Experimental and statistical methods for studying the modes of electric power systems under conditions of uncertainty

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Abstract. The issues of mathematical modeling of the modes of electric power systems in conditions of inhomogeneities such as time drift of the main indicators are considered. In conditions of incomplete knowledge of the mechanism of phenomena, mathematical modeling was carried out by experimental and statistical methods, namely: experiment planning was used.

1 Introduction

One of the urgent tasks is to determine the optimal modes of power systems in the process of production, transmission and distribution of electrical energy.

Most of the research in this direction is aimed at solving complex multifactorial experimental problems related to the optimization of power system modes. Such problems should be solved with incomplete knowledge of the mechanism of the phenomena under study in conditions of the complex influence of a large number of independent variables on the value of the optimization parameter at the same time. Therefore, it is necessary to find solutions that are close to optimal. One of them is the use of modern mathematical methods of experiment planning. At the same time, special attention is paid to the problems of optimal planning of short-term regimes in power systems under conditions of uncertainty, taking into account the probabilistic nature of the initial information.

With optimal planning of power system modes, the calculated parameters of electrical networks and loads of power consumption nodes are used [1-3].

To achieve the optimal mode, calculations should be carried out taking into account the probabilistic nature and partial uncertainty of the initial data on the loads of the elements of electrical circuits.

2 Methods

Traditional methods are associated with an experiment that requires a lot of effort and money, since it is time-consuming and based on alternating variation of independent variables in conditions when other parameters tend to remain unchanged.

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In this case, there is no real possibility of a comprehensive study of the high quality of the elements of power systems and as a result, many decisions are made on the basis of incoming information, which is random.

Currently, two approaches to solving modeling problems have been defined: deterministic and experimental – statistical. In the case of a deterministic approach, the solution of problems is preceded by a comprehensive study of the process and, as usual, it is given in the form of some system of differential equations.

Most of the real processes in the electric power industry are complex and are influenced by a large number of interrelated factors, and in this regard, the use of deterministic methods is largely difficult. On the other hand, theoretical consideration is not able to take into account the whole variety of really acting factors, and therefore the theoretical mathematical model loses its power to a greater extent when moving to real conditions.

Under conditions of incomplete knowledge of the mechanism of phenomena, mathematical modeling problems can be solved by experimental and statistical methods.

In this regard, mathematical methods of experiment planning are becoming increasingly widespread in solving problems related to the modes of operation of electric power systems under conditions of uncertainty such as time drift of the main operating parameters of power systems.

The main mathematical apparatus for processing the results of observations using experimental planning methods is regression analysis, which consists in estimating the regression coefficients by the [2, 4, 5] least squares method followed by statistical analysis of the resulting polynomial model:

$$\text{У} = b_0 + \sum_{i=0}^{n} b_i x_i + \sum_{i>j}^{n} b_i x_i + \sum_{i>j}^{n} b_{ij} b_i x_i + \cdots \quad (1)$$

When planning an experiment, when studying the modes of power systems, one has to deal with sources of inhomogeneities of a continuous type. These sources cause a continuous change in energy modes – the drift of their output indicators over time and is expressed in the form of additive drift, that is, the displacement of the response surface

$$\text{У} = f(x_1, x_2, \dots, x_k) \quad (2)$$

without its deformation, and the drift function type has a fairly smooth character and can be represented by a polynomial of a low degree.

When planning an experiment under conditions of inhomogeneities, in the general case, the results of observations *Y* (power balance, load, conditional fuel consumption, etc.) represent an additive mixture of changes in the output *f(x)* caused by a vector of variable factors *x* of continuous or discrete drift *Y(ω)* caused by a vector of uncontrolled factors *ω* and some error ε with normal distribution:

$$\text{У} = f(x) + \varphi(x) + \varepsilon \quad (3)$$

The task is reduced to choosing a plan orthogonal to the identified drift and providing the best estimates of the effects of the studied factors, regardless of the influence of drift.

Experimental studies have established that the optimization parameter Y - the consumption of conventional fuel undergoes a time drift with properties close to linear. In this regard, planning orthogonal to drift can be obtained using a complete factorial experiment (PFE) at two levels.

For our case, the matrix of the full factorial is given in Table 1.

Table 1. The matrix of the full factorial is given**.**

№ p/p	Driftvectors			x_1x_2	x_1x_3	x_2x_3	$x_1x_2x_3$	У
	P_1	P_2	P_3					
1	+	+	+	+	+	+	+	
2	+	+	-	+	-	-	-	
3	+	-	+	-	+	-	-	
4	+	-	-	-	-	+	+	
5	-	+	+	-	-	+	-	
6	-	+	-	-	+	-	+	
7	-	-	+	+	-	-	+	
8	-	-	-	+	+	+	-	

To represent N values of linear drift, it is necessary $L = log\ _2N$of the first columns of such a matrix:

$$У_{ot} = a_0P_0 + a_1P_1 + \cdots + a_iP_i \tag{4}$$

Where

$$a_i = \frac{\sum_{a=0}^{N} P_{i\,u} У_u}{N}; \tag{5}$$

$$a_{i-1} = 2a_i \tag{6}$$

Equality (6) follows from the fact that the first Chebyshev polynomial is P_1, used to represent a linear combination of K first column vectors of the matrix$2^к$[2,6,7].

Any of the remaining columns can be considered as a vector of the desired planning and the rule for obtaining planning orthogonally to linear drift can be formulated as follows: for N observations, make a PFE matrix and discard the first $L = log\ _2N$ columns in it. The remaining part of the matrix is the desired planning for determining l≤N-L-1 coefficients of influence and mutual influence on the output of controlled factors.

