Optımızatıon of The Power System Mode for Actıve Power by the Hopfıeld Neural Network Method

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Abstract. Optimization of power system modes is a central issue in the work of operational dispatch services. This article examines the application of Hopfield artificial neural networks to solving the problem of optimal load distribution between thermal power plants in the Azerbaijan Electric Power System. The power system is controlled by changing its state. The main control parameters are the active power of the generator equipment operating at the stations and its output. In a market economy, non - optimal operating conditions for thermal power plants can lead to significant economic damage not only to the power system but also to the national economy as a whole. Solving the optimization problem involves formulating an optimality criterion, adequately representing the object, i.e., constructing a mathematical model, and selecting a solution method. Among the most common approaches to formalizing its solution are the relative increment method, various modifications of gradient methods, and hybrid methods. With a large number of variables, their implementation is significantly complicated by the need to solve high-dimensional nonlinear systems of equations. From this perspective, the use of artificial intelligence (AI) methods, in particular artificial neural networks (ANN), is promising. AI methods do not involve complex algorithmic calculations. The performance of the developed program was verified on a test circuit with three power plants using a Hopfield neural network and compared with the results of a numerical simulation method. Unlike existing approaches, this article utilized the dependence of active power losses on power plant generation in the form of a verbal description of an artificial neural network, derived from the results of multivariate power flow calculations.

Key words: power system, optimization, specific fuel consumption, relative gains, Hopfield neural networks.

Market economic conditions require adequate cost allocation methods that reflect the technology of electric power generation. Suboptimal load distribution across plants, depending on the type of equipment and its load levels, leads to an increase in fuel consumption of 2-4% of the total consumption. The relative increment method fully reflects production technology, but it also does not meet market conditions.

The fundamental and primary type of power plant energy characteristic is: the power plant flow characteristic - the functional dependence of the hourly consumption of equivalent fuel B (t.e.f.) on the electrical power P; the power plant cost characteristic -

Z (in rubles) for fuel on the electrical power P (MW); specific consumption characteristic; specific cost characteristic; characteristic of the relative increase in fuel costs [1-3].

The specific fuel consumption characteristics of thermal power plants are approximated by a second-degree polynomial [3].

For preliminary optimization of the active power mode of the Azerbaijan EPS, a program was developed in the Delphi programming system [3]. The minimum total fuel consumption was selected as the optimization criterion in the program. A combined method was used to optimize the mode - using the coordinate descent method to solve nonlinear equations obtained by the Lagrange method. Inequality constraints are taken into account by fixing the unknown value exceeding the limit of the independent variables in each iteration of the coordinate descent method.

Although modular stations with gas engines have an efficiency of 46%, due to the consumption of expensive lubricants and filters, the relatively large number of operating personnel, etc., the cost of electricity is higher than that of some condensing power plants, particularly the Azerbaijan EPS. The Shamkir and Yenikend hydroelectric power plants operate in a natural, optimal flow regime, as the reservoir is not designed for long-term regulation. The Mingechevir hydroelectric power plant, which has a reservoir capable of long-term regulation, is used as a hot reserve and to cover daily fluctuations in the load schedule. Therefore, optimal distribution is primarily determined by thermal power plants.

Using artificial intelligence methods to optimize the active power mode of a power system.

Artificial neural networks (ANNs) are successfully used to solve problems such as image classification, categorization, function approximation, forecasting, optimization, control, and other tasks. It should be emphasized that artificial intelligence (AI) technologies do not employ algorithmic calculations and, therefore, do not require complex computational models.

Optimizing load distribution at thermal power plants is a pressing problem, the solution to which is currently being implemented based on the experience of energy specialists. With minor changes in optimization conditions, modern approaches to this problem, such as the relative increment method, yield widely divergent solutions. From this perspective, the use of AI methods, particularly ANNs, is an interesting approach.

Traditionally, the generator cost function is written as a simple quadratic function [1-3]:

$$И = \sum_i \left(a_i + b_i P_i + c_i P_i^2 \right) \qquad (1)$$

Where I is the total cost; ai, bi, ci are the coefficients of the above characteristic; Pi is the generating capacity of generator i, respectively.

