ч. | H>6%<br>M–2-4%<br>L<1,5% | H>6%<br>M–2-4%<br>L<1% | |
| 1 | M | H | H | D |
| 2 | M | H | M | D |
| 3 | M | H | L | E |
| 4 | M | M | H | C |
| 5 | M | M | M | C |
| 6 | M | M | L | D |
| 7 | M | L | H | C |
| 8 | M | L | M | C |
| 9 | M | L | L | D |
| 10 | L | H | H | B |
| 11 | L | H | M | C |
| 12 | L | H | L | C |
| 13 | L | M | H | A |
| 14 | L | M | M | B |
| 15 | L | M | L | B |

The security of "electric power consumption" subsystem with the values of input parameters *DOO*–17-15 h., *PAI*–2.1-2%, *RDE*–1.5% turns out in the range of 68.5-70.2%, which corresponds to *B*– "normal" security level.

**Reproduction of fixed assets**

Input parameters for evaluation of security of this subsystem– *RFA* and their values are shown in "Table 14".

TABLE 14. Input parameters of “reproduction of fixed assets” subsystem

| Reproduction of fixed assets–*RFA* | | | |
|---|---|---|---|
| Input Parameters | Terms' meanings | | |
| | L-low | M-medium | H-high |
| *DQM*– share of the input generating capacities for every 3 years | <7 | 8-9 | >9.5 |
| *DEO*–share of the input electrical equipment for every 3 years | <5 | 6-8 | >8.5 |

Membership functions of input parameters of "reproduction of fixed assets" subsystem are shown in "Fig. 11".

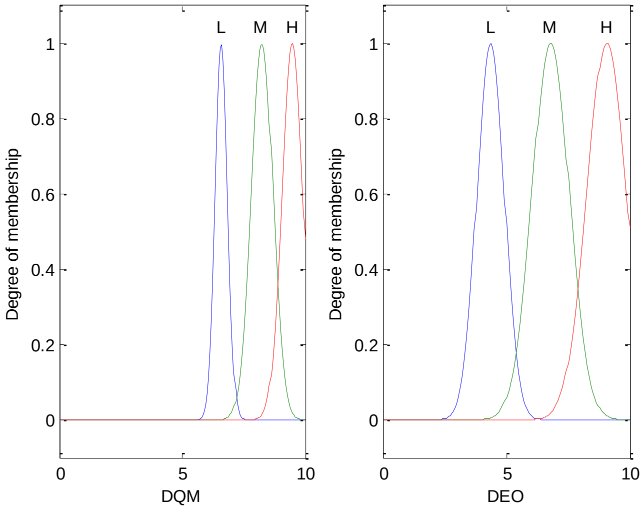



Fig. 11. *Membership functions of input parameters of "reproduction of fixed assets" subsystem*

The fuzzy knowledge base for evaluation of security of "reproduction of fixed assets" subsystem is given in "Table 15".

TABLE 15. The fragment of fuzzy knowledge base for subsystem of "reproduction of fixed assets "

| № | DQM | DEO | O |
|---|---|---|---|
| | H>9,5<br>M–8-9%<br>L<7 | H>8,5<br>M–6-8%<br>L<5% | |
| 1 | H | H | A |
| 2 | H | M | B |
| 3 | H | L | C |
| 4 | M | H | B |
| 5 | M | M | C |
| 6 | M | L | D |
| 7 | L | H | C |
| 8 | L | M | D |
| 9 | L | L | E |

Security of "reproduction of fixed assets" subsystem with the values of input parameters *DQM*–9.3-9.5%, DEO–8.3-8.5% turns out in the range of 76.9-85.1%, which corresponds to the top level of security *B*– "normal" and low level of security *A*.

**Perspective development**

Input parameters for evaluation of security of this subsystem–*PD* and their values are shown in "Table 16".

TABLE 16. Input parameters of "perspective development" subsystem

| Perspective development - *PD* | | | |
|---|---|---|---|
| Input parameters | Terms' meanings | | |
| | L-low | M-medium | H-high |
| *RG*– reserve of installed capacity | <10% | 10-20% | >25% |
| *RW*-- reserve of transfer capability of intersystem connections | <7% | 10-15% | >20% |
| *PC*–energy intensity | >15% | 20-40% | >50% |

The membership functions of input parameters of "perspective development" subsystem are shown in "Fig. 12".

