ENGINEERING SCIENCES

ANALYSIS OF THE IMPACT OF THE NEW ELECTRICITY MARKET ON LEVELING THE LOAD SCHEDULE OF THE UNIFIED ENERGY SYSTEM OF UKRAINE

Rozen Viktor, Doctor of Engineering Science, Professor
Velykyi Serhii, postgraduate student
National Technical University of Ukraine «Igor Sikorsky Kiev Polytechnic Institute», Kiev, Ukraine

ABSTRACT

The article discusses methods of regulating the power consumption regime of the schedule of the unified energy system of Ukraine, which can reduce the irregularity load schedule by using stimulating tariffs for electricity charges. A scheme of the equipment operation principle is shown, which can operate in a mode of consumer-power regulator according to the criterion of reducing electricity charges for industrial enterprises. The result of the energy reform in Ukraine led to the rejection of differentiated electricity tariffs, and the transition to market relations between enterprises that are consumers of electric energy and energy service companies that are responsible for working in the electric energy market. The objective of the article is to demonstrate the practical formation of prices for enterprises and the work of electricity suppliers, which boils down to the ongoing planning of hourly volumes for consumers of electricity and the timely purchase of the said volumes in different segments of the electricity market The aim of the article is to demonstrate the formation of prices for enterprises. The work of energy service companies, which consists in the constant planning of hourly volumes of consumers of electric energy and the timely purchase of these volumes in different segments of the electric energy market. The problem of this formation is that enterprises do not have an incentive to regulating the schedule of the unified energy system of Ukraine, as the new tariffs do not differ in terms of electricity consumption in intraday and a reduce in electricity consumption by the enterprise during peak hours. The authors propose measures that are aimed at solving this problem. The proposed measures are mainly aimed at changes in the day-ahead electricity market, which will entail changes in its other segments.

Introduction. Reducing the irregularity in the electricity load schedule of the unified energy system of Ukraine at the expense of industrial enterprises should be stimulated by tariffs for electricity charges. Before 2019, the stimulation was exercised by using three-zone differentiated tariffs in Ukraine.

As a result enterprises had a clear understanding of the tariff structure, which made it possible to reduce electricity charges by regulating their own consumption schedules. Since the beginning of 2019, the

wholesale electricity market began to operate in Ukraine [1], but the structure of the tariff for electricity remained similar to the three-zone one. Since July 2019, a new model of the electricity market began to operate in Ukraine, which allowed switching to market relations between enterprises (i.e., electricity consumers) and electricity suppliers (i.e., the organizations responsible for working in the electricity market). However, many industrial enterprises are continuing to operate in the old manner, taking into account price changes at differentiated tariffs, which does not lead to significant savings in electricity charges. Since the new market model has only been exploited for four months, domestic and foreign experts have already raised questions about a number of problems in this area [2-4].

The objective of the article is to demonstrate the formation of prices for enterprises in different segments of the electricity market and the problem of the impact of tariffs on the leveling of the load schedule of the unified energy system. The current model of setting the tariff for electricity does not take into account the unbalanced schedule of the unified energy system. As a result, benefits of stimulating industrial enterprises on leveling the load schedule of the electric system are lost.

Main part. The relations between generating enterprises, energy systems, electricity suppliers and consumers are regulated by tariffs for electricity, which solve fundamentally important tasks in the electricity market, namely:

- establishment a relationship between price and actual costs of generating and distributing of electricity;

- restriction of the monopoly of manufacturers and entities that offer services for the transfer of electricity;

- improving the reliability of electricity supply;

- attracting consumers to regulate the schedule of their own electricity load and electricity load of the energy system;

- ensuring the social security of the population;

- stimulation of electricity saving, etc.

Enterprises should adjust their consumption schedule to save on electricity charges and reduce the irregularities in the schedule of the unified energy system of Ukraine thereby. According to the new electricity reform, the purchase of electricity for the future period is carried out in order to reduce the difference between the generated and consumed electricity [5].

The possibility of regulating the electricity load of the unified energy system becomes possible due to the presence of regulatory potential in production systems. There is almost always a number of consumers whose work is spread out over time and whose operating mode can vary within certain timeframe. Such consumers are called power-control consumers. By determining the work schedule of power-control consumers, it is possible to achieve changes in the electricity load schedule of the production system, and as a result, leveling the schedule of the unified energy system [6, 7].

