Quality control of electrical energy production

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Abstract. The problems associated with the control of electricity production from the point of view of the system approach are considered. The analysis of technological process of production of electric energy as object of control is given. The target function of technological process of production of electric energy is shown. The algorithm of allocation of the main criterion of quality of technological process of production of electric energy is given. Modelling of control of technological process of production of electrical energy with the tuning of the model is carried out. The results show the possibility of reducing the influence of uncontrolled parameters in the systems of electricity production.

1. Introduction
Competitiveness in the production sector depends not only on the quality in the usual sense (that is, some set of technical characteristics of objects with sufficient reliability for consumers), but also on a number of economic, legal and other factors. The production of electricity as a whole is a complex system [1, 2]. For such systems, it is not always possible to find a single description that allows you to achieve all the goals and objectives at the same time. In fact, such system can be described as a number of separate models, the number and complexity of which depends on the nature of the objectives.

The use of the process approach allows to take into account the most important factors of production, as well as methods of effective influence on them, taking into account all factors - technical, functional, social, aesthetic. The means of process control is modeling. The functional model is built to identify each process that determines the quality of products, according to the following parameters: documentation, necessary resources, quality indicator, responsibility, process location in the process network.

Also, the functional model defines for each process "input" and "output", as well as the relationship with other processes. The statistical model is used to predict the quality of electrical energy, the formation of measures to prevent marriage, ranking of quality parameters in importance and control of their accounting [3]. In this paper, on the basis of the process approach to the control of the quality of electric energy production, the modeling was carried out and the results were obtained, showing the possibility of reducing the influence of uncontrolled parameters.

2. Target function of the technological process of electric energy production
The General model of technological process (TP) is a sequence of particular models describing all
technological operations.

The main indicator of efficiency of TP of production of electric energy is values of indicators of output characteristics that, in turn, depends on stability of conditions of production of electric energy (adjustment of TP, correctness of technology of control, etc.).

The need for TP control is determined by three main factors: technical input and output characteristics should be maintained at the required level from one time period to another; stopping of each technological operation should be performed in accordance with the available algorithms, synchronizing the inclusion or disconnection or change of the impact on the process from different equipment; constant technological wear of the equipment requires regular correction of process parameters.

We will record the complete TP model as a sequence of separate technological operations. We consider the \((i-1)\)-th operation TP

\[ u_i = F( u_{i-1}, v_i ) , \]  

where \( u_i \) is the quality parameters of electrical energy in the current operation, \( v_i \) – version of the production of electrical energy, that is, a set of parameters affecting the production process, set by the control system.

However, it is necessary to take into account that in fact, not the parameters of the quality of electricity production are required, but the parameters that depend on them (speed, resistance to different influences, etc.), that is:

\[ g_i = F^*( u_{i-1}, k_i ) , \]  

where \( g_i \) is the controlled parameters of the current operation, \( k_i \) is the parameters of energy production [4].

The target function can be represented as for the number of TP operations \((n-1)\):

\[ F_c = G( K_1, ..., K_n, c_1, ..., c_n ) , \]  

where \( c_1, ..., c_n \) are the control variables of the process, that is, the values of which can be selected during control. By entering a parameter that characterizes specific targets for the \(i\)-th operation – \( \varphi_i \), you can write for TP with \((n-1)\) operations:

\[ f_{n-1}( K_n ) = min( \varphi_{n-1}[ K_n, c_{n-1} ] + f_{n-2}( K_{n-1} ) ) = min( K_n, c_{n-1} ). \]  

Accordingly, for TP with one operation can be obtained:

\[ f_1( K_2 ) = min( K_2, \ell_1 ) \]  

taking into account that:

\[ f_0( K_1 ) = 0 . \]  

We can get the target function for such TP:

\[ C_1( K_2, c_1 ) = \varphi( K_1, c_1 ) . \]

3. Algorithm of selection of the main criterion of quality of technological process of electric energy production

Let the operation of the IP production TP is determined by \( k \) parameters (that is, there are \( k \) quality criteria (output parameters) for this system), then we can write:
\[ F(X) = \{ f_1(X), f_2(X), \ldots, f_k(X) \} \] (8)

In this case, by virtue of (1) and (2), \( F(X) \) should tend to the maximum for \( X \) in some optimization space \( S \). In space \( S \) there should be some (even and limited) admissible solutions – \( A_d \).

