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Improvement of algorithms for optimization of electrical energy systems under conditions of uncertainty of initial data using matrices

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Abstract. The problem of optimizing the states of electric power systems is one of the complex problems of nonlinear mathematical programming. Despite the fact that many methods and algorithms for solving this problem have been developed in the last five years, the issue of their improvement, taking into account the modern operating conditions of electric power systems, remains an important task. This paper proposes a new algorithm for the optimization of short-term modes of electric power systems under the conditions of initial data uncertainty. The peculiarity of the algorithm is related to the elimination of the need to select a single intermediate bus with a balancing power plant in calculations, which is typical for many existing methods. It is shown that the consideration of frequency changes and partial uncertainty of the initial data in the optimization of the mode of the electrical system can significantly change the calculation results and lead to a corresponding increase in the resulting economic efficiency.

INTRODUCTION

Planning for the development and operation of energy systems can be carried out for short, medium and long-term periods. In planning the development of energy systems, the main goal is to determine the [1-3] most optimal development option, identifying the sources, volumes and timing [4, 5] of investments in structures. One of the most important tasks to be solved before planning [6, 7] is forecasting consumer loads for the corresponding upcoming period. This takes into account population growth rates and the dynamics of other economic indicators.

Planning the development of an energy system is a very complex task with a large number of parameters of various natures, limiting and influencing factors. Planning is divided into static and dynamic planning. With static planning [8, 9], the problem is solved for one stage or period; adynamic planning involves solving the problem in several stages.

Another characteristic feature [10, 11] of planning problems for the development and operation of power systems is the uncertainty of the initial information used about the states and properties of the system.

In power systems, uncertainty typically resides in the state of the system, the components, and the state of the environment in which an existing state, a future outcome, or more than one possible outcome can be accurately described. Sometimes uncertainty in such problems leads to deviation of real states and modes from the planned ones and a corresponding loss of reliability and efficiency. In problems of optimal planning for the development of power systems [7, 12, 17], the loads of nodes, generated powers, power flows in the circuits of the electrical network, as well as the states of the elements of the electrical network usually have uncertain properties. It is intuitively clear that uncertainty in the operation of the system is more complex and critical than in planning. In systems planning, uncertainty forecasts are usually inaccurate [13], often far from the actual situation, which requires a rough approximation of the uncertainty that is acceptable. Rejection of forecast uncertainty at the planning stage can be "saved" at the operational stage. However, the cost of uncertainty at the operation stage is higher than in planning,

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therefore this section of the dissertation discusses the issues of optimizing power system modes during operation - planning short-term power system modes under conditions of uncertainty of the initial information used.

The main initial information, which has a degree of uncertainty or partial uncertainty in the problems [14-16] of optimal planning of short-term modes of power systems, is information about the load graphs [18-27] of nodes and design parameters of networks. The uncertainty of the design parameters - active resistances of power lines, transformers and other devices is determined by their dependence on the ambient temperature. Typically, they are taken into account by introducing appropriate correction factors based on weather forecast data for the planned period. And the uncertainty of node load schedules must be taken into account in the optimization process through the use of special algorithms.

THE ALGORITHM OF OPTIMIZATION

Let us consider the essence of optimization for a typical case, observed in problems of optimization of power system modes, where most often the load is specified in the form of a certain segment $[P_{min};P_{max}]$, within which no probabilistic characteristics are known due to their unknown nature. Moreover, the loads inside the segment are not assigned any probabilistic characteristics, since they are unknown. In this case, to solve the problem in a given interval, a set of load values is selected $\{P_1, P_2, ..., P_n\}$, and $P_1 = P_{min}$ and $P_n = P_{max}$. In this case, it is recommended to select the number of possible load values in a given range taking into account the required accuracy of solving the optimization problem and the acceptable volume of computational operations performed. Then the deterministic optimization problem is solved n times for specific accepted load values in a given interval $P_k=\{P_1, P_2, ..., P_n\}$. As a result of such calculations, the corresponding optimal values of the sought parameter zk and the values of the objective function are obtained as $B_{kk}=f(z_k, P_k)$. Received $z_k=\{z_1, z_2, ..., z_n\}$

form sets of conditionally optimal plans (decisions), and $B_{kk}=\{B_{11}, B_{22}, ..., B_{nn}\}$ form diagonal elements of the payment matrix of size *nxn*. After this, the values of the objective function are calculated under all possible conditions for the implementation of the obtained conditionally optimal plans, i.e. $B_{kj}=f(z_k, P_j)$ at $k\#j$. These values of the objective function form the non-diagonal elements of the payment matrix. Selecting the best plan among conditionally optimal plans based on the use of the resulting payment matrix seems impossible without the use of additional criteria. This is due to the fact that with unknown probabilities of the initial load, different conditions for the implementation of plans correspond to different values of the objective function B_{ij} and various conditionally optimal plans.

