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Mathematical model of managing of the generating company on the criterion of the profit maximization

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Abstract. The urgency of the work is conditioned by the electric power industry reforming, which implies a gradual transition to a competitive market model. So each producer will be interested in maximizing his own profit and independently determine the volumes of electric and heat energy production. On the basis of the developed criterion of maximizing profits, the following problems are considered in the article: the most advantageous distribution of electric energy of thermal power plants at given values of the rate for electricity; distribution of thermal energy between the plant's units, taking into account the forced heating mode of operation of the stations; finding the optimal modes of operation of the stations for the combined method of producing electric and thermal energy; appointment of the most favorable operating modes of the generating company; substantiation of tariff rates for the products sold, depending on the optimal production volumes at thermal power plants that are part of the generating company, determining the optimal operating conditions of SIBEKO JSC (Novosibirsk, Russia). The results: methodology of optimization of CHPP for electric and heat energy has been developed in the work. And also a new criterion has been proposed for maximizing profits for managing the functioning of a generating company.

Keywords: mathematical model, optimization of operating modes of CHP, characteristics of relative increments of fuel consumption, criterion of profit maximization

1. Introduction

The urgency of the problem of energy saving, environmental friendliness, efficiency and ensuring rational work of the heat and power systems of cities, as well as their reliability throughout the life of the operation is dictated by the priority directions of development of Russia and the world community as a whole. Recently developed documents in the energy sector - “Target vision of the strategy for the development of the power industry of Russia for the period up to 2030”, the adjusted General Layout of the Power Industry Objects until 2030, the Power Strategy for the period until 2030 - as one of the main areas. The development of the country's energy sector considered a wider use of coal-fired power plants, the share of power generation of which was to increase from 17.5 (2010) to 23% in the most likely variant and to 25% in the maximum. This growth predetermines new technologies of coal-fired power plants, which are increasingly used in many countries around the world. As noted by the Institute of World Resources, in 59 countries 1199 coal-fired power plants with a total capacity of more



than 1,400 GW have been proposed for construction, among which 77% of the capacity falls on China and India.

Since cities and the majority of industrial enterprises receive electric and heat energy from CHP, the solution to the task of energy saving set in this project is to develop and implement criteria and methods that significantly reduce energy costs and optimize operating modes of generating companies (GC) and thermal power plants (CHP, as previously existing, and the new generation). The perspective of scientific directions in the energy sector of the economy of the GC today depends on the actual application of the results of scientific research and approbation in practice. It should be noted that one of the current areas is the use of high-tech, low-energy-intensive, energy-saving techniques to optimize the operating modes of the GC and CHP with a high economic effect. In conditions when the power industry was the state branch of management, the operation consisted in fulfilling the following requirements. There are given volume and schedule of supplying electric and thermal energy to consumers and observing the reliability conditions of the energy system, and observing the system constraints, determine the optimal mode that satisfies the given economic criterion understood the minimization of operating costs [1].

Currently, a strategy of reforming the electric power industry has been developed and is being implemented. It involves a gradual transition to a competitive market, where each business entity will independently determine the volumes of production of electrical and thermal energy and modes of operation.

Among the characteristic limitations of the existing principle of control of functioning, the following can be distinguished: the mismatch between the goal of management and modern conditions. Every business entity is interested in increasing its own profit, the ineffectiveness of the former control criterion, which is focused on setting higher levels of control of electricity generation and thermal energy [2,3]. Therefore, the old criteria and methods of management have become inadequate for management purposes.

The presence of these limitations necessitates the development of a different principle and methods for managing the operation of an energy facility.

There is a need to determine the principles and methods of management of the functioning of energy facilities that are acceptable in the new economic conditions. Through the work of several generations of scientists, unique methods of managing energy production were created and successfully put into practice, which ensured its high reliability and economic efficiency. Of course, they should form the basis of the approaches proposed in the work, become its intellectual environment and, in combination with economic levers, create prerequisites for the emergence of competitive relations that increase the economic efficiency of energy production.

The solution to this problem is the development of a fundamentally new criterion for managing the operating modes of GC and CHP, as well as creating an integrated methodology for separating fuel costs between the types of energy produced (electrical and heat), which will allow GC and CHP to take a competitive position in the electricity and heat market.

Urgency of the problem of energy saving, environmental friendliness, efficiency and ensuring rational work of the heat and power systems of cities, as well as their reliability throughout the life of the operation is dictated by the priority directions of development of Russia and the world community as a whole [1,2]. Recently developed documents in the energy sector - "Target vision of the strategy for the development of the power industry of Russia for the period up to 2030", the adjusted General Layout of the Power Industry Objects until 2030, the Power Strategy for the period until 2030 - as one of the main areas The development of the country's energy sector considered a wider use of coal-fired power plants, the share of power generation of which was to increase from 17.5 (2010) to 23% in the most likely variant and to 25% in the maximum [3,4]. Since cities and the majority of industrial enterprises receive electric and heat energy from CHP, the solution to the task of energy saving set in this project is to develop and implement criteria and methods that significantly reduce energy costs and optimize operating modes of generating companies GC) and thermal power plants (CHP, as previously existing, and the new generation) [5, 6].