Constraints in the form of equalities -power balance - and inequalities are taken into account.

The power balance equation is constructed as constraint equations in the form of equalities:

$$P_{нсум} + \Delta P = \sum_i P_i \quad (2)$$

where $P_{сум}$ is the total load, ΔP is the active power loss during transmission of electricity through the power line.

Power transmission losses can be represented as

$$\Delta P = \sum_i \sum_j a_{ij} P_i P_j \quad (3)$$

Where aij are the transmission loss coefficients.

To account for power losses, a power loss system must be solved. This problem is often more complex than the ERP problem. Real systems consist of closed loops and a large number of nodes. This requires that losses be taken into account approximately. Therefore, the generalized objective function consists of the sum of the total costs and the power balance equation:

$$E = \sum_i \left(a_i + b_i P_i + c_i P_i^2 \right) + P_{нсум} + \Delta P - \sum_i P_i$$

For each generator, its active power must be between the maximum and minimum generations

$$P_{i\min} \le P_i \le P_{i\max}. \quad (4)$$

где P_{imin} - минимальный, P_{imax} - максимальный предел мощности генерации, соответственно.

Hopfield Neural Network

Hopfield neural networks have demonstrated excellent solution-finding capabilities for complex optimization problems.

In the field of power systems, Hopfield neural networks have been applied to optimal flow distribution and economic load balancing [4-6].

Hopfield neural networks with inverse connections (Fig. 1) are capable of transmitting signals from outputs to inputs. This means that after a new input is applied, the output is calculated and can be transmitted through the feedback network, changing the input. The output is then recalculated. This process then repeats.

For a stable network, successive iterations lead to increasingly smaller changes in output until, eventually, the output becomes constant [5].

Two types of Hopfield neural networks have been widely used: discrete and continuous models.

The continuous Hopfield model is based on continuous variables. A neuron in dynamics is described as:

$$\frac{dU_i}{dt} = \sum_j T_{ij} V_j + I_i \quad (1)$$

где выход и функция вход-выход i-го нейрона равны соответственно, $V_i = g_i(U_i)$-; $g_i(U_i) = \frac{1}{1+e^{\frac{U_i}{u_0}}}$; вид сигмовидной функции определяется коэффициентом u_o.

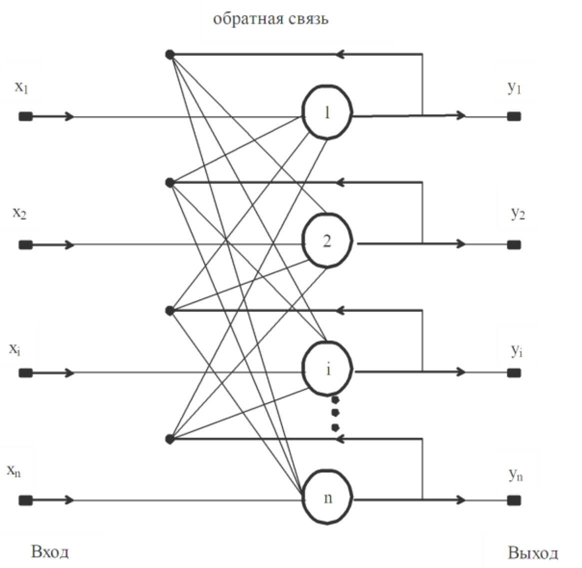

Figure 1. Hopfield neural network

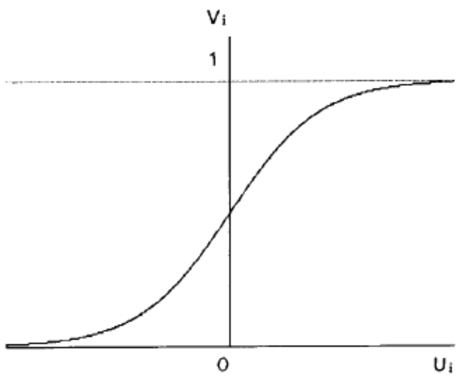

Fig. 2. of sigmoid function

The calculation of the energy function of the Hopfield network is carried out as follows:

$$E = \quad \frac{1}{2}\sum\sum_{j\neq i} T_{ij}V_iV_j \quad \sum I_iV_i + \sum \theta_i V_i$$

When the state of the i-th neuron changes, the energy changes in accordance with:

$$\Delta E = \quad \sum_{j\neq i} T_{ij}V_j + I_i \quad \theta_i \quad \Delta V_i$$

where represents the change in the output of the i-th neuron.

