Taking into account the constraints in power system mode optimization by genetic algorithms

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Abstract. Over the past decades, many publications on the use of genetic algorithms, which offer a new and powerful approach for solving the problem of power system mode optimization, have appeared. Despite this, the issues of effectively taking into account various constraints when solving such problems with genetic algorithms remain opened. In this regard, this article proposes an algorithm for optimizing power system modes by genetic algorithm, taking into account functional constraints in the form of equalities and inequalities by various penalty functions. The results of effectiveness research of the given algorithm in the example of optimization of 8-nodal power system with four thermal power plants and three lines with controlled power flows are presented.

1 Introduction

Optimization of modes of modern power systems on active power is a complex problem of nonlinear mathematical programming with many simple and functional constraints in the form of equalities and inequalities. Therefore, the efficiency of algorithms for its solution is determined, in particular, by the possibility of taking into account such constraints.

Genetic algorithms offer a new and powerful approach to solving optimization problems. Their use in solving the complex technical problems of large dimensions has become possible due to the expansion of capabilities of computing facilities at relatively low costs. Recently, these algorithms have found application in solving global problems of search engine optimization when traditional optimization algorithms cannot be used. They use parallel and global search methods that mimic natural genetic operators. The probability of convergence of the genetic algorithm to the global solution of the problem is the highest since it simultaneously estimates the set of points in the parameter space. These algorithms also do not require the differentiability and continuity of the search space.

Due to the listed positive features, several publications on the use of the genetic algorithm for problems of optimization of power system modes as [1-10] have appeared over the past few years. In [1], the optimization of power system mode on active power by genetic algorithm for various types of fuel in thermal power plants (TPPs) is considered. In [2], an algorithm for optimization of thermal and electrical systems by genetic algorithm

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based on penalty functions is given. [3] is devoted to the improvement of algorithms for economic dispatch of power system modes based on the use of genetic algorithms. In these works, the parameters to be optimized are mainly taken to be active loads of power plants participating in optimization. In [4-10], the results of the author's study of the problems of optimization of power flows in electrical systems based on the use of genetic algorithms are presented. The above-described developments have made a great contribution to the development of theory and methods of optimization of modes of power system based on genetic algorithms. At the same time, it should be noted the insufficiency of studies performed to identify the effectiveness of optimization of the modes of modern complex power systems with such algorithms under the conditions of existence of functional constraints in the form of equalities and inequalities.

At present, methods of taking into account various constraints in optimization of power system modes by traditional algorithms based on methods of gradient [11, 12], reduced gradient [12], Newton [13], Lagrange [14, 15], linear programming [16, 17], etc. are well researched. However, considering some of these constraints when solving the considered optimization problem with non-traditional algorithms, in particular, genetic algorithms, requires additional research.

In this regard, below, based on the studies performed, an effective algorithm of taking into account the functional constraints by penalty functions in optimization of power system modes with a genetic algorithm is proposed.

2 Methods

We consider the problem of optimization of power system mode on active power, where the objective function can be represented as a function of total fuel costs in thermal power plants or as the total consumption of equivalent fuel in them:

$$B = B_1(P_1) + B_2(P_2) + \ldots + B_n(P_n) \rightarrow min \qquad (1)$$

The main constraints taken into account when solving such a problem for a certain point in time are:

- simple constraints in the form of inequality on the minimum and the maximum possible station loads

$$P_i^{\min} \le P_i \le P_i^{\max}, \qquad i = 1, 2, \ldots, n; \qquad (2)$$

- conditions on a balance of active power in power system (functional constraint in the form of equality)

$$P_1 + P_2 + \ldots + P_n = P_L, \qquad (3)$$

where n is the number of power plants in power system; P_i is power of the i th power plant; P_L is total load of power system;

- constraints on power flows along some controlled power transmission lines (functional constraints in the form of inequality)

$$P_l^{\min} \le P_l \le P_l^{\max}, \qquad l = 1, 2, \ldots, L, \qquad (4)$$

where L is the number of controlled power transmission lines (PTL) in the power system, in which active power flows are limited; P_l, P_l^{min}, P_l^{max} are the flow of active power along the l th controlled PTL and its minimum and maximum possible permissible values.

When optimizing by the genetic algorithm, simple constraints imposed on the independent variables (the capacities of power stations involved in optimization) (2) are taken into account automatically following the procedure of this algorithm.

The proposed algorithm provides for taking into account functional constraints by penalty functions. The penalty function, taking into account a certain constraint, should be equal to zero when it is satisfied and increase in case of violation (in proportion to the degree of violation).

