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I | TECHNICAL SCIENCES: COTTON, TEXTILE AND LIGHT INDUSTRY

ANALYSIS OF POWER QUALITY INDICATORS IN LIGHT INDUSTRY ENTERPRISES

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Abstract: In light industry enterprises, electricity consumption and its quality indicators directly affect production efficiency and product quality. This article proposes a new methodology for analyzing and calculating the quality of electricity, in which the production process is divided into interconnected blocks, and specific energy consumption and quality parameters are studied separately for each block. The study uses mathematical models and nomograms and experimental data to determine the relationship between energy consumption modes and quality indicators. The results show that the method of dividing into blocks reduces the difference between real and calculated indicators to 2-5%, which provides high accuracy. It is also proven that a decrease in the quality of electricity leads to additional losses in technological processes and the need for optimization measures to increase energy efficiency. The proposed method serves as a practical solution for improving energy management and ensuring environmental sustainability in light industry enterprises.

Keywords: power quality, electricity consumption, industrial entrprises, indicators, electricity, Load variation, technological process.

Introduction. Analysis of the modes of electricity consumption of industrial enterprises shows that rationalization of electricity consumption, along with optimization of the operation of electrical facilities and technological units, requires rational use of recycled products and energy carriers such as water, oxygen, compressed air, various oils and other types of products [1].

Along with the standardization of electricity for the production of finished products, enterprises develop appropriate energy consumption standards for their control within the enterprise in the main production workshops, pump, oxygen, compressor stations, etc. If we consider energy consumption indicators without correlating them with indicators of the use of technological components, it is impossible to objectively assess the real situation.

Light industry enterprises are one of the important components of the modern economy, and electricity plays a major role in their activities as the main resource. In light industry sectors such as textile, garment, and shoe manufacturing, product quality and production efficiency largely depend on the stability and quality indicators of electrical energy [2]. The quality of electrical energy, i.e. its voltage level, frequency, continuity, and other parameters, not only ensures the uninterrupted operation of technological processes, but also determines the operation of equipment, the final quality of products, and total energy costs. In recent years, in the context of the worsening fuel and energy balance and rising energy resource prices, effective management of electrical energy consumption at light industry enterprises and analysis of its quality indicators have become an urgent issue.

A decrease in the quality of electrical energy, for example, voltage fluctuations or interruptions, leads to malfunctions in the production process, equipment wear, and product quality deterioration [3]. At the same time, the peculiarities of light industry, the variability of the consumption of raw materials, semi-finished products and auxiliary components of the technological process (for example, compressed air, water), complicate the calculation of electricity consumption and assessment of its quality. In current practice, methods for calculating and standardizing energy consumption often do not fully take into account these factors, as a result of which an objective assessment of energy indicators is difficult. Therefore, it is necessary to introduce a systematic approach to analyzing and calculating the quality indicators of electricity. This article proposes a new methodology for analyzing electricity consumption and its quality indicators at light industry enterprises. This methodology is based on the division of the production process into interconnected blocks, which allows for the separate calculation of energy consumption and quality indicators of each block. The study develops mathematical models and calculation methods aimed at assessing the quality of electricity, determining its impact on production efficiency, and ensuring energy efficiency. The main goal of the article is to propose practical methods for the analysis and calculation of the quality of electricity in light industrial enterprises and to test their effectiveness in real conditions.

Methodology & empirical analysis. The proposed methodology is based on a systematic approach to the analysis of electricity consumption and its quality indicators in light industrial enterprises. This approach involves dividing the production process into several functional blocks, separately calculating energy consumption and quality parameters for each block, and synthesizing general indicators. Below are the main steps and methods of the methodology. Taking into account the complex structure of light industrial enterprises and the variety of energy consumption, the production process is divided into the following blocks: the following methodology is proposed to provide interconnected solutions (Figure 1).