The synoptic strength and external input of neuron i in the Hopfield neural network are:

$$T_{ii} = -A - Bc_i; \qquad T_{ij} = -A$$
$$I_i = A(P_{\text{нсум}} + \Delta P) - \frac{Bb_i}{2} \tag{2}$$

The difference model used to calculate the Hopfield neural network is

$$U_i(k) \quad U_i(k \quad 1) = \sum_j T_{ij}V_j(k) + I_i$$
$$V_j(k+1) = g_i[U_i(k)]. \tag{3}$$

The Hopfield network's output value Pi is then found. Losses in the electrical network are calculated using the loss formula. The calculated losses are assumed constant. The above procedure is then repeated. A sigmoid function of the following form was used in the calculations:

$$V_i = g_i(U_i) = (\overline{P_i} \quad \underline{P_i}) \frac{1}{1 + e^{\frac{U_i}{u_0}}} + \underline{P_i} \tag{4}$$

A Methodology for Using a Hopfield Neural Network for Optimal Load Allocation

A Hopfield neural network for solving an optimization problem includes the following steps [3-5]:

1. Developing an energy function with the condition that its minimum coincides with the problem solution.
2. Expressing the energy function's gradient through weighting coefficients and threshold levels.
3. Providing the network with an input vector and calculating output values.

4. Once the function's minimum is reached, the resulting network outputs provide the solution to the problem.

A methodology and software for solving the problem of economic load allocation using a Hopfield neural network in the Delphi programming system have been developed [3]. The software is based on the algorithm (1-4).

Table 1. Consumption characteristics of units in tons/MW.

№	Name of the power plant	P_{nom}, MW	Polynomial coefficients for one unit		
			a	b	c
1	AzTES TPP	180-300	12.666	0.251	0.00006755
2	A-B TPP	75-150	12.7	0.26	0.000075
3	Shimal TPP	200-400	17.078	0.161	0.00006485
4	Baku TPP № 1	30-55	1.4145	0.161	0.0001628
5	Modular TPP	4.0-8.7	0.85	0.14	0.0004373

Figure 2 shows the block diagram and screen form of the developed program, respectively.

For ease of use, various text and graphical output formats are provided. This software includes blocks for reading source data, initializing weighting coefficients, and initializing output vector values. The software generates a weighting coefficient matrix, calculates the inputs and outputs of the Hopfield neural network, and converts normalized values into real values, taking into account constraints.

Results of modeling the economic distribution of the ERN load using the Hopfield artificial neural network.

A test circuit with three power plants was selected to verify the functionality of the developed program. The total load in this example was 850 MW. Multivariate flow distribution calculations were performed, resulting in a verbal dependence of active power losses on the power generation capacity of the power plants.

This system has eight thermal power plants and three hydroelectric power plants. Energy characteristics: characteristics of the consumption of equivalent fuel of the units of the Azerbaijan energy system, obtained on the basis of reference data of thermal power plants, are given in Table .2.

The fundamental and primary type of energy characteristic is the flow characteristic- the functional dependence of the hourly consumption of the energy carrier (or working fluid) on the load.

The flow characteristic of a power plant is the functional dependence of the hourly consumption of equivalent fuel B (cf. e.g., ρ) on the electrical power P (MW); the characteristic of power plant costs (ρ) - the fuel costs (in rubles) on the electrical power P (MW); the characteristic of specific consumption; the characteristic of specific costs (XSC); the characteristic of the relative increase in fuel costs (XRIFC).

The characteristics of specific fuel consumption of thermal power plants are approximated by a second-degree polynomial.