In general, the main problem of TP optimization is to bring some optimized function \( F(X) \) to its optimal value:

\[ F(X) \rightarrow \text{opt} \] (9)

For multi-criteria optimization [5]:

\[ X = \{ x_1, x_2, \ldots, x_n \} \in D, \quad F = \{ f_1, f_2, \ldots, f_n \} \subseteq S \] (10)

where \( X \) is the vector of independent variables in some admissible domain \( D \) (i.e. the set of admissible values of variables), \( x_i \) are unknown, being controlled objects (input objects) in the optimization problem TP, \( S \) is the optimization space (for example – the set of real numbers \( R_n \)).

That is, (9) is the problem of optimal choice of controlled parameters of a technological system, in which for given \( n \) criterion functions \( f_k \) (\( k = 1, \ldots, n \)) there are some technological limitations \( (X \in D) \) (for example, technological capabilities of equipment, etc.).

However as it is noted earlier, in TP of production of electric energy there are mutually inconsistent parameters of quality [6].

Based on the analysis of optimization methods, to simplify the possibility of using a real TP, it is rational to use a discriminatory method by highlighting the main quality criterion.

The mathematical model for this case is the following – it is necessary to determine such an option from the possible, which provides the maximum of the target function:

\[ K(v_i) = \max \left\{ \sum_{k=0}^{n-1} g_k(v_i) \mid g_k(v_i) \geq g_k' \right\} \] (11)

where:

\[ g_k(v_i) = \sum_{i=0}^{\ell-1} g_k(p_i) \] (12)

these are the values of specific quality parameters, \( k = 0, 1, \ldots, m-1; \quad g_k(p_i) \) – values of quality parameters; \( p_i \) and \( v_i \) – quality parameters and manufacturing option (a set of types of quality parameters); \( g_k' \) – restrictions on the values of quality parameters (approximate); \( K(v_i) \) – generalized quality criterion (target function) [7]. The algorithm for selecting the main (main) quality parameter is as follows:

at step \( \#1 \) – the elements are ordered: that is, for each of the \( n \) existing subsystems, according to the values of the current (considered) criterion, elements of different types (for example, economic and physical) are sorted in ascending (or descending) order.

You are prompted to enter a parameter \( \Sigma \) – the sum of the last values of the elements ordered by type (or, conversely, the sum of the first values in the case of ascending sorting).

\( \Sigma \) it is an ideal solution for this system (i.e. a minimum of resources – costs, material costs, etc.).

In the next step \( \#2 \) is the calculation of the admission (for each subsystem: \( e \) – number of the subsystem):

\[ A = \gamma^e_i(\text{pr}) - \Sigma \] (13)

In step \( \#3 \) the elements \( e \) of the subsystems, which exceed the value of the parameter \( A \) are
discarded. If at least one subsystem does not have a single element (that is, there is no valid solution), you must extend the constraints and return to step 1.

At the step №4 we go to the next criterion, as happens until then, until we have considered all of the criteria [8].

During next steps №5 and №6 the value of the target function is calculated. Subsystem elements are used to find a solution. The limitation for the target function is proposed to be set as follows:

$$f(v_i) \geq f_i^{min} = \frac{f_{i-1}^{max} + f_{i-1}^{min}}{2}$$  \hspace{1cm} (14)\]

where $f_{i-1}^{min} = f_{i}^{min}$, $f_{i}^{min}$ – the sum of the minimum values of the target function of each subsystem.

At the final step №7 the presence of elements in each of the subsystems is checked (that is, the necessary condition for the existence of the solution is fulfilled) and the decision is made to extend the restrictions on the target function in the absence of elements in at least one subsystem.

The result of the algorithm will be a solution – the main criterion of quality of TP of electric energy production, obtained in the last iteration.

4. **Modeling of technological process control for electrical energy production with the tuning of the model**

It is known that due to the influence of uncontrolled parameters on the process of electric energy production, in fact, the practical results represent a function of $Y(X)$ of an independent variable with the influence of some random variable.

The regression model is constructed in such a way that it describes the dependence $Y (X)$ as accurately as possible (maximum approximation).