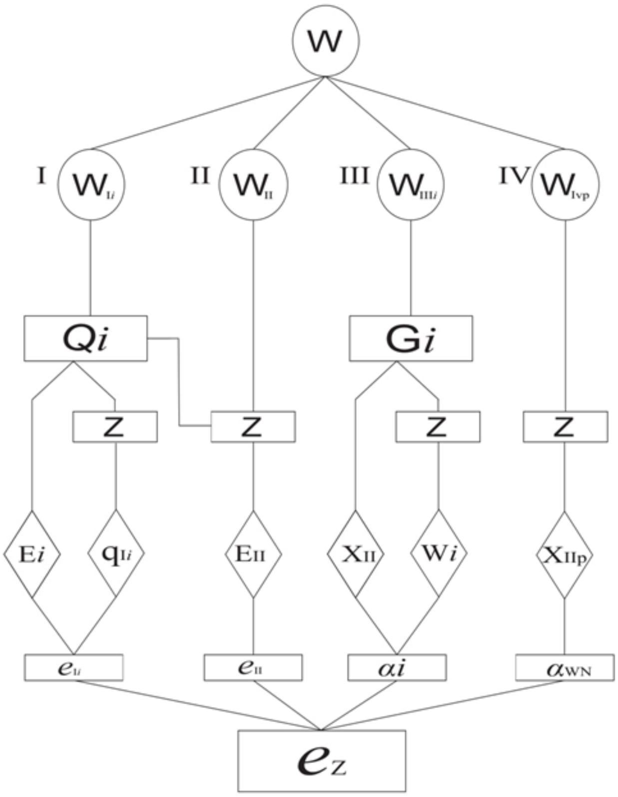

Figure 1. Calculation block formation diagram

Here:
(W_{Ii}) power consumption,
(Q_i) unit of production spent on the production of intermediate products,
(E_i) specific costs,
(W_{Ii}) electricity,
(G_i) unit costs for the production of products,
(q_{Ii}) unit cost,
(Z) unit of final product.

In block I, the intermediate products (Q_i) are associated with the production, where the electricity consumption (W_{Ii}), specific costs (E_i) and unit costs (q_{Ii}) are calculated.

In block II, Z is the final stage of the production process for the production of final products.

Electricity consumer block III (W_{III}) is the unit for the production of technological process components and secondary energy carriers (G_i) .

Similar to block I, in block III, the unit costs of electricity ($W_{III\,i}$) for the product (G_i) are (γ_i) and the unit costs of electricity (W_i) for the final product (Z) are (G_i) (W_i).

Other electricity costs in block IV (W_{IVp}).

Thus, each of the above blocks, in addition to energy consumption indicators, also includes indicators of consumption of raw materials, semi-finished products and technological components.

The share of each unit in the total specific energy consumption of the enterprise is determined by two indicators:

a) specific energy consumption for production of a particular workshop or process.

For type I and II blocks

$$E_I = \frac{W_I}{Q} \qquad E_{II} = \frac{W_{II}}{Z} \tag{1}$$

For type III and IV blocks

$$\gamma_{III} = \frac{W_{III}}{G} \quad \text{va} \quad \gamma_{IV} = \frac{W_{IV}}{Z} \tag{2}$$

b) specific consumption of intermediate products and technological components per unit of final product

For blocks:

For Block I $q = \frac{Q}{Z}$ (3)

For Block III $W = \frac{Q}{Z}$ (4)

The participation of each unit in the total specific electricity consumption of the enterprise is determined by similar expressions;

$$e_I = Eq \qquad e_{II} = E_{II} \tag{5}$$

$$\alpha_{III} = \gamma W \qquad \alpha_{IV} = \gamma_{IV} \tag{6}$$

Thus, the overall indicator of specific power consumption will have the following formula and form (Figure 2):

$$e_Z = \sum_1^n ei + \sum_1^{n`} \alpha i + \alpha_{pr} \tag{7}$$

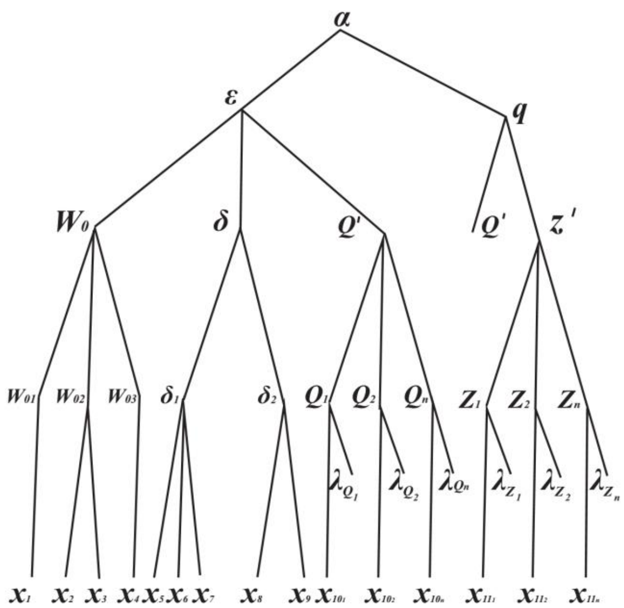

Figure 2. Branching system of the α block

Analysis of energy consumption modes and calculation of energy technical indicators are stored separately for each unit, and then for the entire production. At the same time, research experience shows that the decisive stage is based on a detailed study of the energy consumption modes of the technological units of the units. Research work begins with an analysis of the power balance, identification of sources of constant and no-load losses of electricity in the elements and components of the unit, then the energy characteristics of the consumed power, absolute and relative electricity are developed depending on the efficiency.

