Power System Optimization in Terms of Uncertainty of Initial Information

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Abstract. In the article the problem of power system optimization under partial uncertainty of initial information is considered. The possibilities of using the methods of determinization to solve the problem of power system optimization taking into account the regime and technological constraints in the form of equality and inequality are researched. In basis of performed calculation studies using the example of the test scheme of power system, it was found that the optimization algorithm by the method of determinization can be effectively used for this proposes.

1 Introduction

The problem of optimization of power system development and functioning is a difficult problem of nonlinear mathematical programming with many limiting conditions in the form of equality and inequality imposed on adjustable parameters and on some of their functions. These problems are also characterized, like similar problem for any large system, by the presence of various kinds of initial information. Currently, the initial data used to solve such problems can be divided into four types: deterministic, probabilistic, fuzzy, and interval.

The deterministic data gives a complete picture of the state of object, which meets the requirements of this problem. The last three types of initial data are uncertain data. With a probabilistic initial data, the laws of distribution of probabilistic quantities in known ranges of their possible values are usually set. Fuzzy initial data suggests their task by formulated linguistic distribution of possible parameter values. In the case of interval initial information, the intervals of possible values of the initial parameter (or state) are usually known, and no laws are known about their possible values (or states) in this interval.

Currently, the methods and algorithms for solving power system optimization problems in the conditions of deterministic initial data are sufficiently developed [1-7]. The solution of the problem in conditions of probabilistic initial data is carried out by probabilistic-statistical methods. They provide for the use of the mathematical expectation functions of the objective function and the constraint functions of probabilistic quantities. In this case, the calculation algorithms do not differ much from the algorithms for deterministic initial data. The optimization problems in the conditions of fuzzy initial data are solved by methods of the theory of fuzzy sets [8, 9]. In this paper, we

consider the problem of Power system optimization in the conditions of interval (partial) uncertainty of the initial parameter. In the existing literature, there are no an advanced algorithms for optimization of the development and functioning of power system, taking into account all the constraints in conditions of partial uncertainty of the initial information. In [10–12], the efficient algorithm of power system optimization in terms of partial uncertainty of initial information is described. The algorithm is based on the sequential solution of deterministic problem for the values of initial parameter selected in a given interval and select the best plan for various criteria. In this case, preference is given to the criteria of minimax and minmax risk. At the same time, in these works, the questions of taking into account of constraints in the form of inequality remains opened. The algorithms proposed in [13] for taking into account inequality constraints during optimization under the conditions of probability and partial uncertainty of the initial information do not completely overcome the noted difficulties. In some cases, the determination of a conditionally optimal plan, where all the specified constrains are satisfied for all the possible values of the initial parameter in a given range, requires additional complex calculations. In [14–16] an algorithm of optimization under conditions of interval uncertainty of the initial parameter by the method of determinization, taking into account the constraints is described. This paper presents the results of study of possibility of using this algorithm to solve problems of optimization of a development and functioning of power system.

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2 The optimization algorithm

We consider the possibilities of using the algorithm of optimization in terms of uncertainty by determinization method for solving the problem of power system development optimization, which is formulated as follows:

minimize the function of estimated costs

$$\mathcal{Z}(a_1, a_2, \dots, a_m, x_1, x_2, \dots, x_n) \rightarrow \min \quad (1)$$

taking into account

- simple constraints imposed on adjustable parameters

$$x_i^{\min} \leq x_i \leq x_i^{\max}, \quad i = \overline{1, n}; \quad (2)$$

- functional constraints in the form of equality and inequality imposed on some functions of adjustable parameters

$$f_j(a_1, a_2, \dots, a_m, x_1, x_2, \dots, x_n) = \bar{f}_j, \quad j = \overline{1, N}; \quad (3)$$

$$g_l(a_1, a_2, \dots, a_m, x_1, x_2, \dots, x_n) \leq \bar{g}_l, \quad l = \overline{1, L}, \quad (4)$$

where $\bar{f}_j, \bar{g}_l$ are specified values of the constraint functions.

At partial uncertainty of initial parameters, when their minimum and maximum possible values are known, all functions, in particular, the objective function and the constraint functions, are also partially indefinite. Then the problem described above is reduced to minimizing the functions of the estimated costs determined at the minimum and maximum possible values of the initial partially indefinite parameters, as in [15]

$$\mathcal{Z}(a_1^{\min}, a_2^{\min}, \dots, a_m^{\min}, x_1, x_2, \dots, x_n) \rightarrow \min, \quad (1a)$$

$$\mathcal{Z}(a_1^{\max}, a_2^{\max}, \dots, a_m^{\max}, x_1, x_2, \dots, x_n) \rightarrow \min \quad (1b)$$

taking into account the constraints (2) and functional constraints in the form of equality and inequality imposed on functions determined by the minimum and maximum possible values of the initial parameters