The purpose of the study is to develop a mathematical model of the optimal loading of a generating company in terms of electric power by the criterion of maximizing profit [7, 8].

In conditions when the power industry was the state branch of management, the operation consisted in fulfilling the following requirements. There are given volume and schedule of supplying electric and thermal energy to consumers and observing the reliability conditions of the energy system, and observing the system constraints, determine the optimal mode that satisfies the given economic criterion understood the minimization of operating costs [9, 10]. Currently, a strategy of reforming the electric power industry has been developed and is being implemented. It involves a gradual transition to a competitive market, where each business entity will independently determine the volumes of production of electrical and thermal energy and modes of operation. Among the characteristic limitations of the existing principle of control of functioning, the following can be distinguished: the mismatch between the goal of management and modern conditions. Every business entity is interested in increasing its own profit [11, 12]. Therefore, the old criteria and methods of management have become inadequate for management purposes [13, 14]. The presence of these limitations necessitates the development of a different principle and methods for managing the operation of an energy facility. In this paper, it is proposed to use the economic criterion of profit maximization for optimal control of the load of thermal power plants in modern conditions, and also developed a strategy for managing a generating company [15, 16].

2. A mathematical model for controlling the operation of a generating company

As is known, it is necessary to solve the problem of constructing a mathematical model to solve optimization problems. Modeling can be defined as a method of mediated cognition, in which the object under study i.e. the original is in some relationship with another object i.e. a model. The model object is able in some way to replace the original at some stages of the cognitive process [4].

We represent the control object in the form of a black box (figure 1). Mode parameters are divided into several categories. We will distinguish between input and output parameters. In addition, we divide the parameters (input and output) into controlled (index “c”) and non-controlled ones (index “nc”). The latter include those parameters that we either cannot control e.g. weather, power system load, or do not want to control, translating them into uncontrollable, for example, insensitive parameters that have little effect on the objective function. In addition, process parameters can be measurable (index “m”) or non-measurable (index “nm”).

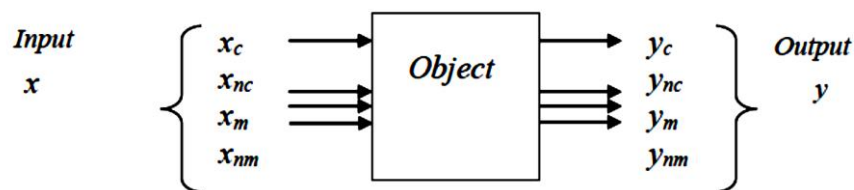


Figure 1. System parameters.

We construct a mathematical model of the most favorable distribution of electrical power between stations or aggregates. We assume that the system has $i = 1, 2, \dots, n$ thermal power plants, for which the flow characteristics $B_i(P_{Ti})$ and total load P_n are known. For this case:

1. The goal equation

$$B = B_1(P_{T1}) + B_2(P_{T2}) + \dots + B_n(P_{Tn}) \Rightarrow \min \quad (1)$$

2. The equation of connection $B_i(P_{Ti})$.

3. Limitations are balance power equations

$$\sum_i P_{Ti} - P_n - \pi = 0 \quad (2)$$

where π is the total loss of active power.

4. To derive the optimization equation, we use the Lagrange method. The use of the method of indeterminate Lagrange multipliers makes it possible to reduce the task to solving a system of algebraic equations.

In some cases, the analytical solution of the problem uses linearization techniques or other idealization of nonlinear dependencies.

$$\Phi = (B_1 + B_2 + \dots + B_n) + \lambda * \sum_i P_{Ti} - P_n - \pi = 0 \quad (3)$$

where λ is a constant Lagrange multiplier.

It should be noted that such a system of equations is compiled for each hour of the day, i.e. there are 24 systems in total.

An analysis of modern methods of mathematical programming (linear and nonlinear, dynamic and the theory of optimal processes) and a general form of the constructed model shows that the only acceptable and possible way to solve this problem is to use non-linear programming methods, namely the Lagrange method.

Let us consider the main provisions of this method as applied to the set task.

Since the expression in the second brackets in expression (3) is zero, the minima of the Lagrange function and the objective function (1) are the same.