RESULTS AND DISCUSSION

The effectiveness of the described algorithm was investigated, we study the computational qualities of the described algorithm under conditions of partial uncertainty of the initial information using the example of optimization of the power system mode, the diagram of which is presented in Fig. 1. An optimal distribution of the total loads of nodes is required between four thermal power plants located in nodes 0, 1, 6 and 7, with the following consumption characteristics of standard fuel, t.e./h.:

$$B_0 = 100 + 0,2 * P_0 + 0,002 * P_0^2, B_1 = 120 + 0,2 * P_1 + 0,0025 * P_1^2, \; B_6 = 60 + 0,15 * P_6 + 0,0015 * P_6^2,$$

$$B_7 = 80 + 0,25 * P_7 + 0,001 * P_7^2.$$

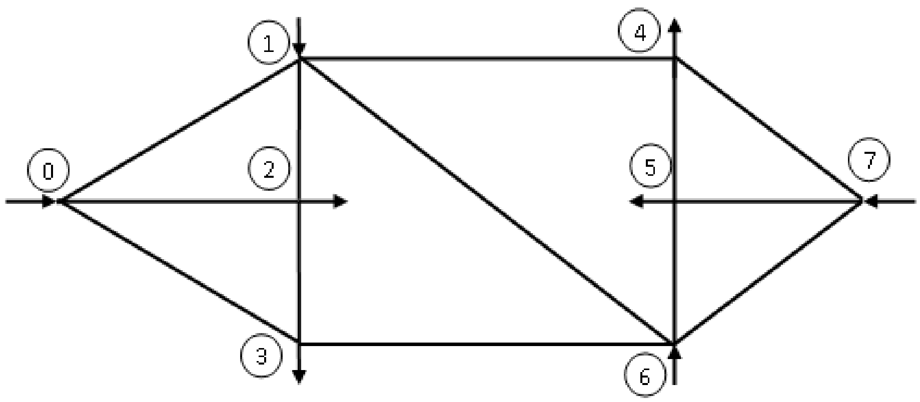

FIGURE 1. Power system diagram

The total load of the power system is partially uncertain, i.e. only the boundary values are known for it P_l= *[1485 MW; 1815 MW]*. The capacities of load nodes 2, 3, 4 and 5 are determined by the coefficients of share in the total load. To solve the problem using the algorithm described above, specified in a given range of an uncertain total load, 5 values were selected at equal intervals and the corresponding capacities of the load nodes were determined according to the coefficients of their share (Table 1.).

TABLE 1. Possible values of power system loads

№	1	2	3	4	5
P_l, MW	1485,0	1567,5	1650,0	1732,5	1815,0
P_2, MW	349,0	369,0	388,0	408,0	427,0
P_3, MW	524,0	527,0	582,0	611,0	641,0
P_4, MW	175,0	198,0	194,0	204,0	214,0
P_5, MW	437,0	473,5	486,0	509,5	533,0

By solving the problem of optimizing the power system mode in a deterministic formulation for the known five values of the total load and power of the load nodes (Table 2), conditionally optimal plans for the original problem were obtained (Table 2).

TABLE 2. Conditionally optimal plans obtained as a result of optimal distribution of the total load of the power system between thermal power plants

Conditional number optimal plan	Total load, MW	Conditionally optimal power of thermal power plants, MW			
		P_0	P_1	P_6	P_7
1	1485	290,91	232,73	404,54	556,82
2	1567,5	306,98	245,58	425,97	588,96
3	1650	323,05	258,44	447,40	621,10
4	1732,5	339,12	271,30	468,83	653,25
5	1815	355,19	284,15	490,26	685,39

Based on the calculation using the algorithm described above, all possible options for implementing the obtained conditionally optimal plans were determined for possible values of the total load. In this case, imbalances associated with the deviation of the total load of the power system from the value at which this conditionally optimal plan was obtained are covered by a balancing station (for example, to cover the total load of the power system of 1650 MW with the first conditionally optimal plan, which was obtained by the optimal distribution total load is 1485 MW, the power of the balancing station becomes equal to 455.91 MW). In table 3. The resulting payment matrix is presented, the elements of which represent the total consumption of equivalent fuel at the corresponding TPP capacities.