$$f_j(a_1^{\min}, a_2^{\min}, \dots, a_m^{\min}, x_1, x_2, \dots, x_n) = \bar{f}_j^{\min}, \quad j = \overline{1, N}; \quad (3a)$$

$$f_j(a_1^{\max}, a_2^{\max}, \dots, a_m^{\max}, x_1, x_2, \dots, x_n) = \bar{f}_j^{\max}, \quad j = \overline{1, N}; \quad (3b)$$

$$g_l(a_1^{\min}, a_2^{\min}, \dots, a_m^{\min}, x_1, x_2, \dots, x_n) \leq \bar{g}_l^{\min}, \quad l = \overline{1, L}; \quad (4a)$$

$$g_l(a_1^{\max}, a_2^{\max}, \dots, a_m^{\max}, x_1, x_2, \dots, x_n) \leq \bar{g}_l^{\max}, \quad l = \overline{1, L}. \quad (4b)$$

Solution of the obtained optimization problem (1a) - (4b) reduces to solving the equivalent two deterministic problems. In the first problem, the objective function is represented in the form (1a), and the constraints consist of (2), (3a) - (4b). In the second problem, the objective function form is (1b), and the constraints are (2), (3a) - (4b). As a result of solving these two deterministic problems, the interval values of the sought-for controlled parameters are determined. In this case, the lower boundary values of the intervals are obtained as a result of solving the first problem, and the upper boundary values are obtained as a result of

solving the second problem. For the final solution of the original problem, one point is taken at which all the given constraints are satisfied. The coordinates of this point are determined by the values of the parameters found in the obtained intervals. The value of the objective function at the point of optimal solution is taken as an interval, the boundaries of which are determined by the results of solving the first and second deterministic problems.

3 The results of calculation experiments

To study the effectiveness of the described algorithm, we consider its application for solving the problem of power system mode optimization using the example of the test circuit (Fig. 1), given in [4] for given interval (partially undefined) values of active power of load nodes 2, 3, and 4. Minimum and maximum possible values of loads in these nodes are given in table 1. The active power of node 5 is deterministic and $P_5 = 500$ MW.

Fig. 1. The scheme of the power system.

Table 1. Minimum and maximum limit values of active loads.

The number of node, i	$P_i^{\min}$, MW	$P_i^{\max}$, MW
2	380	420
3	570	630
4	190	210

In four nodes 0, 1, 6 and 7 there are thermal power plants (TPPs) with oil equivalent consumption characteristics, presented in the form

$$B_i = c_i + d_i P_i + e_i P_i^2, \quad t.o.e./h.,$$

where $t.o.e./h.$ - tonne of oil equivalent per hour.

The values of coefficients of oil equivalent consumption characteristics of thermal power plants are given in table 2. The minimum and maximum permissible capacities of all the TPPs are the same and, MW

$$100 \text{ MBt} < P_i < 1000 \text{ MBt}, \quad i=0, 1, 6, 7.$$

In three power transmission lines (TPLs) 6-3, 6-5 and 0-3 the active power flow are controlled, MW:

$$P_{6-3} \leq 480, \quad P_{6-5} \leq 70, \quad P_{0-3} \leq 100.$$

Power flows through a controlled TPLs are determined by linearized formulas using the node power distribution coefficients:

$$P_i = \sum_{l \in I} C_{li}^R P_l^R - \sum_{j \in H} C_{lj}^H P_j^H + P_{i0},$$

Table 2. The coefficients of oil equivalent consumption characteristics of TPPs

The node number with TPP	c_i	d_i	e_i
0	35	0,14	0,00035
1	42	0,14	0,00042
6	21	0,105	0,00028
7	28	0,175	0,000175

Table 3. Power distribution coefficients of nodes.

PTL	Nodes						
	1	2	3	4	5	6	7
6-3	0,2536	-0,0713	-0,172	0,4106	0,489	0,6343	0,4986
6-5	-0,0701	0,02025	0,0484	-0,281	-0,4223	0,1029	-0,2986
0-3	-0,14	-0,1735	-0,267	-0,1744	-0,1917	-0,224	-0,1939

Thus, in the problem under consideration, functional constraints in the form of both equality and inequality are linear. The right-hand sides of functional constraints in the form of equality and inequality at interval node loads are determined based on interval arithmetic operations. As a result, we have the following interval values for the right-hand sides of the constraint functions in the form of equality on power balance and inequality on power flow in the controlled PTLs 6-3, 6-5, and 0-3, respectively:

$$[1640; 1760], [664,168; 685,592], [-164,877; -155,543], [-273,554; -247,106].$$

In the problem under consideration, the constraint in the form of equality is a condition for the active power balance in power system, therefore, the left-hand sides of the constraints in the form (3a) and (3b) are the same. When translating the components associated with the interval loads of the nodes in constraints in the form of inequality on power flows in the controlled NPLs, the left-hand sides of the constraints (4a) and (4b) also become the same. In this case, in each deterministic problem, one constraint in the form of equality takes part. In the first problem, the right-hand side of the constraint is equal to the lower boundary value, and in the second, to the upper boundary value of the total load of power system specified in the interval form.