The minimum possible value of specific power consumption, in particular for units with a linear change in power consumption, is determined by the following formula [4]:

$$r = \frac{W_a - \sum ai}{P + \sum bi} \tag{8}$$

Where W_a and P are, respectively, the electricity consumption and output for the operating period;

a_{in} b_i - respectively, measures to reduce energy consumption and increase the productivity of the unit.

It is important to assess the impact of emergency failures, unscheduled shutdowns of units and their start-up modes on energy efficiency, the amount of excess energy consumption associated with the start-up of units:

$$\Delta W_{ish} = \left[W_p + \left(\frac{W_n^I}{P_P} - r^I\right) P_p\right] m \tag{9}$$

where W_p - electricity consumption for the period from the start of commissioning (t_1) to the start of production (t);

W_n^I and P_p - respectively, electricity consumption and production of products for the commissioning period until the restoration of the normal operating mode of the device;

m - the number of unscheduled and emergency shutdowns of the unit during the billing period.

The following can be used to solve the problems of regulating the electricity load schedule of the enterprise. in particular, the participation of this unit in the system of maximum power.

Reserves for reducing electricity consumption are determined by the following formula:

$$\Delta W = (r' - r)P - r \sum bi - \Delta W_{ish} \tag{10}$$

Here r is the specific power consumption of the operating unit and the implementation of the activity.

The economic value of the non-linear specific electric charge of power consumption may correspond to the reduced productivity of the unit and. if in this case it is necessary to operate at full load of the unit, then it should be considered optimal with a higher specific power consumption.

The same can be said when the productivity of the unit decreases, while ensuring the required product quality.

Naturally, different types of units (electric drives, electrical technologies, simultaneous use of electrical and thermal energy, etc.) require an independent decision on the selection of optimization criteria. Development of the most profitable energy consumption modes.

In addition, based on the indicators of the main units, mathematical models and corresponding energy characteristics for each block, etc., as well as appropriate multifactor models using known methods $\Delta W = f(P), E = f(Q), \alpha = f(G)$ are developed (Figure 3).

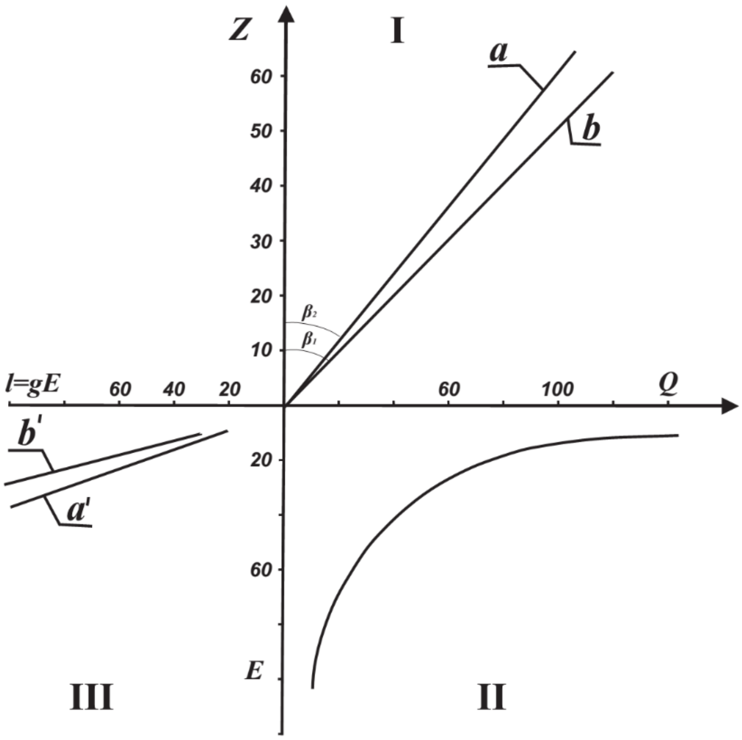

Figure 3. Nomogram for calculating block indicators

To facilitate calculations for blocks I and III, a special nomogram is proposed, shown in Figure 3. The product (Q) of this workshop is sent to the workshop to obtain the product (Z).

