Electricity consumption management at competitive electricity market

V.P. Oboskalov, T.Y. Panikovskaya

Abstract - The paper presents the analysis of the effect of energy consumption limitations on the consumer's profit in the short-term perspective. The consumer's profit is represented by the difference between the return and energy purchase costs, other costs as well as the consumer's loss in case of energy delivery limitations.[1].

***Key words*: competitive electricity market, load control, loss from electricity-a consumption constraint, price bid.**

I. INTRODACTION

At the initial stage of competitive relations introduction most countries normally use the centralized auction sale model with determination of spot price (short-term price) on every time frame. Spot prices can vary dramatically at the time of peak demand and off-peak load, over a number of days, etc. The reduction of capacity of links in an energy-supply system can also lead to the rise of competitive prices for the consumer due to redistribution of power flow and delivery of energy by alternative routes.

Load control or partial consumption constraint at peak hours or in emergencies with rebate of costs can interest the consumer. Moreover, reduction of energy consumption at peak hours and shift to off-peak periods results in leveling of overall load graph and contributes to energy-saving.

II. CLASSIFICATION OF METHODS OF ELECTRICITY CONSUMPTION MANAGEMENT

Rise of prices on fuel resources and considerable deprecation of power stations in Russia against the insufficient financing of reconstruction of the existing generating capacities and construction of the new, efficient ones requires search of new solutions targeting reliable and high-quality provision of consumers with electricity. Foreign practice proposes a set of measures aiming at solving the problem of providing the load at peak hours, which is called DSM (demand-side management) or consumption management [1, 2, 5, 6]. Existence of peak loads results in price rise at electricity markets and from economic point of view it corresponds to deficient supply. As a result, consumer incurs greater energy purchase costs while the suppliers (generating companies) use the least efficient electric equipment at these hours. A possible solution to solve the problem is to encourage the consumer to manage their demand and reasonable price bidding.

Traditionally, demand-side management includes the measures aiming at (Fig. 1):

- Increasing energy efficiency (general decrease in energy consumption);
- Demand response or Load management (leveling of the load graph by peak clip-

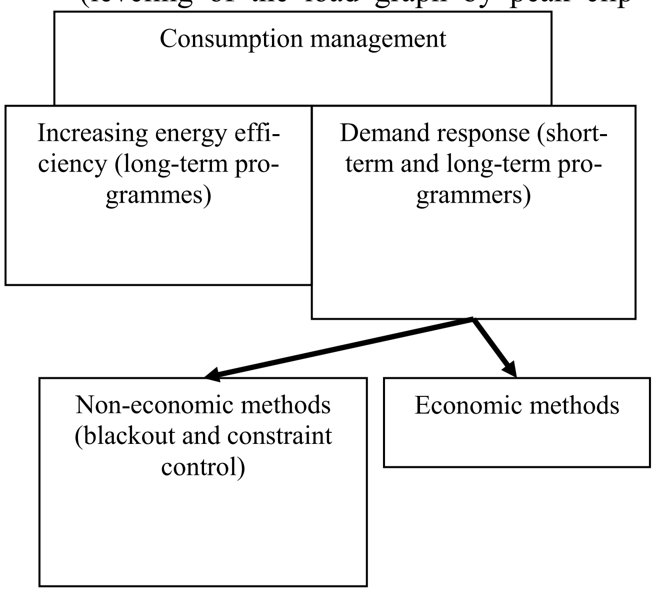

Fig. 1. Classification of consumption management programmes

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ping, shifting the load to valley times and valley filling).

Demand response can be defined as a set of measures, targeting at alteration of the patterns of use of energy consumed by end users in response to cost variation with time or due to rebate, developed to encourage decrease in consumption at peak hours or in case of threat to energy supply system functioning. Such variation of energy consumption in Russia is called voluntary load constraint [2].