TABLE 3. Payment matrix

Conditional number optimal plan	Total load of the power system, MW				
	1485	1567,5	1650	1732,5	1815
1	1524,81	1650,92	1804,26	1984,82	2192,61
2	1535,76	1639,96	1771,38	1930,02	2115,89
3	1568,64	1650,92	1760,41	1897,14	2061,08
4	1623,46	1683,80	1771,37	1886,17	2028,19
5	1700,17	1738,60	1804,25	1897,13	2017,23

In table 4. The optimal plans obtained using the criteria described above are presented.

TABLE 4. Optimal plans obtained using various criteria

Criterion	Conditional number wholesale Planna	Optimal plan (thermal power plant capacity), MW			
		P_0	P_1	P_6	P_7
minimax	5	355,19	284,15	490,26	685,39
minimin	1	290,91	232,73	404,54	556,82
Hurwitz (at α=0,5)	3	323,05	258,44	447,40	621,10
Laplace-Bays	3	323,05	258,44	447,40	621,10
minimax risk	3	323,05	258,44	447,40	621,10

Thus, in the problem under consideration, according to the last three criteria, the third conditionally optimal plan is obtained as optimal. According to the first criterion, 5th and according to the second criterion, 1st, conditionally optimal plans are obtained as optimal. To assess the effectiveness of the results obtained, a calculation of possible excess consumption of standard fuel was carried out in comparison with its values under the most favorable conditions (obtained by the minimin criterion) and the worst conditions (obtained by the minimax criterion) for the conditions of implementation of the optimal plans obtained according to various criteria:

$$\Delta B_{i,min} = min(j)B_{ij} - min(i)min(j)B_{ij}, \quad i = 1, 2, ..., 5, \tag{1}$$

$$\Delta B_{i,max} = max(j)B_{ij} - min(i)min(j)B_{ij}, \quad i = 1, 2, ..., 5 \tag{2}$$

In this problem, the difference between the maximum possible overexpenditure obtained when using the minimin criterion (667.8 t.e.f./h.) and the maximum possible overexpenditure obtained when using the criterion under consideration can be called guaranteed savings for this criterion:

$$\Delta\Delta B_i = min\,min\,\Delta B_{i,max} - \Delta B_{i.max}, \quad i = 1, 2, ..., 5 \tag{3}$$

To compare the results, Table 5 shows guaranteed savings in total equivalent fuel consumption when using various criteria to determine the optimal plan.

TABLE 5. Maximum possible excess fuel consumption from possible deviations of the total load of the power system, t.e.f./h

Criterion	Optimal plans	$\Delta B_{i,min}$, t.e.f./h.	$\Delta B_{i,max}$, t.e.f./h.	$\Delta\Delta B_{i,}$, t.e.f./h.
minimax	5	175,36	492,42	175,38
minimin	1	0,0	667,80	0,0
Hurwitz (at α=0,5)	3	43,83	536,27	131,53
Laplace-Bays	3	43,83	536,27	131,53
minimax risk	3	43,83	536,27	131,53

Analyzing the results of the computational experiment, the following conclusions can be drawn:

When using the minimin criterion, the excess consumption of equivalent fuel under the most favorable condition of implementation of the resulting optimal plan is equal to zero, and under the worst condition of implementation - 667.8 t.e.f./h. When using the minimax criterion, these indicators are 175.36 t.e.t./h. and 492.42 t.e.f./h., respectively. When using the remaining three criteria, where the same optimal plans were obtained (3rd conditionally optimal plan), such possible overexpenditures of conventional fuel equal to 43.83 t.e.t./h. and 536.27 t.e.f./h., respectively. Due to the fact that the maximum guaranteed savings are ensured with the result obtained using the minimax criterion, it is recommended to use this criterion to solve problems of the type under consideration.

CONCLUSIONS

1. An analysis of the effectiveness of algorithms for optimizing power system modes under conditions of partial uncertainty of the initial information was carried out based on the use of a payment matrix and various additional criteria.
2. Based on research, the feasibility of using the minimax criterion to select the optimal solution among all possible plans has been identified.
3. An effective algorithm is proposed for taking into account functional restrictions in the form of inequalities when optimizing power system modes under conditions of partial uncertainty of the initial information based on the use of the payment matrix and the minimax criterion.

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