Since the left-hand sides of the constraints in the form of inequality obtained from (4a) and (4b) are the same, one of these constraints is involved in both deterministic problems, the right-hand side of which is less than the second. In this case, the second constraint with a large right-hand side turns into a passive restriction.

Thus, the first deterministic optimization problem, for the considered example, according to the described algorithm has the following form:

The objective function

$$B = B_0 + B_1 + B_6 + B_7 = 126 + 0,14P_0 + 0,00035P_0^2 + 0,14P_1 + 0,00042P_1^2 + 0,105P_6 + 0,00028P_6^2 + 0,175P_7 + 0,000175P_7^2 \rightarrow \min$$

Constraints

where C_{ii}^F, C_{ij}^H are the power distribution coefficients of the i -th generating and j -th load nodes by PTL l (table. 3); P_i^F, P_j^H are active powers of the i -th generating and j -th load nodes: P_{l0} is a free member of the linearized expression of power flow over the PTL l .

$$P_0 + P_1 + P_6 + P_7 = 1640 ,$$

$$0,2536P_1 + 0,6343P_6 + 0,4986P_7 \leq 664,168 ,$$

$$-0,0701P_1 + 0,1029P_6 - 0,2986P_7 \leq -164,877 ,$$

$$-0,14P_1 - 0,224P_6 - 0,1939P_7 \leq -273,554 ,$$

$$100 < P_i < 1000, \quad i = 0, 1, 6, 7 .$$

The second deterministic problem is represented as follows:
The objective function

$$B = B_0 + B_1 + B_6 + B_7 = 126 + 0,14P_0 + 0,00035P_0^2 + 0,14P_1 + 0,00042P_1^2 + 0,105P_6 + 0,00028P_6^2 + 0,175P_7 + 0,000175P_7^2 \rightarrow \min$$

Constraints

$$P_0 + P_1 + P_6 + P_7 = 1760 ,$$

$$0,2536P_1 + 0,6343P_6 + 0,4986P_7 \leq 664,168 ,$$

$$-0,0701P_1 + 0,1029P_6 - 0,2986P_7 \leq -164,877 ,$$

$$-0,14P_1 - 0,224P_6 - 0,1939P_7 \leq -273,554 ,$$

$$100 < P_i < 1000, \quad i = 0, 1, 6, 7 .$$

It should be noted that the first and second deterministic problems, for the considered example, differ from each other only by the right-hand side of the constraint in the form of equality.

In table 4 the results of solving the first and second deterministic problems are shown.

According to the results given in table 4, we determine the interval values of the optimal powers of the settlement plants and the total of oil equivalent consumption:

$$P_0 = [127,720; 247,701] \text{ MW}, \quad P_1 = [547,769; 547,715]$$

$$\text{MW}, \quad P_6 = [326,838; 326,673] \text{ MW}, \quad P_7 = [637,673; 637,910] \text{ MW}, \quad B = [599,280; 631,857] \text{ t.o.e./h.}$$

Table 4. The Results of solving the deterministic optimization problems.

TPPs load, MW				Power flow on controlled TPPs, MW			The total fuel equivalent consumption, t.o.e./h.
P_0	P_1	P_6	P_7	P_{6-3}	P_{6-5}	P_{0-3}	B
The results of solving the first deterministic problem							
127,720	547,769	326,838	637,673	480,00	39,70	100,00	599,280
The results of solving the second deterministic problem							
247,701	547,715	326,673	637,910	480,00	39,62	100,00	631,857

For the final solution of the problem, according to the above marked rules, we take any point whose coordinates are determined by the powers of the plants in the received intervals. In this case, the lower and upper boundary values of power plant power intervals at nodes 1, 6, and 7 were the same. And the power of the balancing plant can be taken as the average value in the obtained interval. Thus, we take the optimal power of plants as

$P_0 = 187$ MW, $P_1 = 547,75$ MW, $P_6 = 326,75$ MW, $P_7 = 637,75$ MW.

The minimum total oil equivalent consumption in power system has an interval value: $B = [599,280; 631,857]$ t.o.e./h.

4 Conclusion

The problems of power electric system development and functioning optimization taking into account simple and functional constraints in the form of equality and inequality in conditions of partial (interval) uncertainty of initial parameters, can be effectively solved by the method of determinization.

In power system mode optimization on active power and presenting the expression of power flow over a controlled PTL using linear distribution coefficients, solving the problem described by the method of determinization is much easier by halving the number of functional constraints in the form of equality and inequality compared to the classical optimization algorithm in basis of determinization method.

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