In the coordinates Z and Q, we construct curves a and b corresponding to different values of specific consumption Q per ton $\tau - q_1 = tg\beta_1 = 1{,}64$ va $q_2 = tg\beta_2 = 1.867$.\

In the II square we construct the energy characteristic E=f(Q)and in the II square - q_2 and the dependence on the state. q_2 Similar nomograms can be constructed for each block.

In general, the electricity consumption for the enterprise is determined from the expression according to formula (7):

$$W = (\sum_1^n ei + \sum_1^{n^1} d_i + \alpha_{nr})Z \qquad (11)$$

The method of systematic analysis of quality indicators of electricity at light industrial enterprises The current stage of energy development in conditions of aggravation of the fuel-energy balance requires the improvement of methods of accounting, control and standardization of electricity.

The most accurate and accurate results of determining the nature of changes in the level of electricity consumption can be obtained, first of all, by studying the specific consumption of electricity per unit of production (work). The complexity of the problem lies in the fact that a unit of production is a function of many variables, quantitative and qualitative indicators of production.

Its analysis and calculation include, in addition to electricity, the study of technological and operational factors and factors that lead to deviations from the norms of consumption of raw materials, semi-finished products and auxiliary components of the technological process, compressed air, oxygen, water, etc. [4].

In current practice, they are taken into account to one degree or another, but these parameters are not directly included in the calculation of standards, which in many cases prevents an objective assessment of the value of energy indicators. Thus, the lack of indicators of consumption of raw materials and auxiliary components of the technological process in modern methods and calculation formulas leads to this. The inability to take into account the often sharply changing demand for electricity, when their costs change due to technological improvements or changes in the quality of the materials used.

The presence of a large amount of initial data at enterprises, the complexity of the methods used, the requirement for speed and accuracy of calculations, the need to obtain an approximate value of specific energy consumption, etc., require a comprehensive solution to this problem using the method of system analysis. As a first step in synthesizing the above indicator, it is necessary to develop an appropriate continuous one based on retrospective analysis. It contains a general overview of the situation and gives complete information about the interaction of energy and technological factors affecting the projected indicator. The analysis of electricity identifies production units, areas and processes that are crucial for the overall assessment of the electricity consumption indicators of the entire production and that can be considered as autonomous devices in the future [5] (Table 1).

Table 1. Relevant calculation formulas for calculation

Markings	Calculation formulas
W_0	$W_{01}(1 \pm k_1) + W_{02}(1 \pm k_2) + W_{03}(1 \pm k_3)$ $K = f(x_1, x_2, x_3)$
D	$\delta = \frac{W - W}{Q}(1 \pm k_\delta), \quad \delta = \frac{W_B - W_{0B}}{B}(1 \pm k_\delta)$ $K_d = f(x_4, x_5, x_6, x_7, x_8, x_9)$
D	$\delta = \frac{W - W_0}{Q}(1 \pm k_\delta), \quad \delta_B = \frac{W_B - W_{0B}}{B}(1 \pm k\delta_B)$

Q	$K\,d = f(x_4, x_5, x_6, x_7, x_8, x_9)$ $Q = (Q_1 + Q_2 + Q_n)\,(1 \pm K_Q)$ $K_Q = f\,(x_{10\,1} + x_{10\,2}\,.....\,x_{10\,n})$
Q'	$Q = \left(Q_1 + \frac{\lambda_{Q2}}{\lambda_{Q1}} Q_2 + \cdots + \frac{\lambda_{Qn}}{\lambda_{Q1}} Q_n\right)(1 \pm K_Q)$ $Z = (Z_1 + Z_2 + \cdots + Z_n)(1 \pm K_Z)$ $K_Z = f(X_{11\,1}, X_{11\,2}, X_{11\,3})$
Z	$Z' = \left(Z_1 + \frac{\lambda_{Z2}}{\lambda_{Z1}} Z_2 + \cdots + \frac{\lambda_{Zn}}{\lambda_{Z1}} Z_n\right)(1 \pm K_Z)$
G	$G = f(X_{12}, X_{13})$
B	$B = B_1 + B_2 + \ldots + B_n$ $B = f(X_{14}, X_{15}, X_{16}, X_{17}, X_n)$
E	$E = \frac{1}{Q}(W_0 \pm W_{ot14}) + \partial$
E'	$E' = \lambda_{Q1}\left(\frac{W_0}{\lambda_{Q1} Q + \lambda_{Q2} Q_2 + \cdots + \lambda_{Qn} Q_n} + 1\right) \pm \frac{W_{ot14}}{Q'}$
ω	$\omega = \frac{W_0}{B} + \delta_B;$ $\omega = W_B \frac{1}{\gamma_1 Q_1 + \gamma_2 Q_2 + \ldots + \gamma_n Q_n}$
γ	$\gamma = \frac{B}{Q};\quad \gamma = \frac{B}{Q'};\quad \gamma_Z = \frac{B}{Q'}$
q	$q = \frac{G}{Z};\quad q_Z = \frac{Q}{Z}$