By calculating the expansion coefficients, you can check the linearity of the drift. If (6) is satisfied well enough, then the linearity of the drift is satisfied.

Evaluation of the significance of the coefficients of the mathematical model is carried out by the usual method according to the Fisher criterion [3].

When constructing a mathematical model of the operating parameters of power systems using the methods of a planned experiment, the issue of identifying the main parameters and their controllability becomes important. The study of the regime processes of power systems, as well as the analysis of a priori information contained in the practical experience of technologists and operators, allowed us to identify the main parameters that have a significant impact on the course of the process and, thereby, determine the quality indicators [4,5].

Z_1 – fuel costs in thermal power plants;
Z_2 – power balance in the power system;
Z_3 – capacities at stations;
Z_4 – power flow in power transmission lines;
$У$ – the consumption of conventional fuel at thermal power plants.

The relationship of the process parameters can be represented as:

$$У = f_j(U_i, Z_\theta); \qquad \theta = 1,2, \dots 4$$

3 Results and discussion

As a result of the lack of a priori information about the degree of the polynomial model of the process according to the parameter Y, at the first stage of statistical processing of experimental data accumulated according to the PFE type 2^4, a linear mathematical model has been developed. By checking the criteria *F* – Fischer, its inadequacy has been established. The inclusion of interaction effects also did not give positive results. At the next stage, the implementation of the orthogonal plan, followed by the calculation and statistical analysis of the results obtained, allowed us to develop a mathematical model of conventional fuel consumption at a 5% significance level:

$$У = 25.1 + 0{,}43x_2 + 0.53x_3 + 0.82x_1^2 - 0.71x_3^2 \tag{8}$$

$S^2_{(y)} = 1{,}3$the calculated value of the Fisher criterion is determined $F_{kal} = \frac{2{,}5}{1{,}3} = 1{,}92$. By f_{ag}=*10* и $f_E = 25(2-1) = 25$we find$F_{tabl} = 2{,}27$. Thus, equation (8) can be considered correct with a 95% confidence probability.

$$(F_{kal} < F_{tabl})$$

The power system with thermal power stations is characterized by the presence of such uncontrollable factors as fuel costs in thermal power stations, power balance in the power system, power at power stations, power flows in power transmission lines, etc.

All this leads to the fact that the output parameter Y changes indefinitely over time. There is a temporary drift of the characteristics of the power system.

Taking into account the time drift, the total time of the experiment was reduced to a minimum. In order to determine under these conditions k=4 linear effects of the influence of controlled factors according to factor planning, a minimum of N= 8 experiments are required. With the time of one experiment Δt = 5-6 hours, the total time required for the entire experiment was *T*=Δ*t*·*N*=*48* hours.

It was assumed that the drift in this interval could not differ much from the linear one. The absence of interactions of controlled factors was also postulated (the variation steps were chosen small in order to neglect the interactions).

To evaluate the desired linear effects, it was decided to use an experimental scheme of the type 2^3(Table 1), putting in it $Z_1 = x_2x_3$; $Z_2 = x_1x_3$; $Z_3 = x_1x_2$; $Z_4 = x_1x_2x_3$.

As a result of the experiment, eight values of optimization parameters were found, each of which had three repetitions.

The values of the coefficients of the linear model were calculated using the usual factor planning formulas:

$$b_0 = \frac{\sum_{u=0}^{N} y_a}{N}; \qquad b_i = \frac{\sum_{u=0}^{N} Z_{i\,u} y_u}{\sum_{u=0}^{N} Z_{i\,u}}; \tag{9}$$

$$a_0 = b_0; \qquad a_i = \frac{\sum_{u=0}^{N} x_{i\,u} y_u}{N} \tag{10}$$

The values of the coefficients of the linear model calculated by the results of the experiment turned out to be equal:
$b_0 = 76{,}41;\ \ b_1 = -0{,}27;\ \ b_2 = 2{,}72;\ \ b_3 = 3{,}34;\ \ b_4 = -0{,}7.$

Coefficients a_i in the drift decomposition ($a_0 = b_0 = 76.41$), calculated by formulas (10) are equal to:$a_3 = 8{,}31 \simeq 2a_2 = 8{,}42 \simeq 4a_1 = 8{,}4$

4 Conclusion

Thus, the equation of the desired dependence for the encoded variablesZ_i, free from time linear drift, has the form:
$У = 76{,}4 - 0{,}27Z_1 + 2{,}74Z_2 + 3{,}34Z_3 - 0{,}7Z_4$

A variance analysis of this mathematical model is carried out. The total sums of squares are calculated SS_{total}, and also the residual sums of squares are determined SS_{res}.

Calculating the ratio of the variance of effects to the residual variance and comparing them with a tabular value *F*- relations, the significance of the coefficients were checkedb_i, a also the presence of time drift.

The optimal control system is based on the choice of structural relationships from individual links that ensure the complex processing of primary information and the issuance of effective information to the management bodies of the controlled object.

Information from the control systems of technological equipment, manual input data representing the results of laboratory tests, as well as regulatory and reference information is received into the RAM of the UVM using a communication device with the object.

The averaged information to meet the requirements of compliance of the mathematical model with the control object comes from the block of analysis and data transformation into the comparing block and then the correcting block to refine the coefficient of the model blocks of the mathematical model mathematical models of the process are calculated. The obtained results are compared according to the recommended output values of the object stored in the memory of the machine.

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