Let us differentiate the Lagrange function with respect to variables P_{T1}, \dots, P_{Tn} and equate the derived zero. It should be borne in mind that when we take the partial derivatives of the Lagrange function on the load of the i station, the partial derivative of the consumption of the fuel of the i -th station is

$b_i = \frac{dB_i}{dP_{Ti}}$ only on its load P_{Ti} , and on the loads of all other stations is zero. Then we get:

$$\left. \begin{aligned} \frac{\partial \Phi}{\partial P_{T1}} &= \frac{\partial B_1}{\partial P_{T1}} + \lambda * \left(1 - \frac{\partial \pi}{\partial P_{T1}} \right) = 0; \\ \frac{\partial \Phi}{\partial P_{Tn}} &= \frac{\partial B_n}{\partial P_{Tn}} + \lambda * \left(1 - \frac{\partial \pi}{\partial P_{Tn}} \right) = 0. \end{aligned} \right\} \quad (4)$$

The number of equations of the system corresponds to the number of thermal power plants. It is easy to see from (4) that:

$$\frac{\frac{\partial B_1}{\partial P_{T1}}}{1 - \frac{\partial \pi}{\partial P_{T1}}} = \dots = \frac{\frac{\partial B_n}{\partial P_{Tn}}}{1 - \frac{\partial \pi}{\partial P_{Tn}}} \quad (5)$$

Let us introduce the following denotation: $b_i = \frac{dB_i}{dP_{Ti}}$ is a relative increase in fuel consumption of electric stations, which shows how the fuel consumption of the i -th station will change if its load

changes by the value $\sigma_i = \frac{\partial \pi}{\partial P_{Ti}}$, which is a relative increase in active power losses in networks, i.e. the value indicating how much network losses will change if the power of only the i -th station changes by ∂P_{Ti} .

Applying these notation, we obtain the conditions for the most favorable load distribution:

$$\frac{b_i}{1 - \sigma_i} = idem. \quad (6)$$

If we assume that the active power loss is zero, that is to neglect them, then we get the following expression:

$$b_1 = b_2 = \dots = b_n \quad (7)$$

In this paper, it is proposed to use the economic criterion of profit maximization for optimal control of the load of thermal power plants in modern conditions, and also developed a strategy for managing a generating company [5, 6].

According to the criterion of maximizing profits, the manufacturer will maximize profits by producing products at the point where marginal revenues equal marginal costs. This guiding principle of profit maximization is called the marginal cost rule of marginal revenue. A graphic illustration of this condition is presented in figure 2.

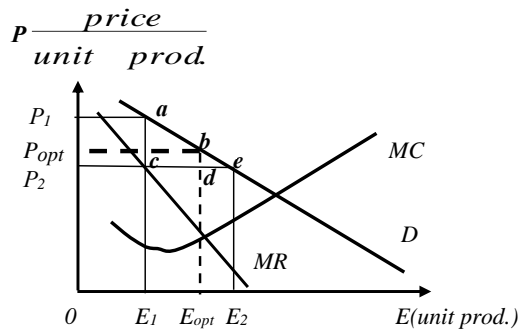


Figure 2. Determination of the optimal production output: D is an energy demand for a specified time interval; E_{opt} is an optimal output for a specified time interval; P_{opt} is an optimal price at the optimal production output.

Marginal revenue (MR) from the sale is determined by the differential demand curve for energy products, and marginal cost (MC) is a differential component of the cost of energy production, which can be represented as a characteristic of the relative increase in fuel costs for thermal power plants. All these values have the same dimension (price / unit prod.), therefore, they can be compared in the calculations [6].

The optimal amount of energy production (E_{opt}) allows the energy company to maximize its profits. Suppose that a smaller number of E_1 products is produced compared to the optimum number, but at a higher price P_1 . In this case, the marginal income of the manufacturer exceeds marginal costs, and by increasing the production volume to E_{opt} , at which an additional profit derived from the release of another unit of production is zero, it would increase the total profit by an amount equal to the area abc .

Larger with respect to the optimal production volume of E_1 also does not maximize profit, since marginal costs exceed marginal revenue. The increase in profit by reducing the volume of production to the value of E_{opt} instead of E_2 corresponds to a value equal to the area bde .

In modern conditions, each economic entity is interested in increasing its own profit, therefore, the proposed method allows to solve the problem of determining the volume of production at the station adequately to the modern conditions of the domestic energy industry.

On the basis of the developed criterion, the following tasks are solved in the paper:

1. The most advantageous distribution of electric energy of thermal power plants for the given values of the tariff for electricity.
2. Distribution of thermal energy between the station's units, taking into account the forced heat and power plants operation mode.
3. Finding the optimal operating modes of the stations for the combined method of producing electric and thermal energy.
4. Appointment of the most favorable operating modes of the generating company.
5. Justification of tariff rates for the products sold, depending on the optimal production volumes at thermal power plants that make up the generating company.

The formulated tasks and stages of their implementation can be represented in figure 3.

Since the main mode of operation of thermal power plants is heat-generating, their operation should be managed taking into account the forced schedule for the release of thermal energy [7]. Therefore, the work examines the question of the possibility of applying the approach to the most advantageous distribution of electricity between the station's units to determine the optimal modes for the production of both types of energy, taking into account the “hard constraints” imposed by the forced operation of the CHP.

3. An optimal distribution of electrical and thermal energy at the stations based on the criterion of profit maximization

The most profitable distribution of electrical and heat energy at the stations in accordance with the conducted analytical analysis. At the same time, various types of restrictions are taken into account, in particular, the forced operation mode of the station according to the heat-generating cycle [8,9].

This problem is solved by several stages. At the first level, the optimal load on the station for electric power, taking into account the forced mode of its work on the generation of thermal energy. Then assignment of optimal operation modes of the stations by thermal energy is carried out. At the final stage, the corresponding work and their mutual coordination is performed.