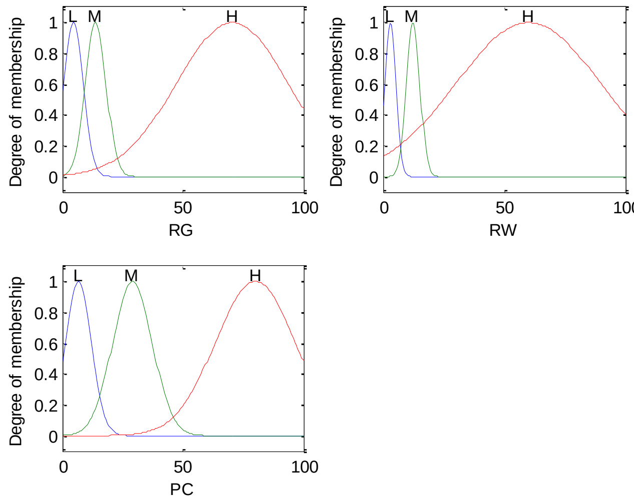



Fig. 12. *Membership functions of input parameters of "perspective development" subsystem*

The fragment of fuzzy knowledge base for evaluation of security of "perspective development" subsystem is given in "Table 17".

TABLE 17. The fragment of fuzzy knowledge base for subsystem of "perspective development"

| № | RG | RW | PC | O |
|---|---|---|---|---|
| | H>25%<br>M–10-20%<br>L<10% | H>10%<br>M–10-15%<br>L<7% | H>50%<br>M–20-40%<br>L<15% | |
| 1 | H | H | M | B |
| 2 | H | H | L | A |
| 3 | H | M | H | B |
| 4 | H | M | M | B |
| 5 | H | M | L | A |
| 6 | H | L | H | C |
| 7 | H | L | M | C |
| 8 | H | L | L | B |
| 9 | M | H | H | C |
| 10 | M | H | M | C |
| 11 | M | H | L | B |
| 12 | M | M | H | C |

| | | | | |
|---|---|---|---|---|
| 13 | M | M | M | C |
| 14 | M | M | L | B |
| 15 | M | L | H | D |

Security of "perspective development" subsystem with the input parameters' values *RG*– 25-27%, *RW*–30%, *PC*–19-17% turns out in the range of 74.4-80.3%, which corresponds to security level of *B*– "normal".

**Electric power industry security of the country**

Electric power industry 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.13".

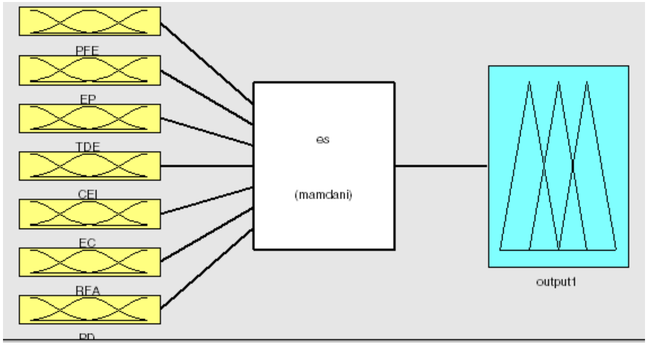



Fig. 13. *Derivation of* electric power industry security

Input values of evaluation system of electric power industry security and their values are shown in "Table 18".

TABLE 18. Input parameters of "perspective development" subsystem

| **Electric power industry security of the country** | | | |
|---|---|---|---|
| Input parameters | Terms' meanings | | |
| | L-low | M-medium | H-high |
| *PFE*–electric power industry fuelling | 0–39% | 39–63% | 63–100% |
| *EP*– Electric power production | 0–39% | 39–63% | 63–100% |
| *TDE*– Transmission and distribution of electric power | 0–39% | 39–63% | 63–100% |
| *CEI*– connection with neighboring power systems and import of electric power | 0-39% | 39-63% | 63-100% |
| *EC*– electric power consumption | 0-39% | 39-63% | 63-100% |
| *RFA*– reproduction of fixed assets | 0-39% | 39-63% | 63-100% |
| *PD*–perspective development | 0-39% | 39-63% | 63-100% |

The membership function of inputs and output for evaluation of electric power industry security are shown in "Fig. 14".

