Identification of the energy consumption macromodel for the energy complex in oil and gas producing enterprise into the generalized golden section metric

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Abstract. The problems of increasing the energy efficiency of oil and gas production are becoming very urgent. The cost of purchasing electricity greatly affects the cost of hydrocarbons. The cost of electricity is an important contributor to the price of oil and gas. This is due to low oil and gas prices and expensive electricity. Reliable power supply to oil and gas fields is a big problem. Oil companies are starting to use gas turbine power plants, solar panels and wind turbines. Under these conditions, oil companies are trying to optimize their energy costs. Most of the electricity is consumed by downhole production and injection wells. Development of mathematical models allows minimizing power consumption. All technological processes of oil and gas production are interconnected. Water injection into the reservoir affects the production pumps. The operation of borehole pumps affects the oil treatment and pipeline transportation systems. The tools’ synthesis for modelling development strategies in the electric power field into oil and gas producing enterprises (OGPE) is considered. The structural and parametric identification of the macromodel for energy consumption in the OGPE energy complex into the generalized Golden section metric is performed. The calculations’ results are given.

1. Introduction

Oil production is an important industry for many CIS countries. The amount of oil produced per year is shown in the table 1. The diagram of oil production by the CIS countries is shown in Figure 1 [1].

Substantiation of the development strategy for large-weights technological systems is a fundamental state’s aim. At the same time, the main difficulty is to understand the development mechanism itself. It ultimately determines the working algorithm of the management process.

Such kind tasks arise, in particular, during the electrotechnical complexes’ efficiency managing in oil and gas producing enterprises (OGPE) [2-4]. Unfortunately, there are no unified approaches and complete clarity in the issues of the efficient approach substantiation for their solution [5, 6]. It makes difficult to achieve an effective result. This article attempts to fill the gap with modern technologies base.
Table 1. The amount of oil produced, million tons/year.

| Country      | Oil production |
|--------------|----------------|
| Russia       | 504.08         |
| Kazakhstan   | 81.21          |
| Azerbaijan   | 50.25          |
| Turkmenistan | 9.42           |
| Uzbekistan   | 4.6            |
| Ukraine      | 3.8            |
| Belarus      | 1.56           |
| Kyrgyzstan   | 0.07           |
| Tajikistan   | 0.02           |
| Moldova      | 0.02           |

Figure 1. Oil production by the CIS countries, million tons in year.

The structure of electricity consumption by various technological processes at the field is shown in figure 2.
Figure 2. The structure of electricity consumption by various technological processes at the field.

The following technological processes are the most energy intensive [7]:
- well pumps (56.70%);
- reservoir pressure maintenance system (26.60%);
- in-field oil pumping (6.70%);
- gas compression (5.10%);
- in-field gas transfer (1.30%);
- water intake (1.20%);
- other production needs (2.30%);
- administrative expenses (0.20%).

2. Problem solution

Electrotechnical complexes on the weights of oil and gas production enterprises belong to the class of complex systems. It is necessary to apply scientific methods based on a systematic approach [8, 9] to improve the efficiency of their management. A well-known authority in the field of complex systems management is the Institute of Management Problems by V. A. Trapeznikov into the Russian Academy of Sciences. This Institute develops a number of scientific methods for improving the efficiency of management that are widely used in practice [10]. One of them is the "Golden section" method (or "Golden proportion"). It is the basis of the modern scientific direction "F-technology" (F – Fibonacci) [11, 12].

Practice shows that in the vast majority of situations, the method of the "generalized Golden section" (GGS) works when a proportion is performed between the parts of single segment [13]:

\[
(1/x)^q = x/(1 - x),
\]

from which it follows

\[
x^q + x - 1 = 0,
\]

where:
- \(x\) – is the dominant;
- \(1 - x = x_c\) – is the subdominant;
- \(q\) and \(g\) – are indicators \((g = q + 1)\).

It is important to note that the classical "Golden proportion" is only a special case of the ratio (1) when \(q = 1\).

The root of equation (2) \(x_{opt}\) characterizes the share of the dominant in the total unit result (figure 3).

Taking into account that \(+ x_c = 1\), the ratio (1) can be written as \(1 - x = x^g\) or

\[
x = 1 - (1 - x_c)^g.
\]
Figure 3. Solution of equation $x_{opt}^g + x_{opt} - 1 = 0$.

In practice, this relationship between the dominant $x$ and the subdominant $x_c$ is widely used in the "Pareto" ABC analysis [14]. This analysis is focused on identifying priority components in a complex multi-component system. It turned out that the Pareto diagram is almost perfectly approximated by the function:

$$y = 1 - (1 - x)^{g(x)},$$  

(4)

where $x = r/r_{max}; r$ and $r_{max}$ – are the current and maximum rank, respectively.

As you can see, the ratio (4) is similar to the ratio (3). The indicator $g$ does not depend on $x$ in a complex system which is ideally suited to the GGS.

