Systematic approach to the analysis of the operation on power technological production lines of agricultural enterprises

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Abstract. Considered the issues of system analysis and synthesis of energy technological production lines (ETL). An algorithm for finding optimal solutions for the design, operation and analysis of ETL is proposed. A methodology for the use of system analysis in the design, creation and operation of ETL has been formed. The algorithm is based on identifying three hierarchical levels of system analysis: principle synthesis, structural synthesis, parametric synthesis. A systematic approach to the design and analysis of ETL functioning, in the general case, is based on the use of the provisions of the theory of probability. As a result of theoretical research, probabilistic mathematical models have been obtained that describe the processes of ETL functioning and make it possible to formulate recommendations for increasing the efficiency of these processes. The basic theoretical provisions and mathematical models formulated in the article are of great practical importance and allow to design and further competently operate production lines for various purposes.

1 Introduction

Energy technological production lines (ETL) are a fairly common type of complex technical systems, in this regard, the tasks of their design and further operation cannot be solved without using the methods of system analysis.

As shown in [1], one of the most important aspects of the system analysis of energy and energy technology objects and systems is that we do not just solve [†]the problem, but find the optimal version of this solution. The search process for the optimal solution, in turn, involves the allocation of three hierarchical levels of system analysis [2, 3]:

- selection of the optimal operating principle of an energy object (system), their elements and subsystems (synthesis of the principle);
- search for the best structure of the energy of the object within the selected operating principle (the problem of structural synthesis);

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- determination of the optimal values of the parameters of the object within the framework of the chosen structure (the problem of parametric synthesis).

Based on the foregoing, it can be argued that the process of system analysis is inextricably linked with the solution of synthesis problems at each level.

The aim of the research in this article is to form a methodology for using system analysis in the design, creation and operation of ETL. Let us restrict ourselves to considering ETL in which all elements and subsystems that provide separate energy-technological processes (ETP) and operations are arranged sequentially from “input” to “output”. The first and second level system analysis in this case can form an ETL generalized structure (Fig. 1).

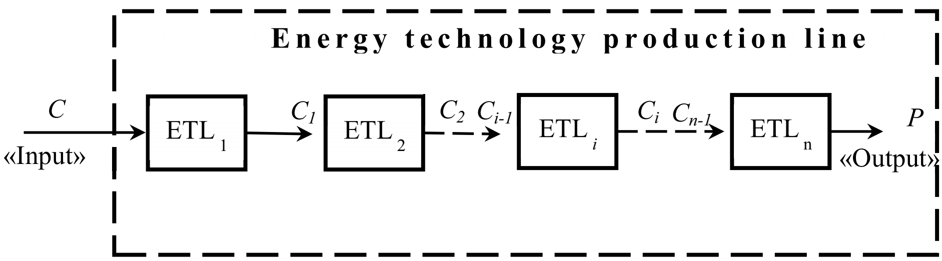

Fig. 1 Block diagram of ETL

ETP*i* – *i*-th energy-technological processes; *C* – the volume of raw materials entering the line; *P* – volume of products; *Ci*-1, *Ci* – the intermediate state of the raw material being processed (semi-finished product) at the input and output of the *i*-th ETP

Suppose that each of the ETPs shown in Fig. 1 is provided by a separate energy technological object (dispenser, mixer, humidifier, grinder, conveyor, etc.).

If we assume that the above-mentioned energy-technological objects also represent complex technical systems, consisting in the general case of n elements (Fig. 2), then it is necessary to repeat the second level of system synthesis (structural), if not, then one should go to the third level - parametric synthesis.

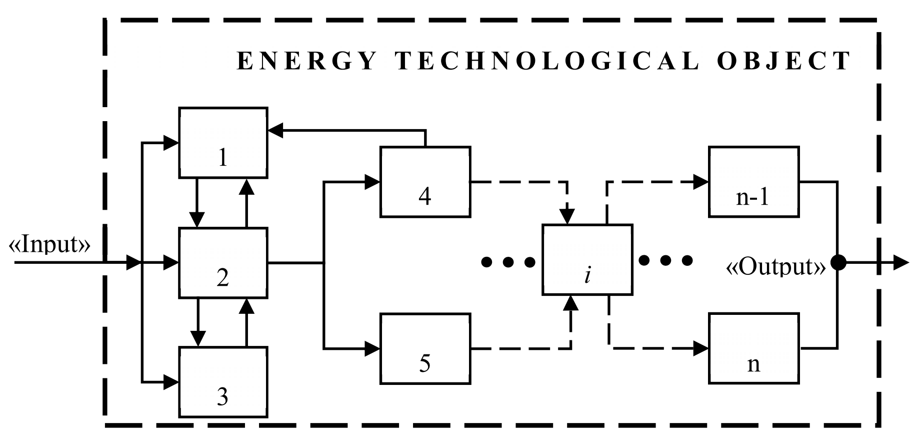

Fig. 2 Generalized diagram of a power engineering facility

The optimized parameters of individual elements of the presented object can be power, speed of rotation or movement, productivity, reliability, maintainability, cost, etc. At the level of parametric synthesis, it is necessary to assess the influence of the parameters of the elements (technical devices) of the object on each other and agree on the range of their possible values. A very important task at this level is to assess the influence of the power of individual elements on their technological performance and to coordinate the performance of these elements.

