Methodological Approach to Energy Consumption Management at Industrial Enterprises

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1 Introduction

In conditions of globalization and increased international competition, the issue of energy efficiency increase is one of the most vital in the world economy [1]. The task of energy efficiency increase is particularly important in the industrial sector, whose share of energy consumption in the total energy balance of most energy-intensive countries of the world, such as Russia, Finland, and Germany, considerably exceeds worldwide average indices (Fig. 1).

Most research devoted to industrial energy efficiency increase is focused on obtaining a result in the production and technical environment of enterprises. At the same time, a significant share of reserves of reduction in industrial energy consumption remains in the environment of energy consumption planning, organization, and control. The task of development of methods and tools for energy efficiency increase in the planning environment has become most vital after the development of energy market mechanisms [4]. The main and, at the same time, the less studied line of energy efficiency increase is the development of methods and mechanisms based on the tools for forecasting of energy consumption parameters.

The cost of electric energy purchased by industrial enterprises in the energy market consists of several components, the basic ones being electric energy and electric power. All industrial enterprises also pay for services tradable outside market

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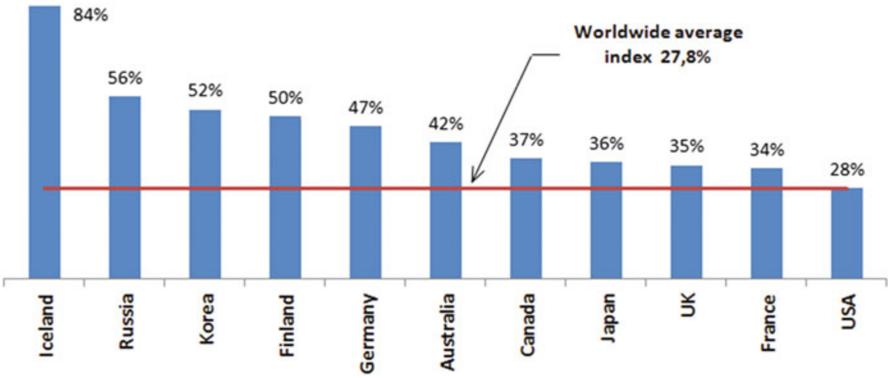

Fig. 1 Share of industrial energy consumption in several countries [2, 3]

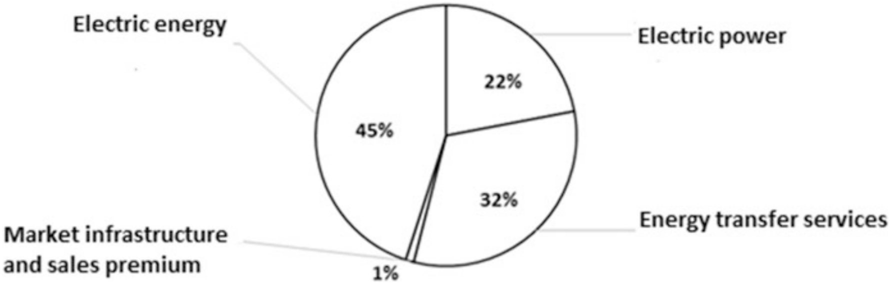

Fig. 2 Structure of costs on industrial enterprises' purchase of electric energy in the Russian energy market

relations – the service on transfer and provision of the market infrastructure, whose tariffs are regulated by the state (Fig. 2). It should be noted that the tools offered can also be used by industrial enterprises of different countries, as the energy market model of Russia is developed on the basis of energy markets functioning worldwide [5, 6].

2 Research Methodology

Based on the electric energy cost components, as well as pricing characteristics in each component, we offered an overall structure of methodological approach to energy consumption cost planning (Fig. 3). The basis of the model is division of energy consumption components into electric energy and electric power, as well as division of energy consumption impact environments into process and market [7].