To analyze the possibility of voluntary load constraint fist of all we should consider consumer classification from the point of view of their participation in electricity markets. We can divide the existing in Russia electricity markets into two types:

- wholesale market implemented in two price zones: European and Ural zone and Siberian zone – such market involves such market players as export-import operators, energy supplying companies, last resort providers, big enterprises.

- retail markets functioning in various price zones, market players of which involve local power stations and consumers. Their interaction is possible though distribution companies, last resort providers and energy supply companies.

For industrial consumers, last resort providers and energy supply companies, as the wholesale market players, the possibility of gradual change in load power is rather infrequent. In case it is necessary to reduce consumption one can distinguish three kinds of limitations:

- the first one consists of least important for technological process and auxiliary loads

- the second one involves the loads switched off with the least loss to the enterprise

- the third one features loads the switching of which is possible without suspension of major production

- the fourth is the partial or complete suspension of production.

At present, commissioning the new generating capacities lags behind the energy consumption in Russia; besides, the problem rapidly compounds in complexity due to existing generating capacities aging. To solve the problem of improving the energy consumption reliability and safety, maintaining the power system stable operation as well as optimizing the electric energy cost, the following solutions can be proposed:

- limiting the energy consumption during the peak load periods and shifting it onto the off load periods;

- making long-term bilateral contracts on energy and power purchasing;

- locating the low capacity sources (distributed generation) near the consumers;

- introducing energy saving technologies into goods and services production.

The first two solutions can be implemented in a short-term perspective without additional investments, while the last two are impossible to realize without significant financial and time resources.

III. CONSUMER PRICE BID MODELING

3.1 Consumer price properties modeling

Now we will study consumer price properties more closely. While considering price bids (PB) consumers rely upon the price property, which expresses the significance of every unit of electricity consumed [4]. Such evaluation originates from time perspective of strategic or operative planning.

In operative planning the most important thing is assessment and consideration of the loss from dramatic increase in electricity price while sustaining the planned consumption or reducing it. In strategic planning there is a possibility of rearrangement or modification of production.

Generally, consumption price property (PP) has the structure illustrated in detail at the graph

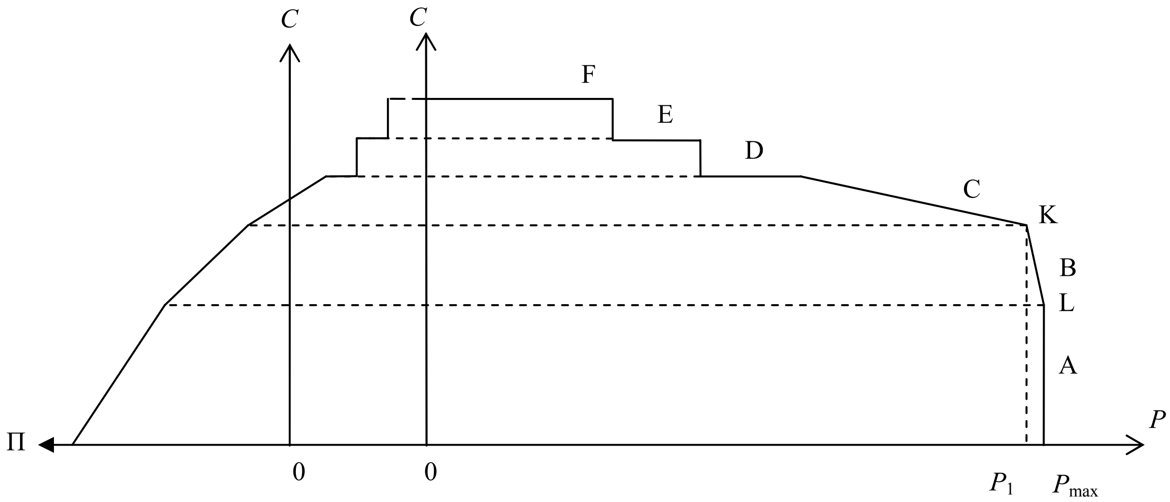


Fig. 2. Consumer price properties

below (Fig. 2), where horizontal axis represents two values – load power (on the right) and company's profit (on the left). Figure 2 also shows a number of typical zones.