2 Materials and Methods

Investigations of the processes of design and operation of ETL under the influence of numerous random factors have been carried out [4, 5]. These factors can be both internal (the skill level of the designers) and external (lack of timely funding). The research carried out is based on the use of theorems of probability theory and the method of probabilistic (stochastic) modeling. In addition, when conducting research, the principle of decomposition of complex systems is used, which makes it possible to distinguish hierarchical levels of research (principle level, structural and parametric level). Mathematical models describing the processes under consideration are based on the use of the total probability formula and are of great practical importance in the design and operation of ETL. It is proposed to evaluate the production and economic effect of ETL at the level of mathematical expectations. Using the dimension of the input data for modeling in the form of conventional units (cu), the proposed methodology can be considered as universal (independent of the type of product produced by the production line).

3 Results

Since in real practice related to the design and further operation of ETL there are many random factors, the results of the system analysis performed are presented in the form of probabilistic characteristics. Due to the fact that system design, as the initial stage of ETL creation, includes three levels of system analysis, the result and its effectiveness are estimated by the mathematical expectation.

$$\mathrm{MO}\left[\mathrm{T}_{pr}\right] = \mathrm{MO}\left[\mathrm{T}_{ps}\right] + \mathrm{MO}[\mathrm{T}_{ss}] + \mathrm{MO}\left[\mathrm{T}_{pars}\right], \quad (1)$$

where $\mathrm{MO}[\mathrm{T}pr]$ — mathematical expectation of the execution time of the entire project;

$\mathrm{MO}[\mathrm{T}ps]$, $\mathrm{MO}[\mathrm{T}ss]$, $\mathrm{MO}[\mathrm{T}pars]$ — mathematical expectations of the execution times of the principle synthesis, structural and parametric synthesis, respectively.

The result of the efficiency assessment is assessed in a similar way for the operation process and analysis of the functioning of the ETL.

Another probabilistic characteristic for the presentation of the research results is the likelihood of high-quality and timely execution of individual projects of power facilities that ensure the corresponding technological processes in ETL. Assuming that the events involving the implementation of individual projects are random and independent, we can write:

$$P_{ETL} = \prod_{j=1}^{m} P_j, \quad (2)$$

where P_{ETL} — the probability of timely and high-quality implementation of the ETL project as a whole;

m — the number of projects of individual energy technology facilities that make up the ETL;

j — the serial number of the corresponding project;

Pj – the probability of timely and high-quality execution of the j-th project.

Let it be required to determine the probability of some event A, which can occur together with one of the events H_1, H_2, ..., H_i, ..., H_n, which form a complete group of inconsistent events. These events will be called hypotheses. In this case, the formula for total probability will take the form:

$$P(A) = \sum_{i=1}^{n} P(H_i) \cdot P\left(\frac{A}{H_i}\right), \quad (3)$$

where P(A) – the probability of some event A;
n — the total number of hypotheses;
i — the ordinal number of the hypothesis;
$P(H_i)$ – the probability of the i-th hypothesis;
$P(A/H_i)$ — probability of occurrence of event A when the i-th hypothesis is fulfilled.

Formula (3) allows us to determine the probability of event A as the sum of the products of each hypothesis by the probability of an event under this hypothesis.

Let's apply the formula of total probability when considering the first level of systems design of a production line - the synthesis of the principle.

As an example, we will restrict ourselves to considering two hypotheses:

1. the first hypothesis H1 is that the synthesis of the principle is carried out on the basis of the analysis of two possible principles of the ETL functioning (continuous and discrete);
2. the second hypothesis H2 is based on the use of three possible principles (continuous, discrete and discrete-continuous).

We will assume that the probabilities of the above hypotheses are $P\ (H_1) = 0{,}85$ and $P\ (H_2) = 0{,}65$. Having chosen as a criterion for the efficiency of the synthesis of the principle, the assumed probability of failure-free operation of the production line during a predetermined period of time during its operation $P_{F.O.}$, and applying formula (3), for our particular case we get:

$$P_{F.O.} = P(H_1) \cdot P\left(\frac{A_1}{H_1}\right) + P(H_2) \cdot P\left(\frac{A_2}{H_2}\right), \quad (4)$$

where A_1, A_2 — events, consisting in the failure-free operation of the ETL under the first and second hypotheses, respectively;
$P(A_1/H_1)$, $P(A_2/H_2)$ — the probabilities of these events.