Let us dwell in more detail on the solution of these issues.

To determine the optimal power plant, the following tasks must be solve:

Construction of the characteristics of the relative increase of the station fuel consumption for given compositions of operating equipment for the seasons of the year.

Getting the dependencies of the marginal costs of stations for each of the seasons.

Finding the optimal electrical power and the corresponding values of the stated price.

To obtain the dependencies of the marginal costs of the station, we used the characteristics of relative increments in fuel consumption, taking into account the average seasonal prices for purchased fuel.

The characteristics of marginal revenue are built on the basis of the demand curves for electrical energy as follows:

$$\frac{\Delta TR}{\Delta E_{ou}} = MR = p + E_{ou} \frac{\Delta p}{\Delta E_{ou}} \quad (8)$$

where $\frac{\Delta p}{\Delta E_{ou}}$ is a slope of the demand curve, i.e. marginal revenue represents the derived demand for electricity;

ΔTR is an increase in total revenue from power generation;

Δp is a change in electricity prices;

ΔE_g is a change in power generation.

For the station, as a characteristic of demand, it is possible to take the characteristic of the cost of production of electric energy, which can be adjusted by the value of the rate of profit. The real demand curve is piecewise due to the variable nature of energy consumption. However, in practice, an

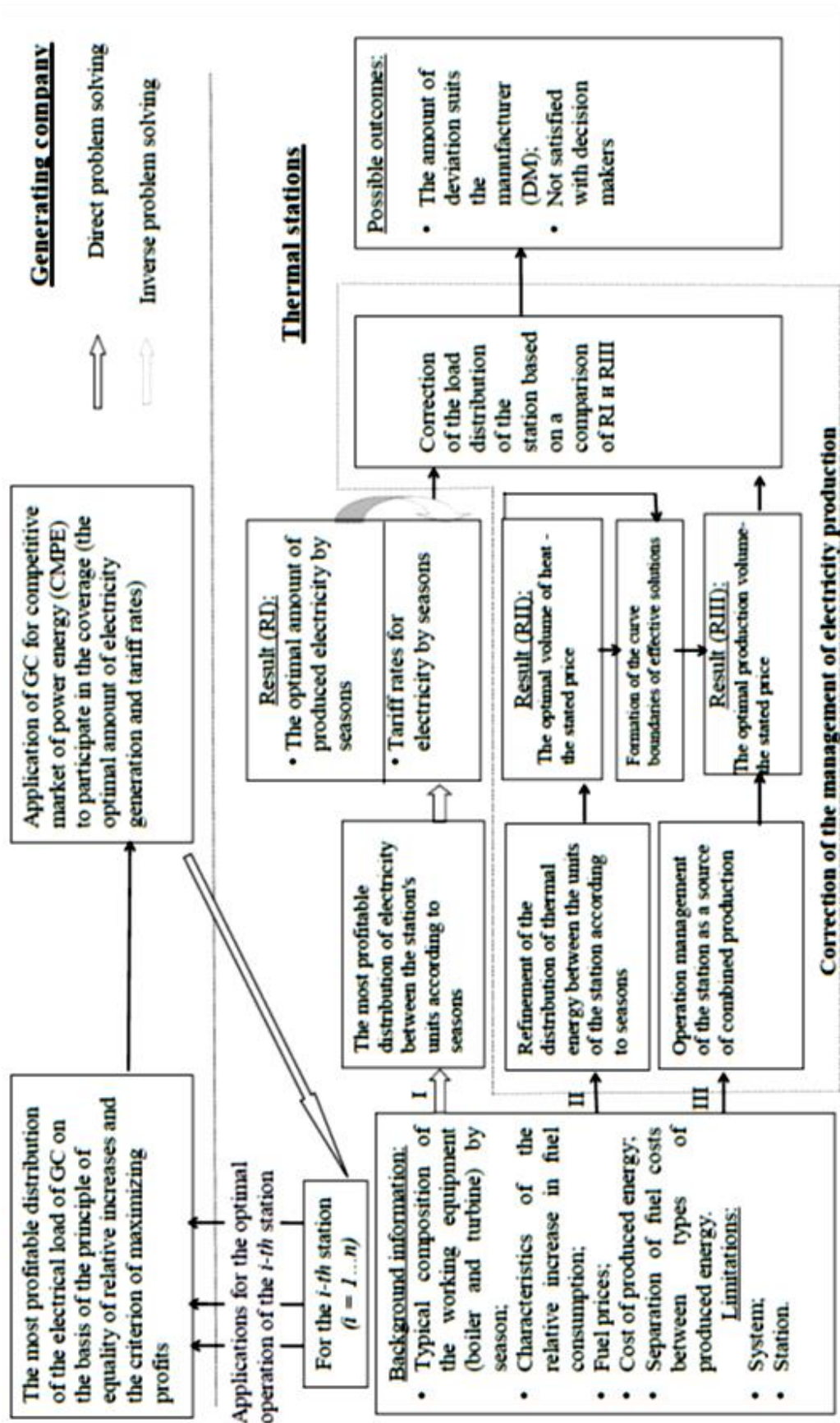


Figure 3. Logic diagram of market generation company functioning.

approximation of these dependencies is used, selecting for this the corresponding polynomials. Approximate dependencies of cost and demand for electricity are shown in figure 4.