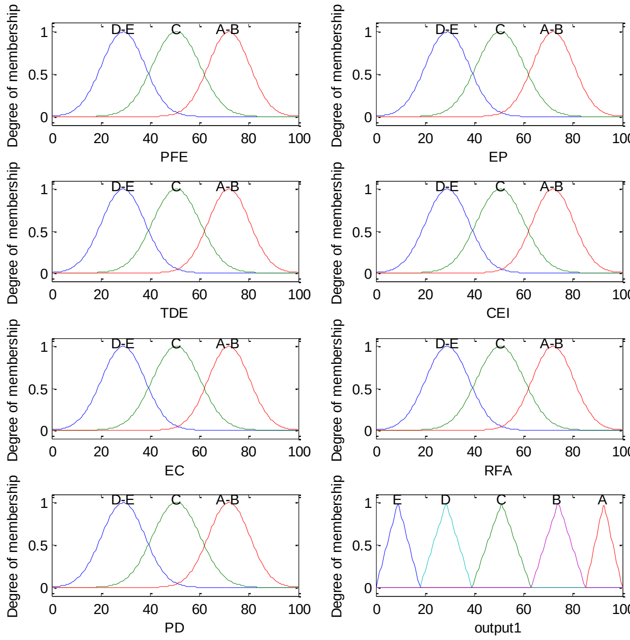



Fig. 14. *The membership function of inputs and output for evaluation of electric power industry security*

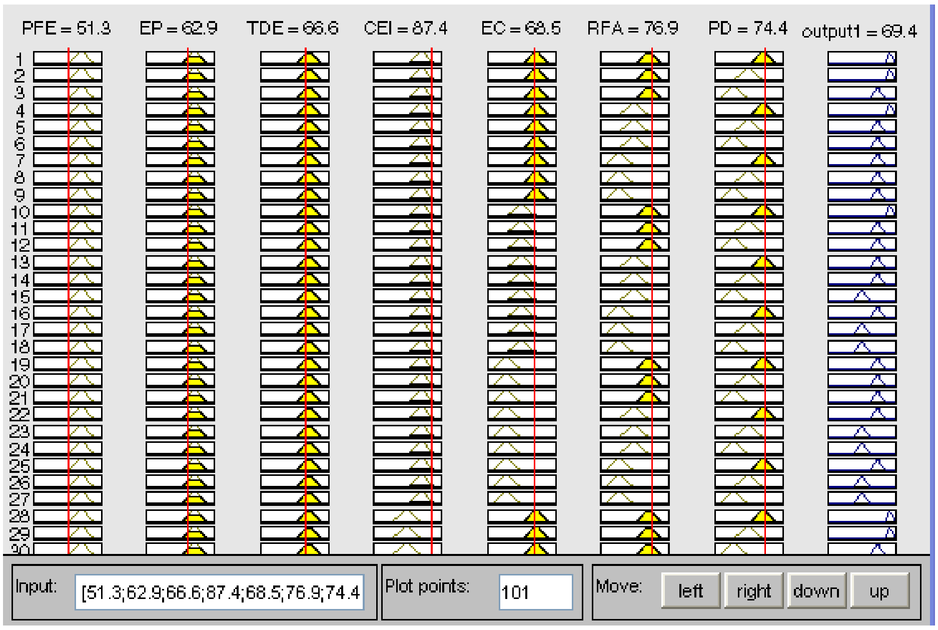
"Table 15" reproduces the fragment of fuzzy knowledge base for evaluation of electric power industry security.

TABLE 19. Reproduces the fragment of fuzzy knowledge base for evaluation of security of electric power industry

| № | Electric power industry fuelling | Electric power production | Transmission and distribution of electric power | Connection with neighboring power systems and import of electric power | Electric power consumption | Reproduction of fixed assets | Perspective development | Result |
|---|---|---|---|---|---|---|---|---|
| 1 | A-B | A-B | A-B | A-B | D-E | D-E | A-B | B |
| 2 | A-B | A-B | A-B | A-B | D-E | D-E | C | C |
| 3 | A-B | A-B | A-B | A-B | D-E | D-E | D-E | C |
| 4 | A-B | A-B | A-B | C | A-B | A-B | A-B | A |
| 5 | A-B | A-B | A-B | C | A-B | A-B | C | A |
| 6 | A-B | A-B | A-B | C | A-B | A-B | D-E | B |
| 7 | A-B | A-B | A-B | C | A-B | C | A-B | A |
| 8 | A-B | A-B | A-B | C | A-B | C | C | B |
| 9 | A-B | A-B | A-B | C | A-B | C | D-E | C |
| 10 | A-B | A-B | A-B | C | A-B | D-E | A-B | B |
| 11 | A-B | A-B | A-B | C | A-B | D-E | C | C |
| 12 | A-B | A-B | A-B | C | A-B | D-E | D-E | C |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 13 | A-B | A-B | A-B | C | C | A-B | A-B | A |
| 14 | A-B | A-B | A-B | C | C | A-B | C | B |
| 15 | A-B | A-B | A-B | A-B | D-E | D-E | A-B | B |

With the obtained calculating values of security of electric power industry's subsystems for long-term periods: electric power industry fuelling– 51.3-58.8%, electric power production–62.9-64.3%, transmission and distribution of electric power–66.6-71.8%, connections with neighboring power systems and import of electric power–87.4-88%, electric power consumption–68.5-70.2%, reproduction of fixed assets–76.9- 85.1%, perspective development–74.4-80.3%, the electric power industry security of Azerbaijan will constitute–69.4-71.1%, which corresponds to "normal" value, as it is shown in "Fig. 15".