Methods for influencing the schedule of the unified energy system

The irregularity of the schedule of the unified energy system can be influenced by both electricity producers and consumers. The methods of electricity load regulation include the methods that are shown in Fig. 1.

Each of the methods has a significant impact on the leveling of the electricity load schedule of the unified energy system; however, many of them require significant investment. The energy saving methods require the highest economic costs. As a rule, methods to increase energy efficiency do not level the schedule of the electricity load, but reduce the maximum electricity load. Electricity load transfer methods and forced methods do not require significant investments if they do not lead to damaging the production process of the enterprise. In this case, consumers can be transferred to the power-control consumer mode.

The operation mode of almost any power-control consumer can be analyzed based on the example of mine drainage [8, 9]. The size of the volume of the reservoir characterizes the capacity of the storage unit, and the volume of filling (inflowing) and pumping characterizes the speed of filling and emptying the storage unit.

The principle of any consumer in the power-control consumer mode is shown in the block scheme (Fig. 2).

a
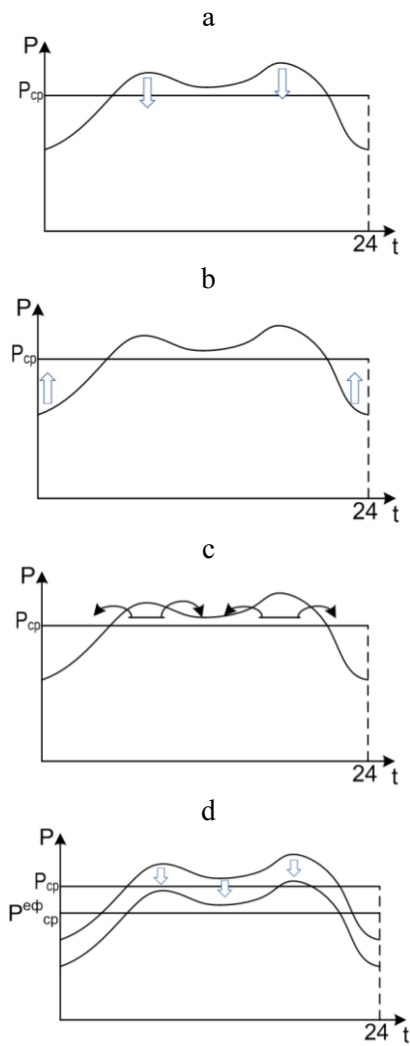
Forced methods:
• rolling blackout;
• shutdown of power-control consumers;
• load control

b

Energy accumulation methods:
• hydroaccumulative power plants;
• heat accumulators;
• electrolysis equipment;
• accumulators of kinetic energy

c

Electricity load transfer methods:
• change in consumer operation mode;
• power-control consumers of discrete action (pump units, refrigeration units, furnaces, etc.)

d

Methods of energy efficiency increase:
• energy management;
• energy labeling;
• energy audit;
• energy-efficient technologies (lighting systems, refrigeration units, electric furnaces, etc.)

Fig. 1. Methods of regulation of electricity load: a – reduction of maximum electricity load; b – filling up of the minimum electricity loads zone; c – transfer of electricity load in the maximum power system zone; d – strategic energy saving
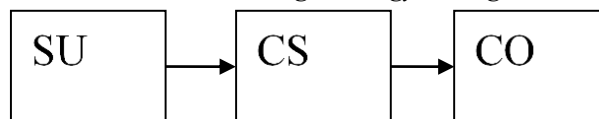
SU → CS → CO

Fig. 2. Block scheme of a consumer in the mode of power-control consumer of discrete action

SU – the storage unit can be represented by a technological reservoir, platform, warehouse, etc.;
CS – the control system can be represented by a technology controller;
CO – the control object can be represented by a technological process, which includes one or more units.

In this case, the volume of the storage unit is not a determining value, which determines the value of the speed of its filling and the emptying of the storage unit. The main factor is the time at which the consumer can operate at minimum power without compromising the production process of the enterprise.