Since energy consumption has a pronounced seasonal nature, it is advisable to consider three demand curves: Zone I (figure 4) corresponds to summer consumption; Zone II (figure 4) is for the transition period (spring-autumn) and, finally, Zone III (figure 4) is for the consumption of the winter period. Each curve can be approximated by the corresponding polynomials [10, 11].

Jointly solving the system of equations describing the curves of marginal costs and marginal revenue, you can determine the optimal values of the average monthly production (E_{opt}) for each season and the average daily capacity:

$$N_{opt} = E_{opt} / t_{month}, \quad (9)$$

where t_{month} is an average number of hours per month (720 h).

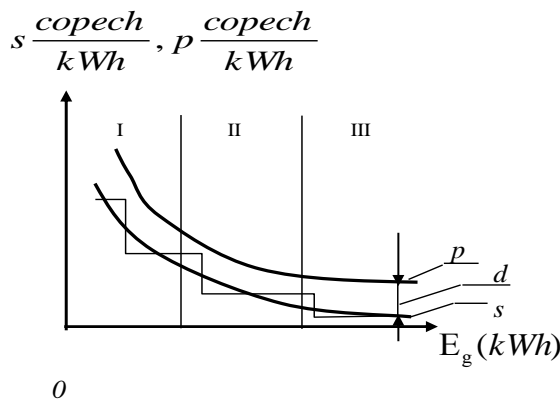


Figure 4. Curves of electricity production cost and electricity demand: s is an electricity production cost, p is an electricity price, E is an electric power released from the station buses, $s = f(E)$ is the electricity production cost function, $D = p = f(E)$ is the electricity demand function derived as the sum of electricity production cost and profit rate, i.e. $p = s + d$.

On the basis of the proposed approach, the work shows the possibility of solving two important and interrelated tasks of controlling station operation modes:

To determine the optimal range of its generation at the power plant, with the tariff for electricity, which is formed in the modern conditions of functioning of the CHP.

It is possible to substantiate the size of the stated price in the power system, based on the optimal power generation at the stations.

As already noted, the calculation of the optimal load of a thermal power plant by electric power is carried out taking into account the forced mode of operation of a thermal power plant by thermal energy [12].

However, the use of this approach allows you to check the loading of the station by thermal energy.

The problem of optimal distribution of thermal energy at the station is solved step by step according to a model developed for the most advantageous distribution of electrical energy [13].

Let us consider the possibility of using the developed model of the optimal distribution of electricity between the station's units to determine the modes for the production of both types of energy, taking into account the "hard constraints" imposed by the forced operation mode of the CHP [14].

To solve this problem, it is necessary to determine the optimal range within which further optimization of station modes is allowed due to a change in turbine selections and variation of electric power generation volumes. A graphic illustration of the solution to this problem is shown in figure 5. Suppose, for example, point 1 corresponds to the optimal mode for the production of electricity, and point 2 - by thermal energy. Then the modes, characterized by a change in the selection of turbines and the variation of electric power, correspond to intermediate points 3, 4 and 5.

Consider the following options for changing the selections at the station.

The first boundary variant is characterized by the optimal loading of the station by electric power at given thermal energy selections. In this case, the optimization criterion is the maximum profit from the production of electric energy.

The second boundary variant is characterized by optimal loading of the station by thermal energy. At the same time, the proposed principle of station operation control is used.

It should be noted that the value of electrical power in the optimization of thermal energy (N_{el2}) is based on the following expression:

$$N_{el2} = N_{el20} + N_{const}, \quad (10)$$

where N_{el20} is the power value corresponding to the optimal load of the station for thermal energy;

N_{const} is the constant component of electric power corresponding to the difference (according to the consumption characteristic) difference of the average for the season of the actual value of the supply of thermal energy and heat load, which is determined by the optimal amount of electricity generation.

Intermediate calculations of the station operation modes vary within the first and second boundary variants [15].

The obtained points form a curve of effective solutions, which is proposed to be used to find the optimal operating modes of the station with the combined generation of electrical and thermal energy [16].

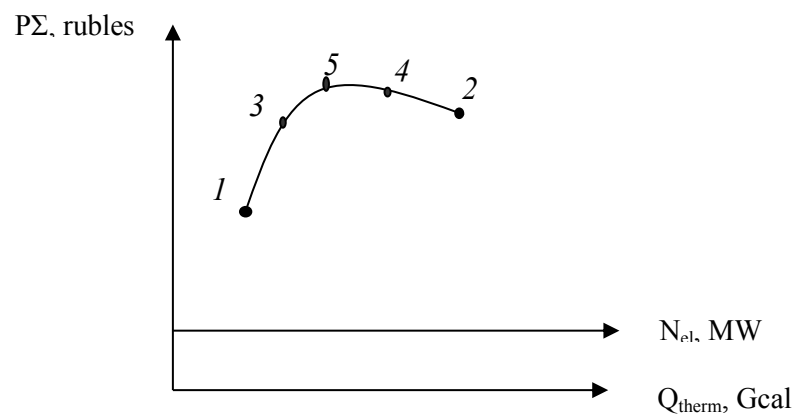


Figure 5. Dependence of total station profit on electric power (heat energy).