As a result of a sequential analysis of possible principles for both hypotheses, carried out using the probabilistic modeling method, we determine the values of the probabilities $P(A_1/H_1) = 0{,}45$ и $P(A_2/H_2) = 0{,}7$. Applying the formula of total probability (4) for our case, we get:

$P_{F.O.} = 0{,}85 \cdot 0{,}45 + 0{,}65 \cdot 0{,}7 = 0{,}83$.

Preliminarily (at the first level), after evaluating the expected efficiency of the ETL operation by the criterion of the probability of failure-free operation of $P_{F.O.}$, Let's move on to the consideration of the second level of systems engineering — structural synthesis. The synthesis of the structure will be carried out within the framework of a continuous-discrete principle of operation, which ensures the maximum probability of failure-free operation ($P\ (A_2/H_2) = 0{,}7$).

Certain issues related to the assessment of the efficiency of ETL functioning in relation to the production of compound feeds are considered in works [6, 7, 8, 9, 10, 11, 12, 13].

The effectiveness assessment in work [14, 15] was based on the results of monitoring the operation of individual energy technology facilities that provide technological processes.

Suppose that ETL consists of 5 elements arranged in series, from "input" to "output" (the first variant of the structure).

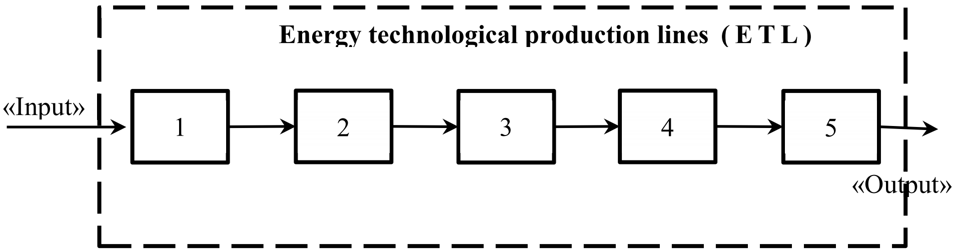

Fig. 3 First variant of the structure

To increase the operational reliability of the designed ETL, we will form the second version of the structure due to the parallel connection of elements 6 and 7 (Figure 4). As a result, we get some improved ETL structure.

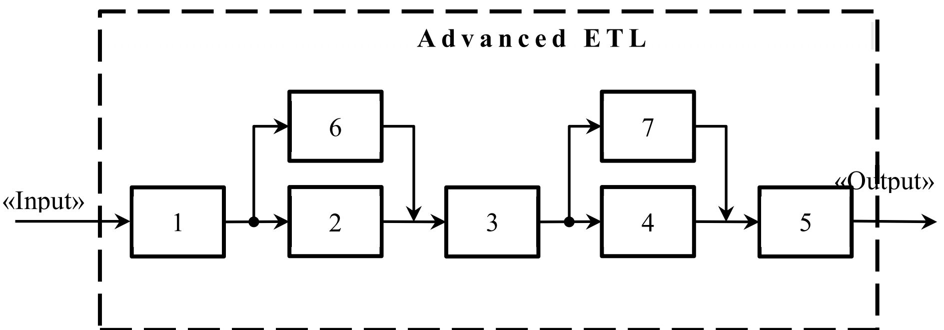

Fig.4 The second (advanced) variant structure

Increasing the reliability of elements 2 and 4 due to redundancy using elements 6 and 7, in turn, leads to an increase in the uptime of the $T_{F.O.}$ and the volume of products manufactured by *P*. For simplicity, the volume of output will be measured in conventional units (cu)

$$P = P_t \cdot \mathrm{T}_{F.O.}, \tag{5}$$

where P_t — productivity of ETL, cu / h;

$T_{F.O.}$ — uptime, h.

Since the values of P_t and $T_{B.R.}$ are random, their product *P* is also a random variable, and, in its simplest version, can be estimated using the mathematical expectation

$$\mathrm{MO}[P] = \mathrm{MO}[P_t] \cdot \mathrm{MO}[\mathrm{T}_{F.O.}], \tag{6}$$

As an example, suppose that for the first and second variants of the structure of ETL MO[$T_{F.O.}$1] = 100h, MO[$T_{F.O.}$2] = 130h, the productivity in both variants remains constant MO [P_t] = 15 c.u/h.

Using formula (6), we obtain for the first and second options, respectively

MO[P_1] = 15 · 100 = 1500c.u.

MO[P_2] = 15 · 130 = 1950c.u.

It follows from this that in the transition from the first to the second variant of the structure, the volume of output increases by 30%.

4 Conclusion

The main findings of the research conducted in this article are:

- formation of a methodology for the use of system analysis to solve the problems of designing and operating ETL at agricultural enterprises;
- approbation of the methodology at each of the levels of systems design in terms of evaluating the effectiveness of ETL as a whole and its individual subsystems.

The results obtained in the article represent, in fact, the initial stage of the formation of a system-process approach to the design and analysis of the functioning of ETL and undoubtedly represent scientific and practical interest.

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