Following this, to take into account the constraint in the form of equality (3), the following form of penalty function is accepted:

$$PF_p = \alpha\left(P_1 + P_2 + ... + P_n - P_H\right)^2 . \tag{5}$$

A special problem in solving the considered optimization problem is taking into account the functional constraints in the form of inequalities (4). In some traditional algorithms for optimization of power system modes, such constraints are taken into account using quadratic penalty functions in the form of

$$PF_l = \alpha\left(P_l - P_l^{max}\right)^2 \text{ or } PF_l = \alpha\left(-P_l + P_l^{min}\right)^2 . \tag{6}$$

This form of penalty function is adapted to take into account functional constraints in the form of equalities. For example, in taking into account the constraint in the problem of determining the minimum of the objective function, the penalty function has a positive value and grows even if the constraint is satisfied (Figure 1,a)

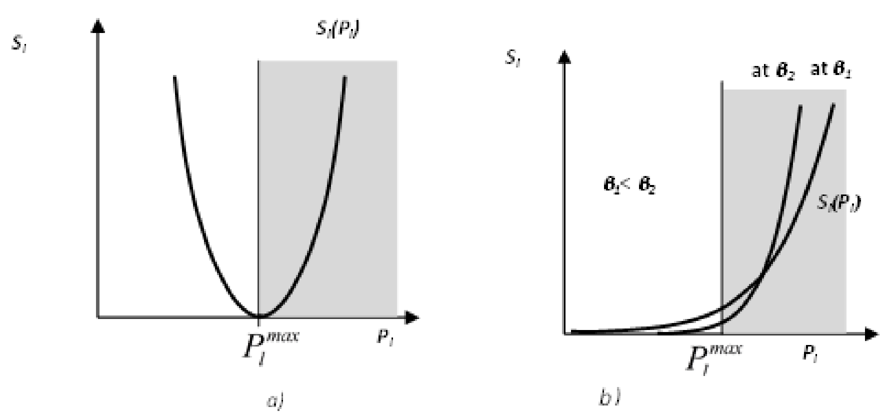

Fig. 1. Penalty function curves.

To overcome this difficulty, in traditional algorithms, after each iteration of the optimization process, the execution of the constraint is checked. If it is executed, the next optimization step is performed without taking into account this constraint. Otherwise, the next optimization step is performed, taking into account the constraint by penalty function.

The research results show that taking into account functional constraints in the form of inequalities by such penalty functions when optimizing with traditional algorithms, in general, there are some difficulties associated with the choice of penalty coefficients and ensuring reliable convergence of iterative computational process, which often fluctuates [12, 14].

It is often difficult to take into account the constraint in the form of inequalities (4) using quadratic penalty function when optimizing by genetic algorithm. The use of an objective function that does not include such constraints leads to unacceptable results, where these constraints are not satisfied. Therefore, to overcome the above-mentioned difficulties, this work proposes to use the exponential form of penalty function:

$$PF_l = \beta e^{\gamma\left(P_l - P_l^{max}\right)} \text{ or } PF_l = \beta e^{\gamma\left(-P_l + P_l^{min}\right)}, \quad (6)$$

where α, β, γ are weight (penalty) coefficients.

The last function quite accurately satisfies the requirements established for penalty functions - equality to zero in terms of satisfaction of constraint and an increase in violation in proportion to the degree of violation (Fig. 1,b).
By choosing the appropriate penalty coefficients α, β, and γ, the constraints can be taken into account with sufficient accuracy.

Thus, the generalized objective function, when optimized by the genetic algorithm, taking into account the constraints by the reduced penalty functions (5) and (6), is represented in the following form:

$$F = B + PF_P + \sum PF_l \rightarrow min \quad (7)$$

3 Results and Discussion

We research the effectiveness of the described optimization method by genetic algorithm, taking into account functional constraints by penalty functions, using the example of optimization the mode of an 8-bus test power system with 13 PTL (Fig. 2). In four buses, there are thermal power plants with the following consumption characteristics of equivalent fuel, toe / h:

$$B_0 = 70 + 0.14P_0 + 0.0014P_0^2, \quad B_1 = 84 + 0.14P_1 + 0.00175P_1^2,$$
$$B_6 = 42 + 0.105P_6 + 0.00105P_6^2, B_7 = 56 + 0.175P_7 + 0.0007P_7^2.$$