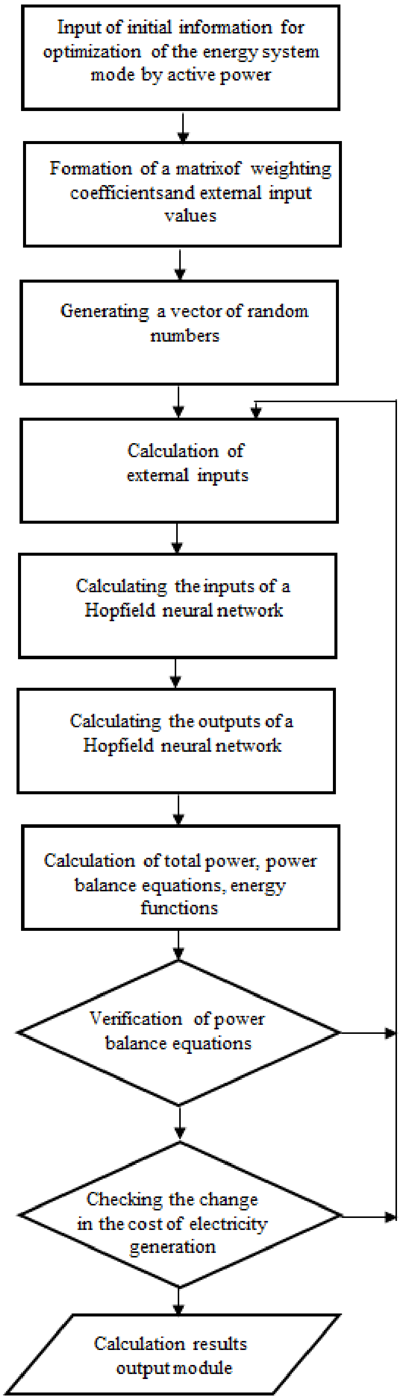

Fig. 3. Flowchart of the developed program using the Hopfield neural network.

The energy characteristics: the characteristics of specific fuel consumption and relative increases (RIFC) of the units of the Azerbaijan energy system, obtained based on reference data for thermal power plants [3], are presented in Table 2.

The fundamental and primary type of energy characteristic is the flow characteristic - the functional dependence of the hourly consumption of the energy carrier (or working fluid) on the load.

The flow characteristic of a power plant is the functional dependence of the hourly consumption of equivalent fuel B (cf. e.g., ρ) on the electrical power P (MW); the characteristic of power plant costs is the fuel costs (in rubles) on the electrical power P (MW); the specific consumption characteristic; the specific cost characteristic; the relative increase in fuel costs characteristic (XRIFC).

The specific fuel consumption characteristics (SFCX) of thermal power plants are approximated by a second-degree polynomial.

Energy characteristics: the specific fuel consumption and relative increase in fuel (XRIFC) characteristics of the units of the Azerbaijan energy system, obtained based on reference data for thermal power plants the characteristic of specific costs [3], are presented in Table 2.

Table 2. Specific Fuel Consumption Characteristics.

№	Name of the power plant	P_{nom}, MW	Polynomial coefficients			SFCX kg.ut/kWh	Efficiency, %
			a_0	a_1	a_2		
1	AzTES TPP	300	410.93	-0.5395	$8.72*10^{-4}$	0.326	38
2	A-B TPP	150	560.3	-2.2197	$9.869*10^{-3}$	0.360	35
3	Shimal TPP	400	346.15	– 0.575	$7.115*10^{-4}$	0.230	53
4	Baku TPP № 1	8.7	357.96	– 23.41	1.4946	0.265	46

The characteristics of specific fuel consumption and the relative increase in fuel consumption for the 300 MW AzTPP and 400 MW Shimal TPP units are shown in Fig. 4,5.

The Azerbaijan Power System (APS) has modern combined-cycle power plants with 53% efficiency: Shimal TPP, Baku TPP-1, modular gas-powered plants with 46% efficiency; and older plants: The Azerbaijan TPP, with an efficiency of approximately 38%, operating since 1981; and the Ali-Bayramli TPP, with an efficiency of approximately 35%, operating since 1962. The energy characteristics of these units differ significantly.