A is a zone without electricity constraint so the price variation only influences the company's profit, which remains above the marginal level, but decreases with the price increase. Costs for more expensive electricity are transferred to the price of the goods.

B – The increase in electricity price results in the commodity price increase, which, in its turn, reduces its competiveness and ends up in demand decrease and reduction in production.

Technology and organization of major production remain intact. There is a possibility of slight consumption constraint by shift of auxiliary production (manufacture and maintenance of the manufacturing equipment, repair of business buildings and structures, manufacture and maintenance of technological equipment etc, mechanical, maintenance, etc workshops) to another part of day. Profits rapidly drop (if the maximum permissible level is maintained).

C If the electricity prices continue rising rearrangement of manufacture is necessary (consumption constraint at peak hours and transfer of auxiliary production to the night shift or weekend). Here the profit may become negative.

D Partial suspension of major production, discontinuous fall in profit.

E Complete suspension of major production. Only electric receivers maintaining system safety and standby mode until a later time span are at work.

E Corporate bankruptcy.

Zones A-E depicted at the graph represent order of consumption constraint (Fig.2).

Zones C-E are connected with routine loss from undersupply of energy. Consequently, while price bidding at short-term market (24 hours ahead) (day-ahead market) the consumer can only represent A-B zones with relatively small range of load variation. The first step of PB refers to point K, where the transfer to the zone of technological process change occurs (C). A pair (c_K, P_1) corresponds to it. Since zone A does not experience variation of load consumed and any increase in price results in decrease in profit, the desirable option for the consumer is the trivial bid ε - minimum width of the price step. If the price is zero the bid will definitely be rejected, so the third step of PB should be a priori determined by possibility ν_3 of bid acceptance. If we know the market price probability-distribution function $F(c)$, then the price bid of the third step can be calculated from the formula

$$F(c_3) = v_3 \Rightarrow c_3 = F^{-1}(v_3). \quad (1)$$

All the consumers are possibly interested in guaranteed supply of the required load, so their strategy should manifest itself through inequation $v_{3i} > 0,5,\ \forall i$. However, as the market functions, it will inevitably lead to the increase in the mathematical expectation of market price, further increase in third-step price, and transfer to the L point (Fig. 2). So in order to prevent the increase in electricity price it is essential that a considerable number of consumers would adhere to the PB constraint strategy.

Since the third step involves some consumption constraint while the first step is restricted by K point, the second step is entirely determined by B zone. Suppose that company's profit for B zone is characterized as $\Pi(\text{c}) = \Pi_0 - \gamma c,\ \gamma > 0$.

The price step (c_2, P_2) is determined by highest company's profit expected at the time frame *(*c_L*,* c_K*)*. And it should be noted that if the price bid x is higher than the market price, the bid is accepted and the company's profit equals to $\Pi(c)$*,* otherwise the bid is rejected and company makes zero profit. Mathematical expectation of profit is calculated by the following formula:

$$\bar{\Pi}(x) = \int_{c_L}^{x} (\Pi_0 \text{-} \gamma c) f(c)dc = \Pi_0 \int_{c_L}^{x} dF(c) - \\ -\gamma \int_{c_L}^{x} cf(c)dc = \Pi_0 \left(F(x) - F(c_L) \right) - \quad (2) \\ -\gamma \int_{c_L}^{x} cf(c)dc.$$

By applying the method of step-by-step integration the last integral can be represented as:

$$\int_{c_L}^{x} cf(c)dc = cF(c)\Big|_{c_L}^{x} - \int_{c_L}^{x} F(c)dc = \\ = xF(x) - c_L F(c_L) - \int_{c_L}^{x} F(c)dc \quad . \quad (3)$$