The constraints on the minimum and maximum loads of TPPs are the same and

$$P^{min} = 200\ MW, P^{max} = 700\ MW.$$

Load bus capacities are:

$$P_2 = 400\ MW, P_3 = 600\ MW, P_4 = 200\ MW, P_5 = 500\ MW.$$

In three PTL, active power flows are limited: $P_{6\text{-}3} \leq 450$ MW, $P_{6\text{-}5} \leq 65$ MW, $P_{0\text{-}3} \leq 95$ MW. The power flows through these controlled PTL are determined on power distribution coefficients C_{li}, given in Table 1, as

$$P_l = C_{l1}P_1 + C_{l2}P_2 + ... + C_{lN}P_N + P_{l0} \quad (8)$$

where N is the total number of buses in the power system; P_{l0}- free component of the linearized expression of power flow along the l th controlled PTL.

Table 1. Coefficients of power distribution of buses along controlled transmission lines

PTL	Buses						
	1	2	3	4	5	6	7
6-3	0.2536	-0.0713	-0.1720	0.4106	0.4890	0.6343	0.4986
6-5	-0.0701	0.02025	0.0484	-0.2810	-0.4223	0.1029	-0.2986
0-3	-0.1400	-0.1735	-0.2670	-0.1744	-0.1917	-0.2240	-0.1939

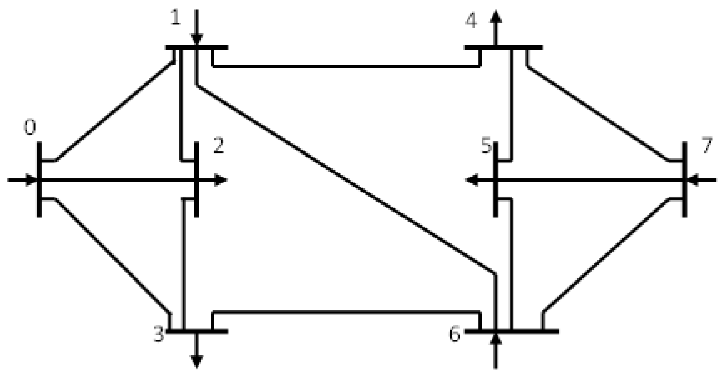

Fig. 2. Power system circuit

To compare the optimization results by the proposed algorithm, Table 2 shows the reference result obtained by the classical gradient method.

Table 2. Reference result of optimization.

TPP	Power of TPP, MW	Fuel consumption, toe / h.
TPP at bus 0	234,7	179,97
TPP at bus 1	505,6	602,14
TPP at bus 6	281,3	154,55
TPP at bus 7	678,4	496,88
Total fuel consumption in power system	-	1433,54
Power flow on controlled lines	P_{6-3}=450,0 MW, P_{6-5}=21,2 MW, P_{0-3}=95,0 MW.	

The results of optimization by the proposed algorithm for the values of the weight coefficients α = 10, β = 10, γ = 2 are shown in Table 3.

Table 3. Optimization results by taking into account constraints by proposed algorithm.

TPP	Power of TPP, MW	Fuel consumption, toe / h.
TPP at bus 0	236.9	181.74
TPP at bus 1	498.8	589.23
TPP at bus 6	273.7	149.39
TPP at bus 7	690.5	510.59
Total fuel consumption in power system	-	1430,96
Power flow on controlled lines	P_{6-3}=449,5 MW, P_{6-5}=17,2 MW, P_{0-3}=95,3 MW.	

Comparing the obtained optimization result with the reference result, we will make sure that the proposed algorithm has a sufficiently high accuracy for practical purposes.

In the problems of power system short-term modes optimization, the initial information about loads of buses in some cases may have a probabilistic or partially indefinite nature. The algorithm described here can be effectively used to solve such a problem based on the use of the procedures described in [17-21].

Thus, the proposed algorithm for taking into account functional constraints in the form of equalities and inequalities in power system modes optimization with genetic algorithms is highly efficient. It allows us to reliably determine the optimal mode of power system, taking into account simple and functional constraints in the form of equalities and inequalities with high accuracy.

4 Conclusions

1. An effective algorithm for considering functional constraints in the form of equalities and inequalities in power system modes optimization by the genetic algorithm is proposed.
2. The genetic algorithm for optimizing power system modes taking into account the functional constraints by penalty functions in exponential form, has reliable convergence of iterative process and sufficient accuracy.
3. The proposed algorithm for optimizing power system modes taking into account functional constraints in the form of equalities and inequalities by penalty functions, can be used by dispatching services of power systems for optimal planning of short-term modes.

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