Although the modular gas-powered plants have an efficiency of 46%, due to the consumption of expensive lubricants, filters, relatively large operating personnel, etc., the cost of electricity is higher than that of some condensing power plants, particularly the Azerbaijan TPP. The Shamkir and Yenikend hydroelectric power plants operate in a natural, optimal flow mode, as the reservoir is not designed for long-term regulation. The Mingechevir hydroelectric power plant, which has a reservoir capable of long-term regulation, is used as a hot reserve and to cover daily load fluctuations. Therefore, optimal distribution is primarily determined by the thermal power plants.

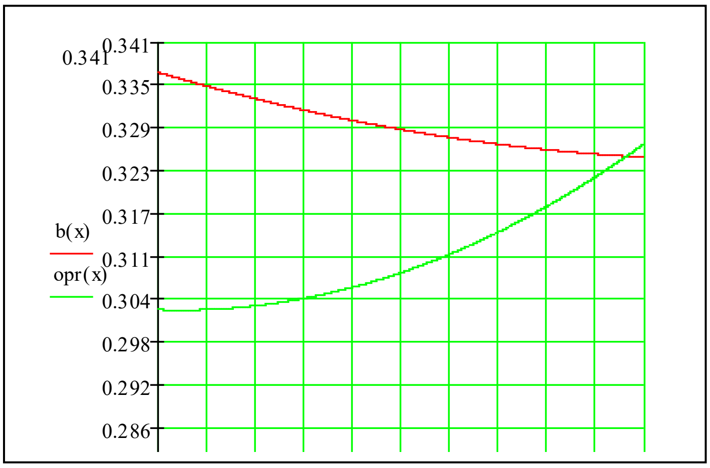

Fig. 4. Specific fuel consumption characteristics of the Az TPP units.

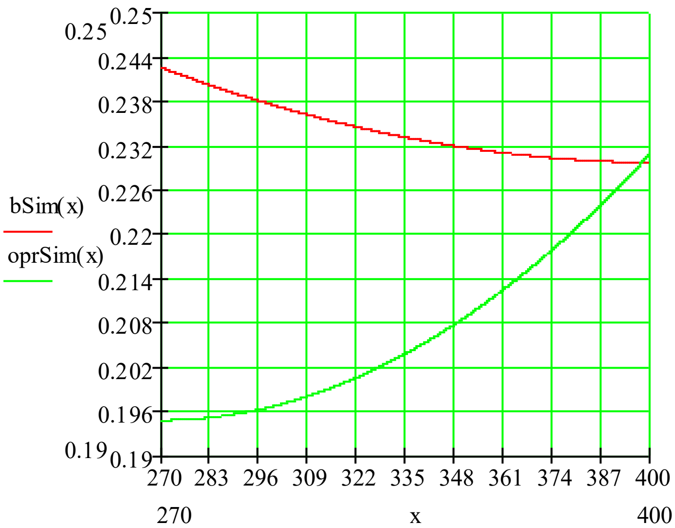

Fig. 5. Specific fuel consumption characteristics of the Shimal TPP units.

Using the Hopfield ANN, optimal active power distribution calculations were also performed using the Azerbaijan Electric Power System (APS) with eight thermal power plants and a total power system load of 3,400 MW.

To account for losses, the dependence of active power losses on the generating capacity of the thermal power plants for maximum operation was used, with a variation range of 0.6 to 1, as a verbal description of the ANN. This verbal description of active power losses was obtained based on the results of multivariate calculations of the steady-state mode of the Azerbaijan power system. The energy characteristics of the Azerbaijan Power System's units, obtained using reference data from thermal power plants, are presented in Table 3. The active power generation of the Azerbaijan Power System's thermal power plants (TPPs) based on actual winter control measurements at 19:00 a.m. in 2008 is given in Table 3. The data for 19:00 a.m. in 2008 correspond to the peak load. Their optimal values, obtained using a program developed using the Hopfield ANN, are also presented in Table 3.

Table 3. Characteristics of the Azerbaijan Power System's Units

№	Name of the power plant	P_{nom}, MW	Efficiency, %	Number of units	P_{min}, MW	P_{max}, MW
1	AzTES TPP	180-300	38	7	1260	2100
2	A-B TPP	85-150	36	4	340	600
3	Shimal TPP	200-400	53	1	200	400
4	Baku TPP № 1	30-55	60	2	60	110
5	Modular TPP	4.0-8.7	46	3*10+12	168	365

The values presented in Table 4 indicate that optimal load distribution in the Azerbaijan EPS leads to a significant reduction in fuel consumption (16.3 tons per winter hour of peak EPS load).