Отсюда

$$\bar{\Pi} = \Pi_0 \left(F(x) - F(c_L) \right) - \\ -\gamma \left(xF(x) - c_L F(c_L) - \int_{c_L}^{x} F(c)dc \right). \quad (4)$$

At the extremum point

$$\frac{d}{dx}\bar{\Pi} = \Pi_0 f(x) - \gamma \left(F(x) + xf(x) - F(x) \right) = \\ = \left(\Pi_0 - \gamma x \right) f(x) = 0. \quad (5)$$

Since on the time frame in question the price vitiation $f(x) > 0$, the extremum point $x_{\text{опт}} = \Pi_0 / \gamma$ goes beyond the time frame in question. The largest extremum corresponds to the time frame border – the K point. As a result the second price step of the load has the following characteristics (c_2=c_K*;* $P_{\min} = P_1;\ P_{2,\max} = P_2 - \varepsilon$). Since the second price step goes beyond the zones (A, B) of permitted load variation, the first price step degenerates and the price property features two steps.

The consumer who as a result of elaborate economic analysis managed to represent zone B (for example, as several piecewise linear sites) gets the opportunity of price bidding in three or more steps, and every new step is determined by the salient point of the price property.

The price exceeding the admitted for PB at the day-ahead market of zones (A, B) of the price property implies the necessity to switch it off completely. However, the consumer retains the opportunity of electricity purchase at the balancing market where electricity price is normally higher than at day-ahead market. If the consumer accepts this possibility, the most sensible decision for them is to follow the strategy of selecting the first-step value, which is determined by the highest price of the PP. In this case the first step is very likely to be accepted. At the same time in accordance with the PP the economically sensible load for the consumer should be lower than the one of the first step. Thus, imbalance of load should be made up at the balancing market, and the load constraint itself is unscheduled and it is characterized by loss from electricity undersupply. For this research we employed the data of typical load in eastern regions of Russia. We have analyzed the consumer base – electricity wholesale market players and their average load. The essential consumers for the region in question are as follows:

- Energy supply companies (Fig.3. Graph share of consumers - electricity wholesale market players) those are the two most biggest sectors), which supply electricity at flexible or fixed prices)
- Large consumers of metallurgic, mining and construction industries)

For energy supply companies the main technique of demand response is implementation of time-of-use rates.

Industrial consumers in consumption planning are guided by real-time price at day-ahead market. And now we will study in detail when consumers would prefer to limit the load instead of buying electricity at peak price.

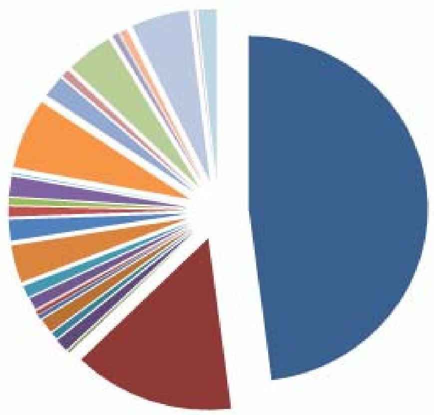


Fig. 3. The consumer base – electricity wholesale market players

The loss from electricity load constraint can be classified as emergency (unexpected), constraints with a day's notice of the consumers, and planned (scheduled) [3]. The last two kinds can occur as a result of damage or unscheduled blackout of generating units or electric grids in periods of load reduction of electrical power systems, while scheduled maintenance of major equipment to increase its capacity, etc. Specific loss from constraint is characterized by the following components:

- underproduction and delayed production of goods with decrease in company's profits
- underemployment of company's basic production assets, overheads on different kinds of energy
- idleness and irrational employment of work force during load constraint
- reduction of competiveness.