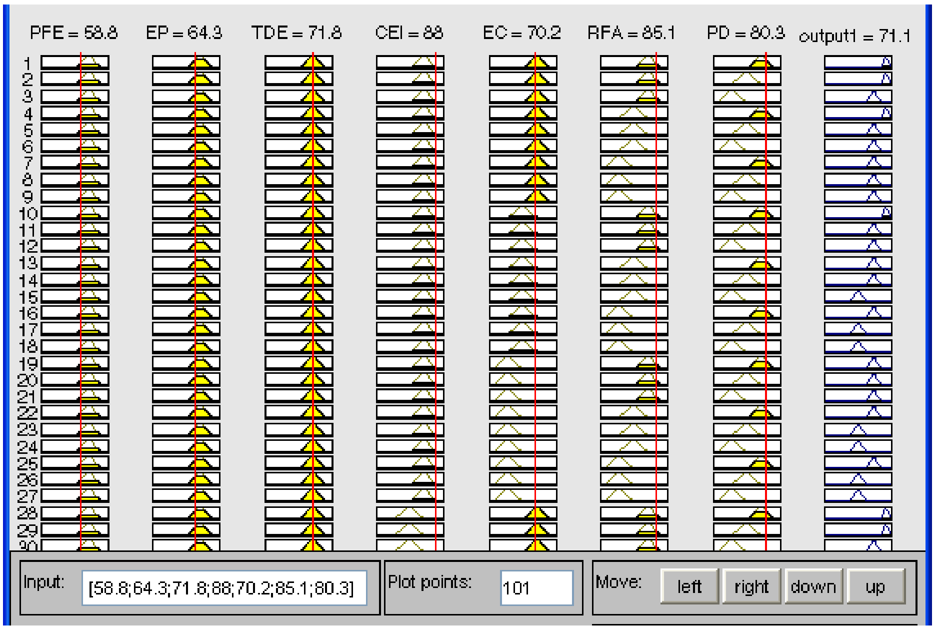




Fig. 15. *Values of electric power industry subsystems' security and* electric power industry *security*

As it is seen from the drawings "Fig 15", security of electric power industry as a function of seven subsystems indicates for long-term periods a weak susceptibility to the great changes of security values of individual subsystems, which allows minimizing the impacts of long-term forecasting errors of input values of individual subsystems.

Besides that, with such method of determination of energy security for long-term periods the subjective estimation of expert is transferred to the very beginning, when a conformity of indicators' values with the linguistic variables of "high", "medium" and "low" types is determined, all other stages are determined strictly in accordance with the theory of fuzzy inference on the basis of fuzzy sets. Conformity of indicators' values with the specified linguistic variables can be adjusted on many sources and minimized the subjectivity of evaluation.

## Conclusions

The basis for study of energy security is the method of an indicative analysis. Applied methods of indicative analysis are based on the comparison of current values of indicators with their threshold values. In this process the interactions and interdependence of indicators of power industry systems are poorly taken into account.

With the development of economy and living standards the demands for energy security become tougher and for all this can be changed both the composition of indicators and their threshold values.

When passing from energy security to electric power industry security the fuzziness and incompleteness of indicators' values as well as a time history create uncertainty for determination of security of electric power industry.

Electric power industry security for long-term periods can be studied with using 7 interconnected subsystems.

Electric power industry security can be determined by the security of subsystems' components with using the theory of fuzzy sets and fuzzy logic.

Applying the fuzzy sets theory the following values have been obtained for electric power industry security and subsystems' components of Azerbaijan for long-term periods: electric power industry fuelling–51.3-58.8 %, which corresponds to *C* security level; electric power production-62.9-64.3%, the security level–*B;* transmission and distribution of electric power–66.6-71.8%, the level of security–*B*; connections with neighboring power systems and import of electric power–87.4-88%, the level of security–*A,* electric power consumption–68.5-70.2%, the level of security–*B,* reproduction of fixed assets–76.9-85.1%, the level of security *B*– "normal" and low level of security *A,* perspective development–74.4-80.3%, the level of security–*B*, the electric power industry security of Azerbaijan will constitute 69.4-71.1%, which corresponds to firm "normal" *B*–value.

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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