Considering the annual peak load utilization rate of 5,000 hours, a preliminary fuel consumption reduction of approximately 16.3 x 5,000 = 81,500 tons per year can be estimated.

The results of the ERN simulation using the Hopfield neural network were compared with the results of other numerical methods, taking into account active power constraints in the form of penalty functions. A comparative analysis with the results of the numerical method shows that the accuracy results are practically acceptable. However, the use of the Hopfield neural network does not require the construction of complex computational sequences, as it does not involve algorithmic calculations.

The Azerbaijan EPS has modern thermal power plants with combined-cycle plants and an efficiency of 53%: Shimal TPP, Baku TPP-1 modular plants with gas engines and an efficiency of 46%, and older ones: the Azerbaijan TPP with an efficiency of approximately 38%, operating since 1981, and the Alibayramli TPP with an efficiency of approximately 35%, operating since 1962. The energy characteristics of these units differ significantly.

Although modular gas-powered stations have an efficiency of 46%, due to the consumption of expensive lubricants and filters, the relatively large number of operating personnel, etc., the cost of electricity is higher than that of some condensing power plants, particularly the Azerbaijan Thermal Power Plant.

The Shamkir and Yenikend hydroelectric power plants operate in a natural, optimal flow mode, as their reservoirs are not designed for long-term regulation. The Mingechevir hydroelectric power plant, which has a reservoir capable of long-term regulation, is used as a hot reserve and to cover daily load fluctuations. Therefore, optimal distribution is primarily determined by the thermal power plants.

The screen form for preparing the initial information and energy characteristics of the power system units is shown in Figure 4. This form shows that the power system prioritizes the more efficient units with a higher efficiency. 53% and depending on the cost of electricity, the units of Az TPP and modular stations [5].

Simulation results. The performance of the developed program was verified on a test circuit with three power plants from [5-8]. The results of the ORN simulation using the Hopfield neural network were compared with the results of the numerical method [4]. The total load in the test example was equal to 850 MW. In this article, in contrast to [5], the dependence of active power losses on the power generation of power plants was used to calculate losses in the form of a verbal description of the artificial neural network obtained based on the results of multivariate flow distribution calculations.

Modeling of optimal active power distribution was also conducted using a Hopfield neural network for the Azerbaijani electric power system with eight thermal power plants. The total power system load was 3400 MW.

The energy characteristics of the units of the Azerbaijan power system, obtained on the basis of reference data for thermal power plants, are presented in Table 4.

Table 4. Energy characteristics of units of the Azerbaijan power system.

№	Name of station	P_{rated}, MW	Efficiency, %	Q-ty of units	P_{min}, MW	P_{max}, MW
1	AzTES TPP	180-300	38	7	1260	2100
2	A-B TPP	85-150	36	4	340	600
3	Shimal TPP	200-400	53	1	200	400
4	Baku TPP № 1	30-55	60	2	60	110
5	Modular TPP	4.0-8.7	46	3*10+12	168	365

Screen form for solving the optimization problem Fig. 6..

