Possibilities of managing electricity consumption through the application of time-classified tariffs

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Abstract. This manuscript is devoted to the issue of smoothing the load schedule of enterprises in “peak” periods in return for using the results of energy audits and applying a system of time-classified tariffs. Considering the mentioned issue above, using the results of the energy inspection and using the system of time-classified tariffs will create an opportunity to achieve smoothing the load schedule of the electric power system during “peak” periods. The use of the time-classified tariff system by consumers will reduce the loading period of the electric power system and change its regimes.

1. Introduction

In the Republican electric power system, electricity consumers are divided into following groups: population, construction (architecture), industry, transport, agriculture and communal household consumers. This causes rugged load graphs in the power system as the electricity consumption of these consumers varies. Therefore, in all countries of the world, rugged load graphs in the electric power system and the issue of their alignment is a specific problem [1]. The average daily electricity consumption in Uzbekistan in 2021 was 205.1 mln. kWh, in 2022 this figure will increased by 4.5%, and reached at 214.4 million kWh. This shows 50.9% increase compared to 2016 (142.1 million kWh).

In order to correct the rugged graphs of the morning and evening “peak” loads in the electric power system and eliminate them, in this scientific research work, it is aimed to use the time-classified tariffs using the results of the energy audit of the consumers, and to transfer the consumption in the “peak” periods to other periods of the day, i.e. it is advisable to transfer to day or night periods. As a result, the operational reliability of existing equipment in the electric power system is increased and its smooth operation is scientifically based [2].

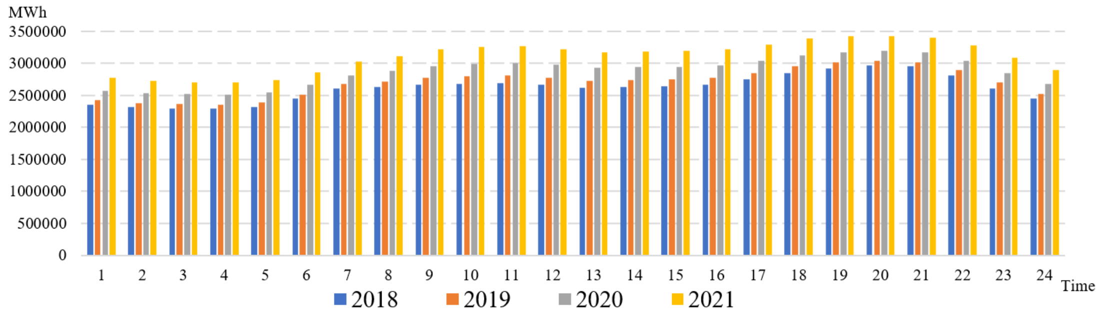

Fig. 1. Hourly consumption indicators of electricity consumption in the Republic of Uzbekistan over the years from 2018 to 2021

Demand of the consumer for electricity is manifested daily, weekly, monthly, annually and seasonally. At the same time, it can be noted that during the period of consumption, the graphs of the daily electricity load are variable in nature and have a negative effect on the operation of the electric power system [3, 4]. Changes in the demand for electricity can be presented in the form of appropriate tables or graphs, and depending on the climate and socio-economic conditions of different countries, the electricity system graph has its own characteristics [5].

Electricity consumption in summer and winter creates a very rugged graph in the Republic’s (Uzbekistan) electricity system. In addition, it is noticeably that the load graph (minimum, average, and maximum) of the Republic's electric