Also, power-control consumers include consumers without a storage unit, the block scheme of which is shown in Fig. 3.
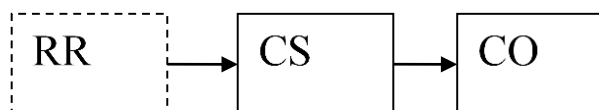
RR → CS → CO

Fig. 3. Block scheme of equipment in the mode of the power-control consumer without a storage unit

According to this scheme, consumers can operate when there is a sufficient regulation range (RR), which allows not to turn off the equipment, but only to reduce the electricity load in the required

periods. To regulate the mode of operation of possible power-control consumers of power at an industrial enterprise, it is necessary to take into account the principle of pricing in segments of the electricity market, which should lead to a reduction in electricity charges.

Pricing in various market segments

The new model of the electricity market includes trading relations between generating companies and electricity suppliers for the end-consumer. The operation algorithm of electricity suppliers implies constant planning of hourly volumes of electricity consumers and timely purchase of volumes of electricity in various market segments, namely: the day-ahead electricity market (DAEM), the intraday electricity market (IEM), as well as the bilateral agreements market (BAM). A significant difference between DAEM, IEM and BAM is that when working on BAM, the electricity supplier and the generating company sell electricity directly between themselves. When working on DAEM and IEM, there is a government agency between the supplying companies and the generating ones called the Market Operator (MO).

Under the conditions of market relations, the purchased daily amount of electricity and the price for it may differ depending on the result of trading in various market segments (DAEM, IEM, BAM). In this case, consumers in active cooperation with their electricity supplier can establish periods of consumption depending on the price that may be formed in various segments of the electricity markets.

As a result of trading on various segments of the electricity supplier's market, several situations of regulating one's own electricity schedule can be simulated to reduce the payment for electricity. Fig. 4 shows two options of forming a cost of an electricity consumer in case if a supplier is working in different market segments.
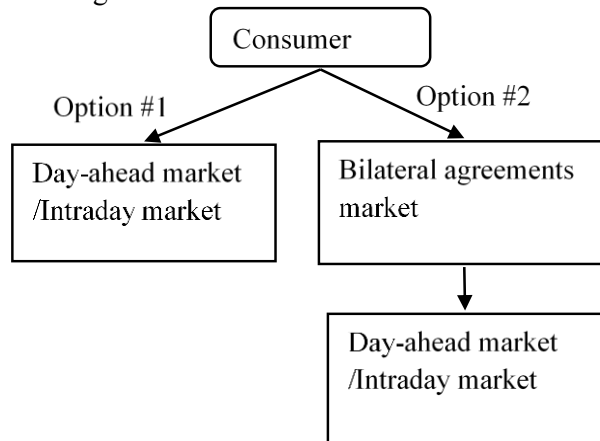

Fig. 4. The scheme of pricing for consumers in various market segments

Each option has its own special characteristics and can be beneficial with a certain configuration of the electricity consumption schedule.

For the bilateral agreements market an electricity trading was created [10]. On the trading a minimum purchase unit (lot) is 1 MW * hour and the price may vary depending on the period of purchase of electricity. The periods of purchase of electricity can be divided into three blocks, namely BASE, OFFPEAK, PEAKS. The periods of lots on the electricity trading for the bilateral agreements market are given in Fig. 5.
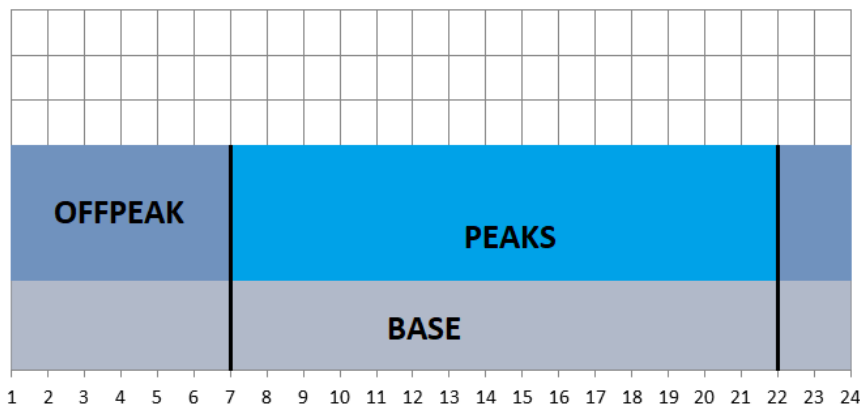