The electric energy cost planning model is based on the two-level mechanism grounded in short-term forecasting of the industrial enterprise energy consumption

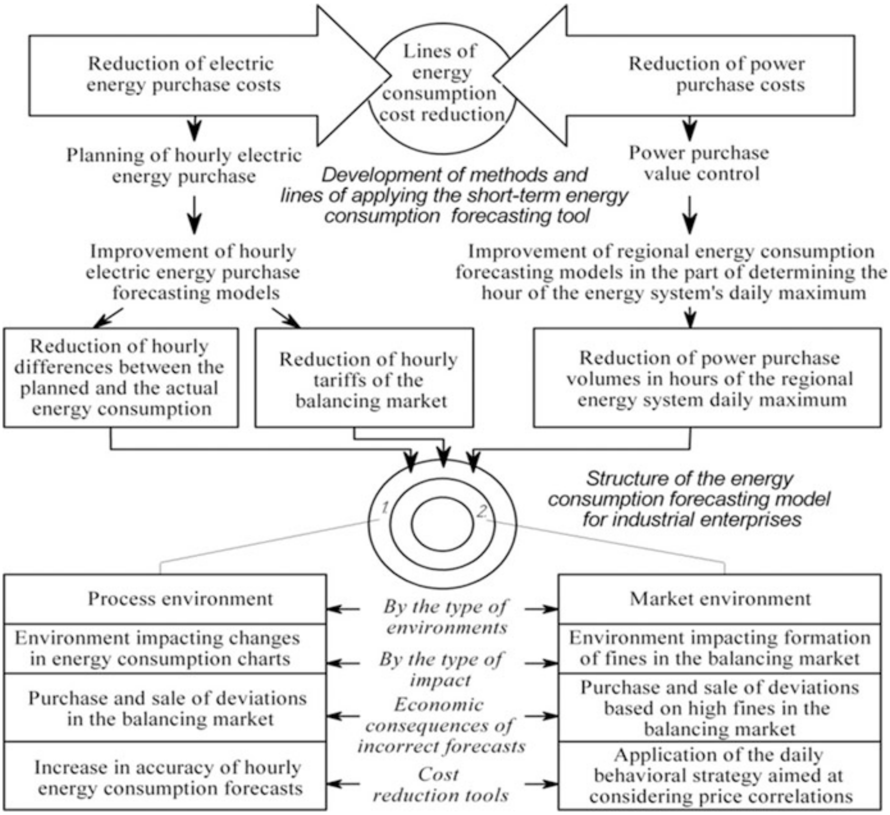

Fig. 3 Structure of the methodological approach to industrial enterprises energy consumption cost planning

parameters and considering the market environment factors (Fig. 4). The electric energy price consists of two components – the price of planned volume ordered by the enterprise for purchase one day before the actual electric energy delivery date and the price of deviations of the actual energy consumption volume from the planned one. Incorrect forecasting of hourly electric energy purchasing plans leads to appreciation of the electric energy cost in the form of fines for each error [8].

However, even at the highest accuracy of hourly energy consumption planning, due to the impact of many factors, errors in plans and, consequently, fines are inevitable. In this connection, during purchase of electric energy in the energy market, in our opinion, it is necessary to forecast and account for price factors forming fines or, in other words, market environment factors, which will allow one to reduce fines (see Fig. 3).

We propose to consider the market environment factors by forecasting the most favorable directions of deviations between planned and actual hourly energy