The optimal criterion of the combined method of producing electric and thermal energy will be the maximum of the total profit P_{Σ} :

$$P_{\Sigma} = P_E + P_Q \Rightarrow \max \quad (11)$$

where P_E is a profit from the production of electricity;

P_Q is a profit from the production of heat energy.

In this case, it may be that the solution obtained will give serious deviations in the production of electrical and thermal energy at the station.

Therefore, the paper proposed a method for adjusting the production of electric power by the optimal value of heat [17].

To do this, it is necessary to calculate the deviation (Δ) of the optimal generation of electric energy (obtained with a strictly specified selection) with the optimal mode, which is calculated based on criterion (11):

$$\Delta = \frac{\Delta_w * \mathfrak{O}_w + \Delta_s * \mathfrak{O}_s + \Delta_t * \mathfrak{O}_t}{\mathfrak{O}_w + \mathfrak{O}_s + \mathfrak{O}_t} \quad (12)$$

where $\Delta_w, \Delta_s, \Delta_t$ is the deviation for the winter, summer and transition periods, respectively;

$\mathfrak{O}_w, \mathfrak{O}_s, \mathfrak{O}_t$ is an optimal power values for the characteristic season of the year.

The proposed model allows distributing fuel costs between the types of energy produced by the criterion of profit maximization, taking into account mode constraints.

4. Management of operating modes of thermal power plants as a combined production sources

The next iteration is the practical implementation of the models proposed in the article for determining the optimal operating modes of the CHP-2, CHP-3, CHP-4, CHP-5 in Novosibirsk.

In accordance with the proposed approach, it is necessary to calculate the boundary and intermediate energy production options at the stations (figure 5). Then, according to criterion (4), determine the optimal mode of operation of each of the above stations by electrical and thermal energy.

As a general note, it should be noted that all calculations are carried out for given compositions of operating equipment [18-20].

Table 1 shows the composition of the operating equipment of NCHP-4 by seasons of the year:

Table 1. Typical operating equipment structure at the Novosibirsk CHP-4.

Season	Boilers				Turbines	
	ТП-170	ТП-81	ЦКТИ-75-39	ПТ-22-90	T-100-130	T-24,5-90
Winter (months XI,XII,I,II,III)	4	3	—	2	3	1
Summer (VI,VII,VIII)	2	1	1	2	2	—
Transition period (IX,X,IV,V)	2	3	—	2	3	—

In figures 6, 7 and 8 showed characteristics of the relative increase in fuel consumption, marginal costs and marginal revenue for the winter period of NCHP-4, respectively.

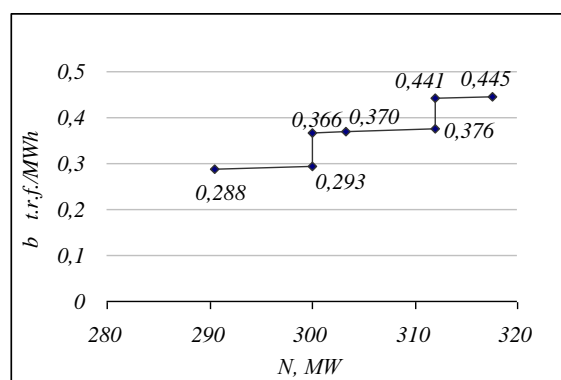


Figure 6. Characteristics of the relative increase in fuel consumption of NCHP-4 for the winter period.

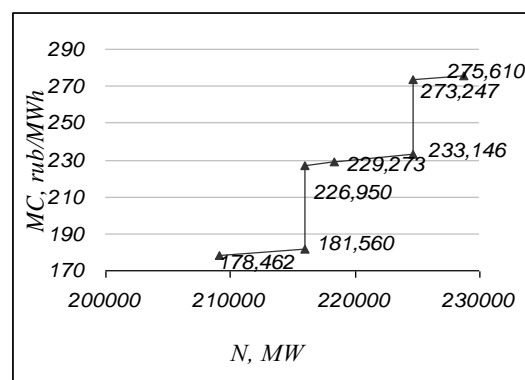


Figure 7. Characteristics of the marginal costs of NCHP-4 for the winter period.