Fig. 5. Periods of lots on the electricity trading for the bilateral agreements market

The values of the OFFPEAK and PEAKS periods are set only for working days (Fig. 5). Also, on weekends, the OFFPEAK period is set from 00:00 to 24:00, and the PEAKS period is not set. The main advantage of the BAM trading is the possibility to purchase electricity for a long-term period (i.e., a week, a month) and the price remains constant. For the PEAKS period, the price varies in the range of 1900 - 2010 UAH / MW * hour, and for the OFFPEAK period, the price varies in the range of 1070 - 1300 UAH / MW * hour. For the BASE period, the price varies in the range of 1600 - 1700 UAH / MW * hour excluding the value added tax and all charges for the transfer, distribution, extra charge of the supplier and costs of the trading services. Mathematically, the formation of the price for BAM is given below:

$$c_{BAM}(t) = \begin{cases} c_{BASE}(t); 1 \le t \le 24 \\ c_{PEAKS}(t); 7 \le t < 22 \\ c_{OFFPEAK}(t); 1 \le t < 7, \ 22 \le t \le 24 \end{cases}, \tag{1}$$

For DAEM, the situation is different; its main advantage is that the minimum purchase unit is 0.1 MW * hour and you can buy electricity at any time, but only a day in advance. The main challenge of DAEM is that the actual price received based on the trading results is unknown and the actual volume of electricity that can be purchased, according to the DAEM results, may be less than that ordered. It is called the accepted volume. Since the beginning of DAEM operation, ceiling prices (limits) have been introduced [11] for the periods from 00:00 - 08:00 and 23:00 - 24:00 amounting to UAH 959.12 / MW * hour, 08:00 - 23:00 amounting to 2048.23 UAH / MW * hour. The price can be any at DAEM, however, it should not exceed the ceiling price.

Since the beginning of the operations of the new market, the trend of deficit in the purchase of electricity during an incomplete accepted volume on DAEM has remained in the IEM. So, for example, with incomplete acceptance on DAEM etween 8:00 a.m. and 9:00 a.m. there will be a large number of buyers on IEM, but there may be no sellers or their number might be so small that they will not fully satisfy the demand for electricity. The price for electricity in this period will be maximum and equal to the ceiling price. In this case, the insufficiently accepted volume on DAEM may increase the final price of electricity for the consumer. The options for setting the price and volume of electricity purchase on DAEM market can be described by the conditions as follows:

if $W_{i.gen.} \ge W_{i. \, declaired}$ then $c_{i.PCB} < p_{ceil.DAEM} \ W_{i.зn.} = W_{i.act.}$

if $W_{i.gen} < W_{i.declaired}$ then $c_{i.PCB} = p_{ceil.DAEM} \ W_{i.зn} > W_{i.act.}$

where $W_{i.gen}$ – the volume of electricity put up for sale by generating companies for each hour of DAEM; $W_{i.declaimed}$ – the declared volume of electricity for the purchase by all electricity suppliers every hour on DAEM; $C_{i.DAEM}$ – the price, which is formed as a result of trading every hour on DAEM; $P_{ceil.DAEM}$ – the ceiling price for DAEM; $W_{i.decl.}$ – the declared amount of electricity for a single electricity supplier every hour on DAEM; $W_{i.act.}$ – the accepted volume of electricity for a single electricity supplier every hour on DAEM.

The difference between the purchased electricity in all market segments at a certain time and the consumed electricity is an unbalance (NB), and can be sold or bought on the balancing market every hour. According to the results of trading of the balancing market (which can no longer be influenced on), only the final price of unbalance is formed for the consumer. The task of consumers is to reduce the difference between the declared (forecast) and the actual schedule of electricity load to minimize the unbalance.