3.2 Consumption constraint properties modeling

The consumer's primary goal at refusal of the second and third price steps consists in definition of optimum loading restriction as functions of the electric power price. Thus the damage to the consumer from restriction of a power consumption which can be submitted by expression is determining.

$$Y = y(z)z - \bar{c}z \,, \qquad (6)$$

where *y(z)* is company's specific loss function from load constraint, $\bar{c}$ - mathematical expectation of electricity price.

The optimal load constraint for this price is determined in accordance with minimal loss criterion (6)

$$\frac{dY}{dz} = y'(z)z + y(z) - \bar{c} = 0. \qquad (7)$$

Specific loss call is represented (Fig. 4) by linear characteristic:

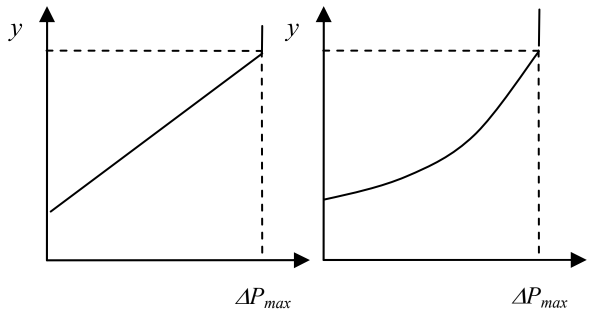
$$y(z) = \alpha z + \beta \qquad (8)$$

or exponential function

$$y(\varepsilon) = \alpha\varepsilon^{\gamma} + \beta \,, \qquad (9)$$

$\varepsilon = z/P_{\max}$.- relative depth of load constraint.

Now we will study in detail the criteria delimitations under which the loss from consumption constraint depends on the electricity price and the mathematical representation.



a) б)

Fig. 4. Properties of load constraint
a) linear; *б)* exponential

Let the specific damage is submitted by linear function, then in the optimum point $z_{\text{опт}} = \dfrac{\overline{c}-\beta}{2\alpha}$. The full damage from loading restriction is defined by expression

$$У = \left(\alpha z + \beta - \overline{c}\right) z = \left(\alpha \frac{\left(\overline{c}-\beta\right)}{2\alpha} + \beta - \overline{c}\right) z = \\ = \left(\beta - \overline{c}\right)\left(\frac{1}{2}\right) \cdot \frac{\left(\overline{c}-\beta\right)}{2\alpha} = -\frac{\left(\overline{c}-\beta\right)^2}{4\alpha} < 0, \quad (10)$$

i.e. with the positive profit and optimal load constraint the special loss $y\left(z_{\text{опт}}\right) = \alpha z_{\text{опт}} + \beta = c - \alpha z_{\text{опт}}$. should be lower than price.

If with any $z > 0$ $y(z) > \overline{c}$, then the trivial value $z_{\text{опт}} = 0$, i.e. the optimal operative consumer strategy is no load constraint. And the consumer suffers the loss from excessively high electricity price because they assume that on the whole this loss will be covered by positive profit on the nearest time frames, and the loss $У_0(Т_{\text{откл}})$ from the complete blackout on the time frame $Т_{\text{откл}}$ (where $y(z) > c$) is higher than the total loss from the high price.

$$У_0(Т_{\text{откл}}) > \int\limits_{t \in Т_{\text{откл}}} (c(t) P_{\text{н}}(t) - Д_{\text{н}}(t)) dt, \quad (11)$$

where $Д_{\text{н}}(t)$ is the company's profit from product output in the standard operating mode.