II. Results. When analyzing and calculating the indicators of an industrial enterprise, it is reasonable to consider the enterprise divided into blocks:

a) when analyzing and calculating the indicators of an industrial enterprise - indicators of the main production workshops, auxiliary workshops producing auxiliary components of the technological process, as well as the electricity consumption unit for other needs of the enterprise (outdoor lighting, repair services, etc.);

b) when analyzing and calculating the energy indicators of production associations, factories and the entire industry, indicators of individual industrial enterprises.

When calculating industrial enterprises, taking into account the above factors, the following method can be used.

Ei is the electrical energy (W_i) required to produce the product (semi-finished product) of the workshop (Q_i).

$$E_i = \frac{W_i}{Q_i} \tag{12}$$

The specific consumption of product (semi-finished product) for production (Z) is as follows:

$$q_i = \frac{Q_i}{Z} \quad (13)$$

Combining equations (12) and (13), we can form the following expression.

$$d_i = \frac{W_i}{Z} = E_i q_i \quad (14)$$

is a mathematical expression of the specific consumption unit of finished products (semi-finished products), which is the share of the i-division's participation in the total cost of the final product of the enterprise.

In enterprises that include a number of main and auxiliary workshops, the cost of the final product can be calculated using the following formula:

$$e = \sum_{1}^{n} Eiqi + \sum_{1}^{n} \gamma i\omega i = \sum_{1}^{n} \alpha i + \sum_{1}^{n^1} \alpha^1 i \quad (15)$$

where n and n^1 - the number of workshops, respectively, the main and auxiliary workshops:

respectively, the specific consumption of auxiliary components of the technological process (B_i) for the final product (Z) n production unit for production B_i.

If an enterprise produces semi-finished products for delivery to other enterprises in addition to its main product, then, as a rule, [6], the energy consumption for the production of this type of product should be standardized separately. In this case, the calculation should include the energy consumption for the production of technological process components produced by auxiliary workshops. In a number of cases, the same component is consumed by several workshops - compressed air (B_h), water (B_s), oxygen (B_k), etc. In this case, the energy consumption, for example, for the production of compressed air, will be as follows:

$$W_s = W_c\ (B_h + B_s + B_k) \quad (17)$$

In general, the calculation formula for the production unit block, taking into account the energy performance of the auxiliary components of the technological process, will be as follows:

$$\alpha i = (\varepsilon_i \sum_{1}^{m} \omega i\gamma i)\ q_i \quad (18)$$

where m is the number of high-voltage transformer substation blocks used in the production of workshop products (semi-finished products) - Q_i.

$\gamma i = \frac{B_i}{Q_i}$ Specific consumption of auxiliary components of this type of technological process per unit of production (B_i) fugure 4.

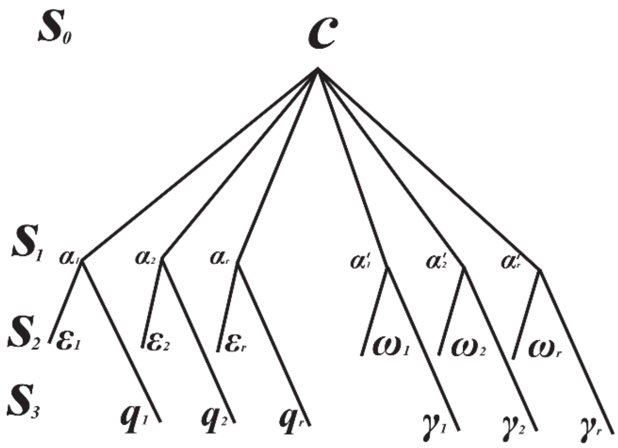

Figure 4. System branching

The proposed method allows for independent research, calculations and optimization for each block.