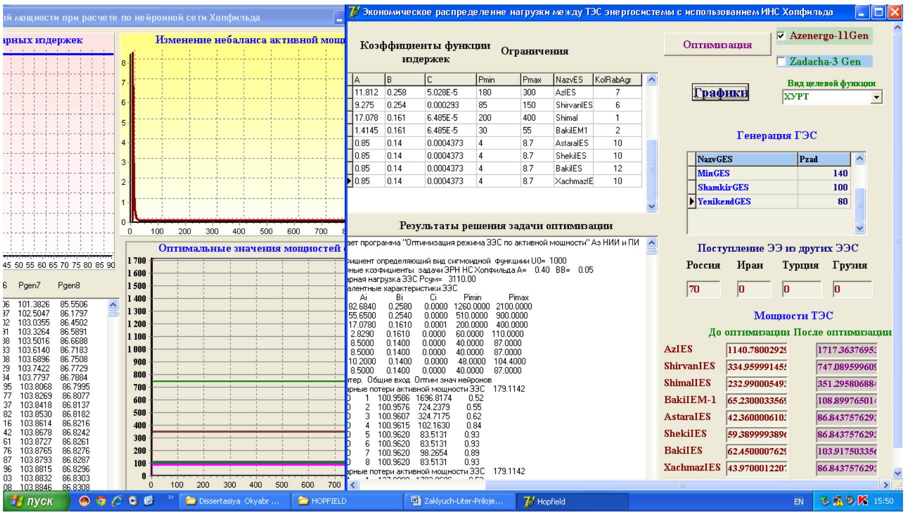

Fig. 6. Screen form for solving the optimization problem.

Graph of the change in total costs during the iterative process is shown in Fig. 7.

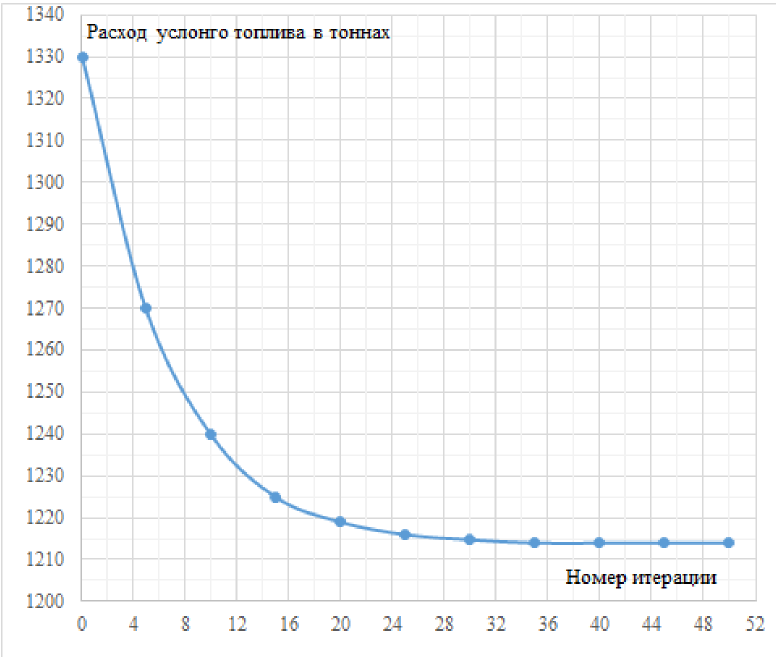

Fig. 7. Change in total costs during the iterative process.

The results of the optimization of the Azerbaijan Power System's operating mode under this program show that more efficient units with combined-cycle plants and modular stations are loaded first, followed by less efficient units of TPP.

To take into account the losses, the dependence of active power losses on the generating capacity of thermal power plants for the maximum mode for change limits of 0.6 ÷1 was used in the form of a verbal description of an artificial neural network obtained on the basis of the results of multivariate flow distribution calculations.

The results of optimal load distribution modeling using the Hopfield neural network were compared with the results of the Lagrange method, taking into account active power constraints in the form of penalty functions. A comparative analysis with the results of the numerical method shows that the results are practically acceptable in terms of accuracy. However, the use of the Hopfield neural network does not involve algorithmic calculations and does not require the development of complex computational procedures.

CONCLUSIONS

1. An algorithm and program using the Hopfield artificial neural network for economic load distribution between power plants have been developed.
2. Calculations were performed to determine the economic distribution of active power in the Azerbaijan EPS. The results of modeling using a Hopfield neural network were compared with the results of numerical simulations.
3. Calculations for efficient active power distribution for various test circuits were performed using a program developed by Delphi and a Hopfield neural network. The simulation results using the Hopfield neural network were compared with the results of numerical simulations using known programs based on constraint-based numerical optimization methods, showing that the results are virtually identical in accuracy.
4. The simulation results for efficient active power distribution were compared with the results of known programs based on constraint-based numerical optimization methods.
5. A comparative analysis with the results of known numerical optimization methods shows that the results are virtually identical in accuracy. However, the use of the Hopfield neural network does not require the development of complex computational algorithms, as it does not involve complex analytical algorithmic calculations.

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