A special aspect of the task is that the dependence of the cost of electricity on time is specified as the function and it can vary during the day depending on the results of the work of the electricity supplier in the electricity markets. The function can be represented as follows:

$$c(t) = \begin{cases} c_{BAM}(t) \\ c_{DAEM}(t) \\ c_{IEM}(t) \\ c_{NB}(t) \end{cases}, \tag{2}$$

where $c_{BAM}(t)$, $c_{DAEM}(t)$, $c_{IEM}(t)$, $c_{NB}(t)$ are the prices in various segments of the market of BAM, DAEM, IEM, NB respectively, UAH / kW per hour.

The daily purchase price of electricity in various market segments is calculated by the formula as follows:

$$C = \sum_{i=1}^{24} c_{BAMi} \cdot W_{BAMi} \pm c_{DAEMi} \cdot W_{DAEMi} \pm c_{IEMi} \cdot W_{IEMi} \pm c_{NBi} \cdot (W_{BAMi} + W_{DAEMi} + W_{IEMi} - W_{FACTi}), (3)$$

where W_{BAMi} is an hourly volume of electricity that must be purchased on the market of bilateral agreements; $W_{DAEM/IEMi}$ is an hourly volume of electricity that it needs to buy / sell on the day-ahead market and / or on the intraday market; W_{FACTi} is an hourly volume of electricity consumed in fact.

The formation of the resulting price of unbalances is identified taking into account the actual needs for electricity of the consumers of the power system and which are identified on the balancing market. At present, the price for unbalances also has ceiling values, which range from 85% to 115% of the established price for BAM.

As a result of the functioning of the new market, the tendency to change the daily tariff does not stimulate the leveling of the load schedule of the energy system, since it does not take into account the maximum load points (of the morning and evening). This is due to the fact that the purchase in the markets, namely BAM based on which most of the electricity is sold, takes place in the ranges (PEAKS, OFFPEAK). It reduces the incentive to regulate the consumer's own electricity load schedule during the daytime. Each electricity supplier tries to level the consumption of its consumers for more profitable work in the market. The compensation for the unbalanced load schedule of the unified energy system, which is made up due to the consumption of the population, is not necessary. When purchasing electricity on the DAEM market at a certain time, a shortage of electricity may appear which forces electricity suppliers to submit an application at the maximum high possible price (08:00 - 23:00 - UAH 2,048.23 / MW * hour), what leads to a proportional change in the daily tariff for electricity. The proportionality of the price of electricity during the day does not encourage enterprises to regulate their demand for electricity. The Fig. 6 shows the average monthly graphs of changes in the daily price based on the results of trading in various market segments and also the schedule of the load of the Ukrainian energy system for September 2019.
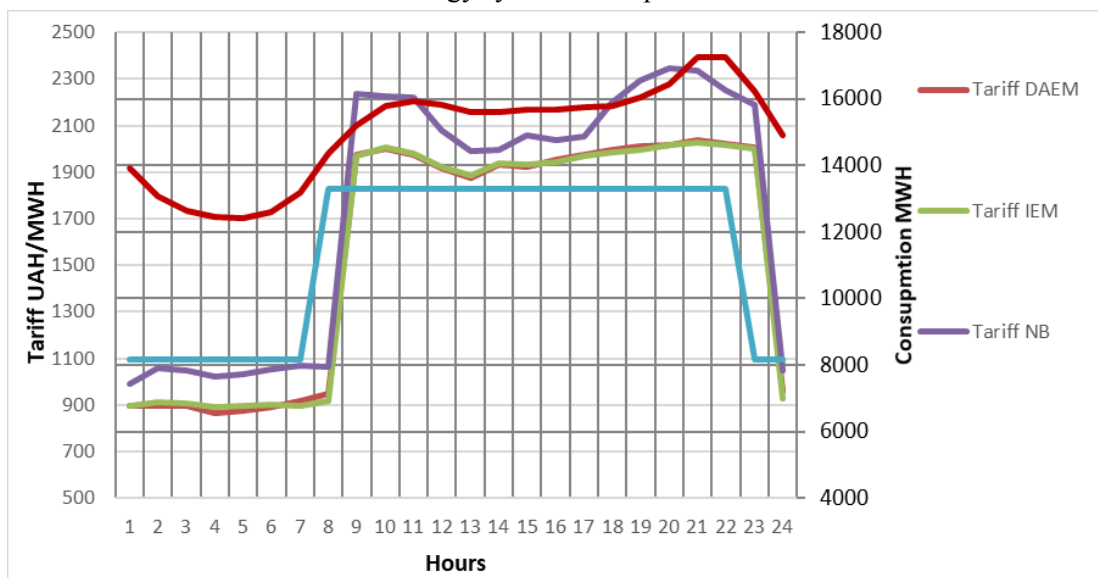