Determining the range of factors and the forecast object covered by these equations allows us to synthesize the desired indicator and determine the relationships between these factors, which is a prerequisite for developing a scenario. Let us consider the main parameters of the dependencies given in Figure 2:

Electricity consumption can be expressed by the equation.

$$W=W_0+\delta \tag{19}$$

where W_0 - the consumption of electricity, independent of the volume of manufactured products. δ- is a constant component of the production unit, which represents useful energy and load losses.

Each of the above parameters, in turn, is associated with a number of factors that directly or indirectly affect them. Based on experimental studies and statistical analysis of operational materials, we find the factors that have the greatest impact on energy indicators, this problem is solved by constructing energy characteristics of the type W=f(Q) and obtaining multifactor correlation models of the form.

$$e = f(x_1, x_2, x_3 .... x_n) \tag{20}$$

Here x_1, x_2, x_3, etc. are factors related to the electrical power of the products.

The same models are developed for all the sets of indicators given as examples in Table 1.

After the logical sequence of events has been established, studied and developed separately, we carry out an initial decomposition of the Correction Unit system (Fig. 5), dividing it into a number of subsystems (blocks) - “C” where S_0 , S_1, S_2, S_3 are the corresponding levels of the system [7].

In addition, it is necessary to consider and solve a number of problems associated with the implementation of many activities. For this, we use the following structure of the system, through which, after certain stages, the final "branching of block C" - this is also a branching scheme of block α, since it is designed to achieve the total value "C" (Fig. 4, Fig. 5), step by step, so that the activities of the next level provide the tasks of the previous one and technological indicators, performance indicators of machines and mechanisms, quality of semi-finished products, raw materials, etc.

Products developed in light industry - indicators of electricity consumption by nature and groups of consumption, volume of products manufactured taking into account the assortment, specific indicators of consumption, raw materials, semi-finished products, components of the technological process, specific indicators of production, electricity consumption, etc. The sequence of these states is represented in the technological scheme of light industrial enterprises (Figure 5).

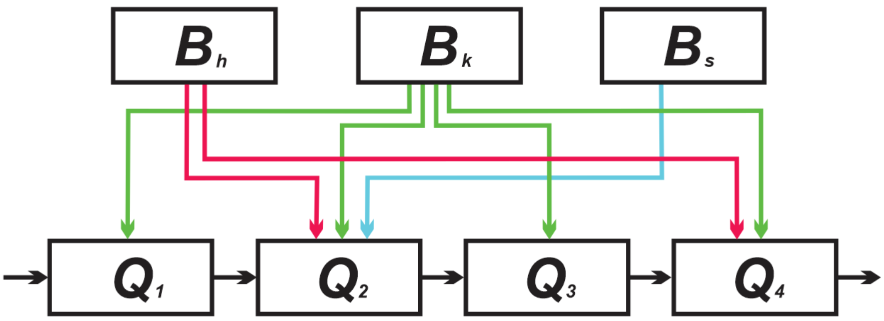

Figure 5. Supply scheme of technological process units

This scheme depicts the energy and resource flows between the main and auxiliary blocks of technological processes in light industry enterprises. The scheme shows the relationship between the main production workshops (blocks I and II), auxiliary components of the technological process (block III) and additional energy consumption (block IV). The energy consumption of each block and its specific share in product production are analyzed, and optimization opportunities are identified to increase overall efficiency.

III. Conclusions. The proposed block-based method for analyzing electricity consumption and calculating quality indicators at light industrial enterprises provides high efficiency in energy consumption management. This method allows you to achieve accurate and reliable results, taking into account the specific characteristics of each technological process. The mathematical models and nomograms developed during the study have proven to be an important tool for assessing and optimizing the quality of electricity. The fact that the difference between real and calculated data is within 2-5% confirms the practical applicability of the method.

It was found that a decrease in the quality of electricity (voltage fluctuations, interruptions) leads to additional losses in technological processes, which indicates the need for constant monitoring and improvement of quality indicators. This effect was especially significant in the production of auxiliary components (block III).

The proposed methodology is an effective solution for ensuring energy efficiency, bringing economic benefits to enterprises by calculating the minimum power consumption (8) and losses in emergency situations (ΔW_{ish}). Due to the flexibility of this method, it can be used in various sectors of light industry, including textile and garment. At the same time, additional research is required to take into account energy costs when planning the introduction of new technologies and automation equipment.

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