For exponential function the full damage from loading restriction at the fixed price $\overline{c}$ is equal

$$У = \left(y(\varepsilon) - \overline{c}\right) \varepsilon P_{\max}. \quad (12)$$

In a point of the minimal damage

$$\frac{dУ}{dz} = \frac{dУ}{d\varepsilon}\frac{d\varepsilon}{dz} = y'(\varepsilon)\varepsilon + y(\varepsilon) - \overline{c} = 0. \quad (13)$$

Considering $y(\varepsilon) = \alpha\varepsilon^{\gamma} + \beta$ we recieve

$$y'(\varepsilon) = \alpha\gamma\varepsilon^{\gamma-1}. \quad (14)$$

From here in a point of an extremum

$$\varepsilon_{\text{опт}}^{\gamma} = \frac{\overline{c}-\beta}{\alpha\left(\gamma+1\right)}, \quad (15)$$

thus specific and full damages are equal

$$y(\varepsilon_{\text{опт}}^{\gamma}) = \frac{\overline{c}+\beta\gamma}{\left(\gamma+1\right)}, \quad (16)$$

$$У = P_{\max}\left(\frac{\left(\beta-\overline{c}\right)\gamma}{\left(\gamma+1\right)}\right)\sqrt[\gamma]{\frac{\overline{c}-\beta}{\alpha\left(\gamma+1\right)}}. \quad (17)$$

3.3. Результаты тестовых расчетов

In order to carry out test calculations, the specific loss was modeled by exponential function (9), values of parameters α, β, γ are accepted on the data [3] for structure of loading containing a significant share of industrial consumption. Such structure is characteristic for large industrial cities of east territory of Russia.

The following values of factors of specific damage are accepted: $\alpha = 0{,}85$; $\beta = 0{,}4$; $\gamma = 3$.

For $\overline{c} \le \beta$ a share of load constraint $\varepsilon_{\text{опт}} \le 0$ that means absence of necessity of its restriction. At $\overline{c} > \beta$ it is necessary to compare values of damage and reduction in payments for electric power at load constraints on size ε.

On fig. 5 dependences of full damage $У(\varepsilon)$ for different competitive prices $\bar{c}$ and depths of load constraint ε are resulted, areas for which it is expedient to enter restrictions are determined. At growth $\bar{c}$ of the characteristic of damage increases ε are displaced aside, defining the limiting price $\bar{c}^{\text{пр}} = \alpha + \beta$ at which the unique correct decision for the consumer is its full switching-off.

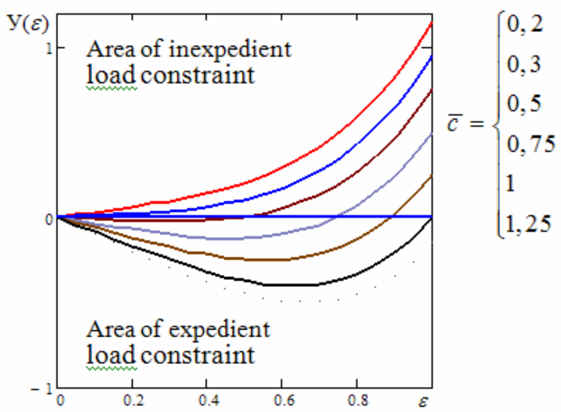


Рис. 5. Dependences of full damage $У(\varepsilon)$ for the various prices $\bar{c}$ and depths of load constraint ε

IV. CONCLUTION

A day-ahead price bid from the consumer at the market is less elastic. When the price suddenly deviates from the expected value, the power limitation for the consumer is determined by the properties of loss from load constraint.

A consumer price properties modeling for various peak market prices makes it possible to determine the optimal constraint values.

We have demonstrated that under certain conditions it is profitable (in case it is technically possible) for the consumer to reduce consumption at peak hours, which results in leveling of the load graph and positive system-wide effect. Thus the consumer sector is shown to have to be of a greater regulating power in the electricity spot market operation.

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VI. BIOGRAPHIES

Vladislav P. Oboskalov, born in 1941, graduated from UPI (Yekaterinburg) in 1963, received the qualification of electrical engineer, specialty "Electric systems and networks". Received the degree of Candidate of Technical Sciences in 1970, doctor of Technical Sciences in 1999. Professor since 2000. Currently is working in the Automated Electric Systems Department of Ural Federal University. His research interests include Reliability, optimization, operation and economics of electric power systems.

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