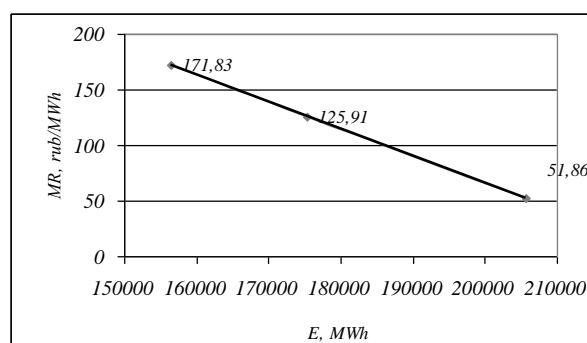


Figure 8. Marginal revenue curve of NCHP-4 for the winter season.

The results of calculations according to the developed principle of controlling the operation of a power generation station are presented in table 2.

Table 2. Optimum values of power for the seasons of the year for NCHP-4.

Season	Winter		Transition period		Summer	
Profit rate	0%	12%	0%	12%	0%	12%
N, MW	220	234	151	166	39	41
E, MWh	158702	168394	109058	119635	28412	29716
Stated price, rub/MWh	560	650	600	800	1500	1700
Revenue, rubles	285807009	331995964	152955789	185715182	76410172	88707757
Profit, rubles		46188955		32759394		12297585

The range of changes in the generation of electricity of NCHP-4 for the winter period is 158702-168394 MWh. In this case, the stated price of electricity will be from 360 to 394 rub/ MWh; for the transition period of 109058-119635 MWh with the stated price from 351 to 388 rub / MWh, respectively. For the summer period, these values are equal to 28411-29715 MWh and 896-995 rub / MWh.

Table 3 shows the results of verification of the volumes of electricity generation using the existing (the principle of minimizing fuel costs) and the criterion developed by the author to control the operation of stations.

Under the second boundary option is understood this mode of operation, which is characterized by the optimal load for the production of thermal energy.

This problem is solved for a given composition of operating equipment at the station [21-23].

In accordance with the developed approach, the characteristic of the relative increase in the station's fuel consumption is obtained on the basis of the characteristics of the boiler shop, by extracting from it a component that corresponds to the supply of heat energy to the CHP plant. Below are the results of the implementation of the developed approach for calculating the station heat load on the example of the winter period of the NCHP-2 (table 4).

A comparison of actual and optimal volumes of electricity generation shows that the use of the principle of profit maximization allows us to obtain solutions belonging to the range that took place with the existing criteria for managing the operation of thermal power plants.

According to the results of the implementation of the developed approach at NCHP-4, the specific fuel consumption for power generation was saved on the order of 5, and in some cases 10 g / kWh.

For NCHP-2, the range of change in heat supply for the winter period is 215450-229629 Gcal. In this case, the stated price of thermal energy will be from 142 to 163 rub / Gcal. Similarly, for the transition period is 165126-191910 Gcal with the stated price ranging from 156 to 175 rub / Gcal, respectively. For the summer period, these values are 52232-56255 Gcal and 195-216 rub / Gcal.

Table 5 summarizes the results of verification of heat generation volumes using the existing and proposed by the author optimization criterion. A comparison of actual and optimal volumes of electricity generation shows that the use of the principle of profit maximization allows us to obtain solutions belonging to the range that occurred with the existing criteria for controlling the operation of thermal power plants.

As a result of the calculation of intermediate optimal variants of station operation modes as a combined production, an efficient decision curve is obtained, which allows making decisions on the most advantageous distribution of electrical and thermal load between units at CHP. For an example in figure 9 shows the curve of effective solutions for the winter period of NCHP-4.

Table 3. Verification of electricity generation volumes.

Season	Winter		Transition period		Summer	
CHP	Rate of production E, MWh	E_{opt} , MWh	Rate of production E, MWh	E_{opt} , MWh	Rate of production E, MWh	E_{opt} , MWh
NCHP-2	147300-238000	155685	85600-150000	88213	23900-87400	65500
NCHP-3	176000-257040	191890	89280-221760	150057	23600-76320	62554
NCHP-4	156486-234964	168393	38518-121769	119635	23577-32766	29715
NCHP-5	295200-666000	408000	207360-547200	280000	115200-288000	158000

Table 4. Optimal value of power output at the Novosibirsk CHP-2 for seasons of the year.

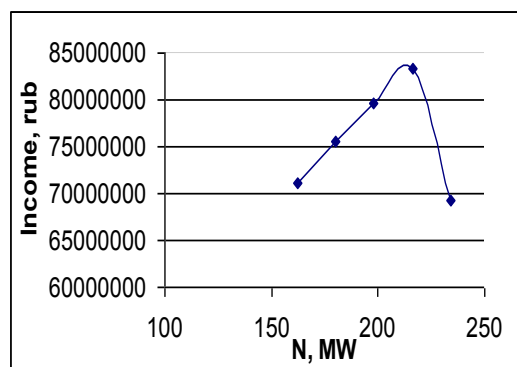
Season	Winter		Transition period		Summer	
Profit rate	0%	12%	0%	12%	0%	12%
Q_{opt} , Gkal	215450	229630	165126	191910	52232	56255
Stated price, rub./Gkal	145	163	156	175	195	216
Revenue, rubles	153101233	186633440	103032019	134347042	30607245	36408433
Profit, rubles		33532207		31315023		5801188

Analysis of the obtained results shows that for the NCHP-2 in the winter period it is advisable to produce 216 MW (348942 Gcal), in the summer is 91 MW (79149 Gcal) and for the transition period is 146 MW (191910 Gcal); for NTEC-4 in winter, the optimal load is 253 MW (356589 Gcal), in the summer is 59 MW (81282 Gcal) and for the transition period is 210 MW (264725 Gcal). It is these modes of operation that will allow stations to get the maximum profit for each season of the year.