As the accuracy parameters, the standard error is usually used: the sum of the squares of the difference between the values of the model and the variable $Y$ for all values of $X$. In this case, the model of the real TP is described by a linear equation:

$$Y_i = K_i + BU_i$$  \hspace{1cm} (15)\]

where $Y = \{y_1, y_2, ... , y_m\}$ – vector of dependent (output) variables (characteristics) of electric energy, $U = \{u_1, u_2, ... , u_m\}$ – vector of control variables TP. Write in the form of individual errors:

$$Y_i^* = K_i + BU_i + \xi_i, \quad \xi_i = \xi_i(t)$$ \hspace{1cm} (16)\]

So we have:

5.1.1. **Example:**

$$\xi_i = \xi_i^* \pm \Delta_i$$ \hspace{1cm} (17)\]

where $\xi_i^*$ – a regular component of the, $\Delta_i$ – random errors at a given time.

The effect of $J$ on the production of electricity varies over time.

| № | Modeling results $Y$ Before modeling | After modelling – Linear model | № | Modeling results $Y$ Before modeling | After modelling – Linear model |
|---|---|---|---|---|---|
| 1. | 0,86 | 0,88 | 6. | 0,86 | 0,98 |
| 2. | 0,89 | 0,91 | 7. | 0,9 | 0,91 |
3. 0,84 0,91 8. 0,92 0,93
4. 0,91 0,94 9. 0,89 0,91
5. 0,88 0,90 10. 0,91 0,92

Figure 1. Modeling results of the TP control algorithm for electric energy production for the linear model: 1– Initial value. 2 – The value after the adaptive control.

To take into account the influence of uncontrolled variables and measurement errors in the system of electric energy production, it is necessary to transfer the parameters that will be further used to analyze the TP and the state of the process equipment: the time $t$, the values $Y$ and $Y^*$, the regular and random components of the errors $J$ and $\Delta$ and the control variables $U$. Data transfer to the control system begins at the time $t=t_0=0$. At time $t=t_i$, the implementation of the control algorithm begins. Time $t=0$ – the moment of the first measurement of TP parameters. In this algorithm, $Y$ is an optimization function that depends on one variable $G$, which is the main quality criterion:

$$Y = Y(G) \quad G = G(Y_1, Y_2, ..., Y_n)$$

The values of the model are calculated from the values of parameters transmitted to the system with the described algorithm.

Further for weight values of specific criteria of quality of the generalized criterion of quality of production are calculated and normalized:

Figure 2 Modeling results of TP control of electric energy production for the linear model: 1– Initial value. 2 – The value after the adaptive control.
(the total coincidence of the values of the ideal (error-free) data with the value of the data modeled with an error, according to the above algorithm, was taken as one), \( Y_{ideal} \) – the ideal case when the model accurately described all the errors and losses of the process. Figure 1 and Table 1 present the results of ten cases of modeling of the developed optimization algorithm TP with the adjustment of the model parameters. Similar modeling was carried out for the following values of uncontrolled parameters:

\[
\varepsilon_i^n = 0,1 \cdot t^2.
\]  

Figure 2 and Table 2 what is typical for undeveloped or poorly configured processes of electric energy production.

| № | Modeling results Y Before modeling | After modelling – Linear model | № | Modeling results Y Before modeling | After modelling – Linear model |
|---|-----------------------------------|-------------------------------|---|-----------------------------------|-------------------------------|
| 1. | 0,67                              | 0,88                          | 6. | 0,5                              | 0,83                          |
| 2. | 0,57                              | 0,85                          | 7. | 0,35                             | 0,75                          |
| 3. | 0,53                              | 0,81                          | 8. | 0,59                             | 0,89                          |
| 4. | 0,45                              | 0,81                          | 9. | 0,41                             | 0,75                          |
| 5. | 0,56                              | 0,85                          | 10. | 0,53                            | 0,81                          |

According to the results of computer modeling, it is obtained that the application of the developed control algorithm of TP of electric energy production (with the adjustment of the model) allows to reduce the influence of uncontrolled parameters (random and constant component) on the characteristics of the produced electric energy.

5. Conclusion
In the paper the characteristics of optimization of TP of production of electric energy are considered. The main results of the work are as follows: an algorithm for controlling the TP with the model adjustment is developed, which allows to take into account the influence of uncontrolled parameters (random and constant component) on the final quality of electric energy during the TP. According to the results of mathematical modeling, the efficiency of this algorithm and improvement of the quality of electric energy in the case of its application are shown.

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