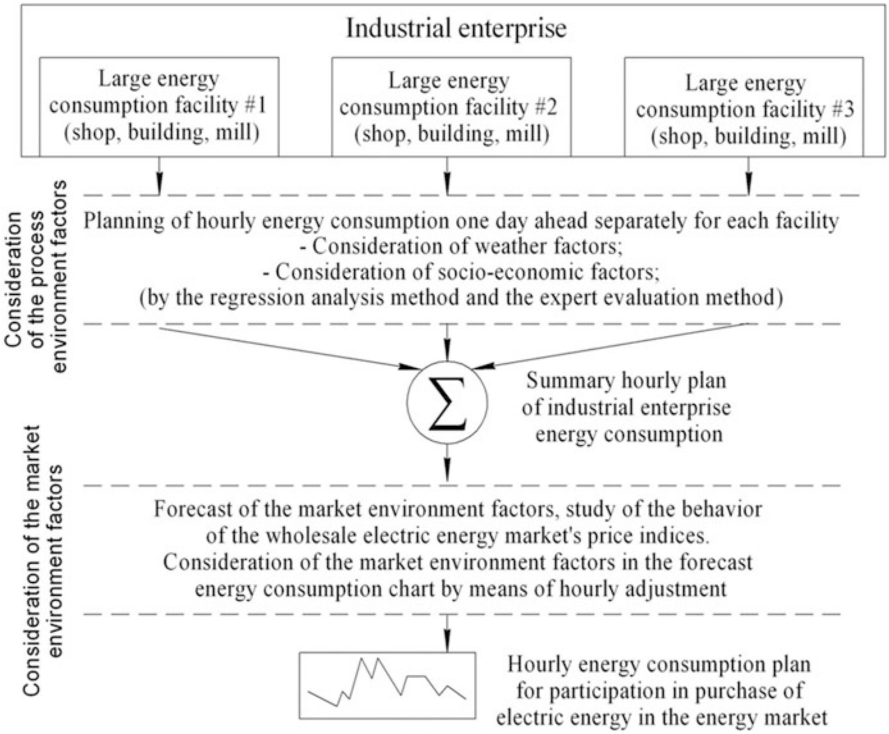

Fig. 4 Structure of the electric energy purchase cost planning model

consumption volumes and further adjustment of hourly plans in the knowingly favorable direction in terms of fines minimization [7].

The amounts of hourly fines for deviations in the balancing market are calculated as the difference between the price of the day-ahead market (PDAM) and the price of the balancing market (PBM) (Eqs. (1) and (2)). This is preconditioned by the fact that the market participant in any case purchases electric energy at the scheduled energy consumption price – PDAM, therefore, expenses incurred above the planned value prices are taken as fine amounts (Eqs. (3) and (4)).

Deviation purchase price:

$$P_{BM} \text{ purchase} = \max \ (P_{DAM}; P_{BM}), \tag{1}$$

deviation sales price:

$$P_{BM} \text{ sale} = \min(P_{DAM}; P_{BM}), \tag{2}$$

where P_{BM} purchase – purchase price in the balancing market; P_{BM} sale – sales price in the balancing market; P_{DAM} – price of the day-ahead market; P_{BM} – price of the balancing market.

Table 1 Combinations of different correlations of prices and volumes in the balancing market

№	Correlations		Market transaction	Calculation formula	Transaction price	Wholesale market participants' behavior strategies
	Price	Volume				
1	$P_{BM} > P_{DAM}$	Vplan > Vact	Sale	Min (P_{DAM}; P_{BM})	P_{DAM}	Sale of excessively purchased volume at a lower price. Fine in the form of price difference
2	$P_{BM} > P_{DAM}$	Vplan < Vact	Purchase	Max (P_{DAM}; P_{BM})	P_{BM}	Purchase of deficient volumes at the same price as planned volumes. No fines
3	$P_{BM} < P_{DAM}$	Vplan > Vact	Sale	Min (P_{DAM}; P_{BM})	P_{BM}	Sale of excessive volumes at the same price as planned volumes. No fines
4	$P_{BM} < P_{DAM}$	Vplan < Vact	Sale	Max (P_{DAM}; P_{BM})	P_{DAM}	Purchase of deficient volumes at a higher price. Fine in the form of price difference

Fine amount upon purchase:

$$P_{BM} fine_{upon\ purchase\ hour} = \max(P_{BM}; P_{DAM}) - P_{DAM}, \quad (3)$$

fine amount upon sale:

$$P_{BM\ fine\ upon\ sale\ hour} = |\min(P_{BM}; P_{DAM}) - P_{DAM}|, \quad (4)$$

where $P_{BM\ fine\ upon\ purchase\ hour}/P_{BM\ fine\ upon\ sale\ hour}$ – fine amount upon electric energy purchase and sale in the balancing market for one specific hour (rub/MWh).

Analysis of the variants of directions of price relations in the day-ahead market and the balancing market and mutual deviations of planned and actual energy consumption volumes allowed one to outline combinations, upon occurrence of which market participants do not incur losses in the part of payment of fines in the balancing market, in spite of inconsistencies between forecast and actual hourly energy consumption values (Table 1). The outlined correlations formed the basis of an energy consumption forecasting model and formation of electric energy purchase bids in the energy market.