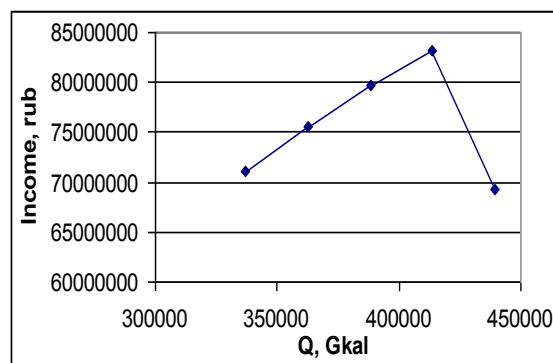
The possibility of applying the approach to managing the operation of CHP for the production of electricity to find the optimal operating conditions of the plant as a combined production in modern conditions allows us to judge the amount of deviation found by expression (11). For NCHP-4, it is 13%, for NCHP is 2 - 4%.

Table 5. Thermal power production volumes comparison.

Season	Winter		Transition period		Summer	
CHP	Rate of production Q , Gcal	Q_{opt} , Gcal	Rate of production Q , Gcal	Q_{opt} , Gcal	Rate of production Q , Gcal	Q_{opt} , Gcal
NCHP-2	223400-352600	229630	62700- 196900	191910	45000- 70000	56255
NCHP-4	336081-499962	356589	93126- 269552	264725	533331- 109444	106640



a)



b)

Figure 9. Determination of the optimal operation mode of the NCHP-4 (winter) by: a) electric power, b) thermal energy.

5. Management of operating modes of the generating company

The task of managing the operation of the generating company (GC) is solved on the basis of the obtained optimal operating conditions of thermal power plants that are part of it.

The principle of interaction within the generating company is as follows:

each station included in the group of companies calculates and transmits its optimal mode of operation (for each of the seasons of the year) taking into account the station and system limitations, indicating the volume of possible supplies and the stated price for electricity;

GC, having collected applications from CHP, loads the stations in an optimal way, guided as an optimization criterion by the rule of profit maximization;

on the basis of regimes, energy supply contracts are concluded with manufacturers with detailed deliveries by month, working day, holidays and weekends.

For the described principle of interaction within the GC, an approach has been developed that allows one to calculate the range of optimal volumes of electricity generation, based on the criterion of profit maximization.

The implementation of the approach is carried out sequentially according to the model proposed for controlling the operation of CHP.

As a result of the optimization of the operating mode, the Communications Department of the GC submits its application for participation in the coverage of the total load schedule of the consumer.

It should be noted that this application has the character of “solid supplies”, which the management of the GC undertakes to deliver to the CMPE [24-26].

All calculations were made for the generating company on the basis of the Novosibirsk CHPs based on data on the operating modes of the stations, as well as information on the average monthly values of fuel prices and the cost price of the products sold. The results of the calculation according to the developed methodology are given in Table 6.

Table 6. Optimal power generation for the generating company.

Season	Winter		Transition period		Summer	
Profit rate	0%	12%	0%	12%	0%	12%
Electricity output, MWh	489300	554900	129250	143690	343370	388100
Stated price, rub/MWh	1150	1275	2500	2750	1670	1800

Analysis of the obtained results shows that the range of changes in the power generation of the station for the winter period is 489300-554900 MWh. In this case, the stated price of electricity for the group of companies will be from 52 to 57 copecks/ kWh. Similarly, for the transition period 343370-388100 MWh with the stated price from 89 to 99 copecks/kWh, respectively. For the summer period, these values are equal to 129250-143690 MWh and 127-142 copecks/kWh. It is with this proposal that the GC can enter the CMPE. Thus, the developed mathematical model allows to provide significant competitive advantages of the Russian energy industry [27].

6. Conclusion

The most significant results obtained are formulated, which should include the following:

A mathematical model has been developed for controlling the functioning of the GC in modern conditions;

A critical analysis of the existing criteria for the management of electric power system, which are not suitable in market conditions, has been carried out;

A criterion for controlling the operating modes of an energy facility that combines the technological features of the energy industry with new economic controls is proposed;

Principles and methods for managing the operation of a thermal power plant for the production of heat and electricity based on the principle of profit maximization have been developed;

A comprehensive methodology has been created for distributing fuel costs between the types of energy produced at CHP by the criterion of profit maximization;

A method has been developed for obtaining optimal operating conditions for thermal power plants that form a generating company, based on the principle of maximizing profits;

The calculated and experimental verification of the developed approaches and methods was carried out, as well as the implementation of the main provisions of the research at specific sites was carried out.

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