Fig. 6. The average monthly graph of the load of the Ukrainian energy system and graphs of changes in the daily price according to the results of trading in various market segments

At present, the influence of the irregularity of the schedule of the unified energy system on the formation of prices is taken into account only in the volume of actual purchase (acceptance) on the DAEM market. Electricity suppliers are not able to stimulate consumers at the expense of tariffs due to the market pricing, as the purchase price for electricity varies in the range of day and night. Therefore, leveling the schedule of the unified energy system in the current tariff structure is difficult.

It can be conclude that now the price in various market segments is associated with the price that is formed on DAEM. The influence of ceiling prices on DAEM, the formation of acceptance and the resulting price should be reviewed, which may entail favorable changes in the interaction of all segments of the new electricity market.

Conclusions. To solve the problem of stimulating consumers, it is necessary to change the conditions of pricing in various market segments. It can be carried out by several ways that can affect the pricing in the electricity markets, namely:

1. To review the formation of ceiling tariffs in the day-ahead market and the intraday market, which repeated the nature of the change in the schedule of the unified energy system with indicative daily highs and lows;

2. To increase the tariff difference between the day and night periods for stronger stimulation of the transition of industrial enterprises to operating at night;

3. To introduce the priority of day-ahead purchase on the market between the market participants that purchase volumes of electricity for the needs of their own consumers and traders that resell a significant percentage of electricity in the intraday market.

Such changes are supposed to affect the stimulation of consumers and the regulation of their own consumption schedules as well as electricity suppliers that are expected to create conditions for consumers aimed at leveling the schedule of the unified energy system of Ukraine.

REFERENCES

1. LAW OF UKRAINE (2017) On the Electricity Market. *Data of the Supreme Council,* 312, #27-28 (in Ukrainian).
2. Kostin Yu. D., Telegin V. S. (2018) Reforming the electricity market of Ukraine. *Economic Bulletin of the University. Collection of scientific works of scientists and graduate students*, 33-1, 101-108 (in Russian).
3. Dzerskii, V. G. (2012) Market reform in the electric power industry of Ukraine and pricing. *Energy saving. Energy consumption. Energy audit*, 11 (105), 13-29 (in Russian).
4. Kostyukovsky B. A., Leshchenko I. Ch. (2014) Problems of implementation of the provisions of the law "On the principles of the functioning of the electricity market in Ukraine". *Problems of general energy,* 3, 43-49 (in Ukrainian).
5. Gitelman L. D., Kozhevnikov M. V., Gitelman L. M. (2016) Electricity: smart partnership with the consumer: monograph. *ZAO Publishing House "Economics"*, 160 (in Russian).
6. Prakhovnik A. V., Rosen V. P., Degtyarev V. V. (1985) Energy-saving modes of power supply for mining enterprises. *Nedra*, 232 (in Russian).
7. Hronusov G.S. (1998) Formation of effective modes of power consumption of industrial enterprises. *UGGGA*, 340 (in Russian).
8. Rosen V. P., Velykyi S. S. (2018) The general model of a horizontal-shaft drainage system. *Bulletin of the Krivoy Rog National University*, 46, 56-60 (in Ukrainian).
9. Rosen V. P., Velykyi S. S., Storozhilova G. I. (2018) Control of the mode of operation of a drainage pumping unit of a mining enterprise on the criterion of payment for electricity. *Electrical and Computer Systems*, 27 (103), 136-143 (in Ukrainian).
10. Procedure for conducting electronic auctions for the sale of electricity under bilateral agreements: *Approved by the Resolution of the Cabinet of Ministers of Ukraine,* (2019) 499, 29 (in Ukrainian).
11. NCRECP (2018) On Approval of the Rules of the Market «Day-ahead» and Intraday Market: *NERCEP Resolution*, (2018) 308, 74 (in Ukrainian).