Then, we will consider in detail the approach to electric power purchase cost planning. The amount of liabilities is calculated for each month and determined as an arithmetical average of electric power consumption values in the hour of the daily maximum of working days of the electric energy system of the region, where the industrial enterprise purchases electric power (Eq. (5)):

$$\bar{P}_{month} = \frac{\sum_{i=work.days}^{n} (P_i \in t_{maxi})}{n_{work.}} \quad (5)$$

where $\bar{P}_{month}$ is the amount of liabilities on purchase of power (MW·month.), n_{work} is the number of working days in the estimated month, P_i is the amount of the industrial enterprise's power in the hour of the daily maximum of the region's electric energy system (MW), and t_{maxi} is the number of hour, when the daily maximum of the region's electric energy system is formed.

3 Practical Application of the Considered Approaches

In the course of application of the proposed mechanism at the industrial enterprise, the main task is forecasting of the hour of the daily load maximum of the electric energy system of the region, where electric power is purchased. An example of diagrams of shares of distribution of hours of the energy systems' load maximum for two regions is presented in Fig. 5.

As a result of empirical analysis of hourly daily charts of electric energy system load of Russian regions, we have outlined and generalized factors impacting the formation of the daily maximum's hour (Table 2).

Taking into account the outlined factors in the formalized model will allow one to forecast the daily maximum's hour for the energy system of any region with a sufficient degree of probability.

The obtained forecast shall be further considered while organizing the industrial enterprise production processes, which, in its turn, will allow the power purchase expenses to be cut down.

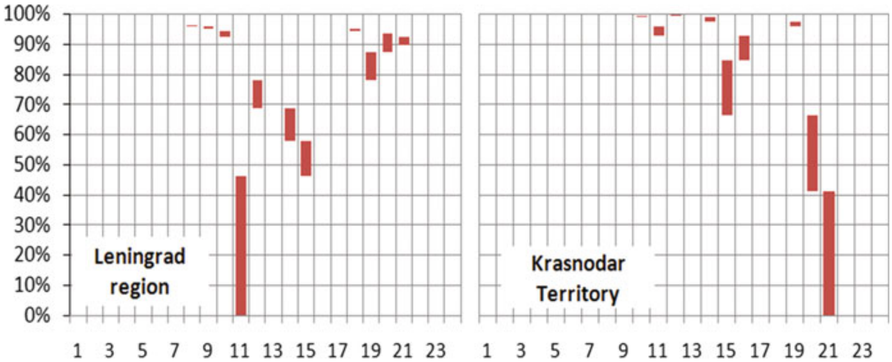

Fig. 5 Diagrams of shares of distribution of hours of the energy system energy consumption maximum during working days of 2013 (Moscow time)

Table 2 Summary table reflecting the impact of factors on parameters of the hourly daily chart of the regional energy system load

Impacting factors	Factor sphere of impact				Degree of impact on the peak load maximum hour
	Total energy consumption value	Hourly chart form	Morning peak form	Evening peak form	
Climate and geographical conditions of the region location	+	+	+	+	High
Time zone		+	+	+	Average
Planned hours of the energy system peak load			+	+	Below average
Level of the region socioeconomic development	+	+	+	+	High
Share of energy consumption by the region industry	+	+	+		Average
Length of the light day		+	+	+	Average
Season	+	+	+	+	High
Month	+	+	+	+	High
Type of the week working day		+	+	+	Average
Individual features of the region energy consumption	+	+	+	+	High
Climatic changes in the region	+	+	+	+	High

4 Conclusion

The methodological approach developed allows management of energy expenditures on purchase of both electric energy and power in an integrated manner. Planning of purchasing costs of electric energy does not only increase forecast accuracy but also accounts for the market environment factors, which allows one to significantly reduce losses preconditioned by the energy market penal sanctions even in the presence of errors in hourly plans. In planning power purchase costs, the model proposed also accounts for the regional energy system daily maximum hour, which allows one to considerably reduce the amount of power payment liabilities at an insignificant change of production process charts.

The practical importance of the methodological approach lies in its universality and applicability to different types of industrial enterprises, irrespective of energy consumption volumes, field characteristics of load patterns, as well as regions purchasing electric energy [9]. The practical approval of the model at industrial enterprises underlined its ability to reduce the number of hourly plan errors by up to

5%, to cut down expenses on fines connected with outlining the market environment factors by 10%, as well as to lower power payment liabilities by 10–50%. Reduction of the total energy consumption cost due to using the complex of proposed methods ranges from 2% to 20%.

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