As you know, the Pareto diagram is based on the rank distribution of the "weights" $w_k$ for the complex system components. It is essentially their cumulate, the increasing sum of the "weights" $y = \sum_{k=1}^{n} w_k$ (here $k$ - is the rank number; $n$ – is the number of the system components).

In a complex system that perfectly corresponds to the GGS, when $y = 1 - (1 - x)^g$ the "weights" structure is clearly determined and subdues the regularity

$$w_k = \left(1 - \frac{k - 1}{n}\right)^g - \left(1 - \frac{k}{n}\right)^g.$$  

(5)

In this case, the senior " weights" $w_1$ is associated with the indicator $g$ by the ratio

$$w_1 = 1 - \left(1 - \frac{1}{n}\right)^g,$$  

(6)

it allows to easily determine the indicator

$$g = \frac{\ln(1 - w_1)}{\ln(1 - 1/n)}$$  

(7)

by the known value $w_1$ and then build a rank distribution of "weights" $w_k(r)$. 


According to the studies [15, 16], the senior "weights" is estimated at 0.5 level with the energy efficiency analysis for the seven-component electrical complex of OGPE (figure 4).

\[ g = \frac{\ln(1-w)}{\ln(1-1/n)} = \frac{\ln(1-0.5)}{\ln(1-1/7)} = 4.4966. \]  

The total energy is

\[ W_\Sigma = \sum_{k=1}^{7} W_k \]  

and the "weights" of the components is

\[ w_k = W_k / W_\Sigma. \]  

At the same time, the rank distribution \( g = 4.4966 \) of "weights" \( w_k \) and the Pareto diagram

\[ \gamma(r) = 1 - \left( 1 - \frac{r}{7} \right)^4.4966 \]  

based on it should have the form shown in figure 5. Comparison of calculated and actual "weights" gives reason to believe that the real results do not contradict the accepted hypothesis about the mechanism operation of "generalized Gold division" in practice.

3. The "weights" structure of the system components

The "weights" structure of the system components carries information about its organizational level. The structural entropy

\[ H = -\sum_{k=1}^{n} w_k \ln w_k \]
or its normalized value

\[ H_n = H / \ln(n) \]  

acts as a numerical characteristic. The relative entropy of a binary system (in which \( n = 2 \)) is usually used as a reference standard.

The relative entropy of a real system is compared with it. It corresponds to a situation where

\[ -\sum_{k=1}^{7} w_k \cdot \ln(w_k) / \ln(7) - \ln(2), \]

where \( w_p \) and \( w_h \) are shares of order and chaos that meet the normalization condition \( w_p + w_h = 1 \).

The "weights" data is required to calculate the relative entropy of a seven-component electrotechnical complex. Their values are shown in the table 2. They are calculated in the GGS metric. Entropy is \( H = 1.238 \). Relative entropy is \( H_n = 0.6362 \). The \( H_n = 0.6362 \) level in the binary system (reference standard) corresponds to the share of order – \( w_p = 0.84 \) and the share of chaos \( w_h = 0.16 \). It means that the OGPE electrotechnical complex belongs to the class of open systems with a high organizational level.

**Table 2.** The "weights" data of a seven-component electrotechnical complex.

| Rank (r) | \( w_k \) | \( w_k \cdot \ln(w_k) \) |
|----------|------------|--------------------------|
| 1        | 0.5        | 0.347                    |
| 2        | 0.28       | 0.356                    |
| 3        | 0.14       | 0.275                    |
| 4        | 0.059      | 0.166                    |
| 5        | 0.019      | 0.074                    |
| 6        | 0.003      | 0.019                    |
| 7        | 1.585 \times 10^{-4} | 0.001                   |
In addition, the results of the Pareto ABC analysis are presented in figure 5. Its specifics are described in [17, 18] point in detail. The key role of ABC analysis is the priority objects’ identification [19, 20]. They make a major contribution to the output product. The main objects are those whose ranks are in the A+B area (see figure 5). There are three of them: \( W_{PW} \) (electricity consumed by producing wells), \( W_{RPM} \) (electricity used to maintain reservoir pressure) and \( W_{BPS} \) (electricity consumed by booster pump stations).

4. Conclusion
Thus, the following conclusions can be made on the results of the conducted researches:
1. The actual structure of the energy consumption weighting coefficients for the electrotechnical complex OGPE does not contradict the law "generalized Golden section".
2. The rank distribution of "weights" indicates that the analysed complex system belongs to the class of open systems with a high organizational level.
3. The number of priority ranks does not exceed three ranks in the analysed seven-component complex system. It determines the prospective direction for further work to improve management efficiency.
4. The producing wells, the system for maintaining reservoir pressure and the system for infilling oil pumping are the objects with priority ranks to improve the energy efficiency of OGPE.

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