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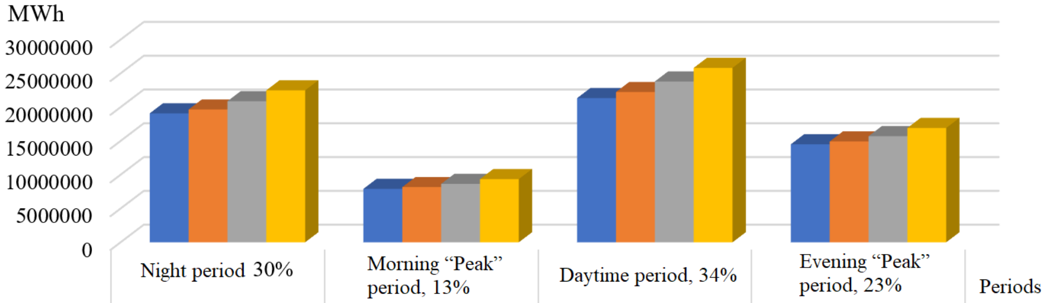
power system differs in order of magnitude. It is clear that only visual assessment is not enough to compare the level of the ruggedness of consumption demand for electricity [6]. The ruggedness of electricity consumption graphs has negative consequences. It is appropriate to use time-classified tariffs when adjusting it.
Indicators of the using the installed capacities of the Republic's electric power system by hours on a daily basis in 2018, 2019, 2020, 2021 (Fig. 1).
In the condition presented in Figure 1, the demand for electricity in Uzbekistan from 2018 to 2021 is formed by hours of the day. According to this condition, the consumption increases in the morning and evening "peak" periods when it is observed in the section of hours.
Figure 2 shows the consumption indicators of electricity consumers in Uzbekistan over the years according to the classified tariff periods of the day.



	Night period 30%	Morning "Peak" period, 13%	Daytime period, 34%	Evening "Peak" period, 23%
2018 й.	19086095	7912126	21341707	14501960
2019 й.	19655574	8171460	22242811	14926040
2020 й.	20880817	8644767	23803833	15706327
2021 й.	22490016	9354841	25809923	16920748

■2018 ■2019 ■2020 ■2021

Fig. 2. Consumption indicators of electricity consumers in Uzbekistan over the years according to the classified tariff periods of the day

It can be seen from figure 2 that the demand for electricity in Uzbekistan is high during the "peak" periods of the day. Over the years, it is observed that the demand for electricity is 6% higher in the morning and evening "peak" periods of the day compared to the classified periods of the tariff system classified by night time, and 4% higher in the daytime periods. It is clear from this that it is possible to adjust the load schedule in the electric power system due to the implementation of electricity consumption in time-classified tariff periods.

2. Research Methods

Industrial enterprises with an installed power of more than 750 kVA and other consumers of electricity can pay at reduced prices for electricity during "off-peak" hours of the day as a result of the application of time-classified tariffs. The operating modes of transformers in substations depend on the state of consumption by consumers. More clearly, using the results of energy audits and applying time-classified tariffs, it affects the load regimes on the electric power system [7].
Reduction of the maximum load of consumers in maximum load periods of the electric power system is expressed according to the economic expediency:

$$C_0 \leq C_{ot}/(1+P_p/Z_{ich}); \quad (1)$$

Where, P_p – the planned accounting profit of the enterprise, (sums);
Z_{ich} – product production costs, (sums);
C_o – payment for additional electricity determined by electric meters, (sums/kW·h);
C_{ot} – maximum load of the enterprise in the maximum load period in the electric power system (payment value for 1 kW·h) kW/sum.
The overall economic effect of the studies to adjust the load graph is expressed as follows:

$$Э_g=(P_{at}-C_0)(P_{max}-P_{max}^1); \quad (2)$$

where $P_{мax}$ – the maximum load of the enterprise during the maximum load of the electric power system, (kWh);
$P'_{мax}$ – the last load after applying the research, (kW·h).
The adjusting cost the schedule of values can be determined as following:

$$Z=E*\Delta k+\Delta U; \quad (3)$$

Δл – additional capital expenditure (to adjust the graph);

E – sum factor divided from annual capital expenditure;

ΔU – changes in one year to adjust the graph.

The last comparative price after reducing the maximum loads of the enterprise at the time of the electric power system's maximum loads is expressed as follows:

$$C_0=3/P_{мах}-P'_{мах}\leq C^*_{ot}; \quad (4)$$

Where, $P_{мах}$ and $P'_{мах}$ – maximum load time of the electric power system, maximum load of the enterprise, shows the capacities before and after the application during the study period.

C_0 – the payment cost for the consumption of 1 kW·h for the maximum load of the enterprise at the maximum load of the electric power system, (sum/kW·h);

C^*_{ot} – payment value for 1 kW·h of the maximum load during the maximum load period of the electric power system, (sum/kW·h).

If the measures (tariff system for electricity consumption) that conducted to adjust the loading graph of the electricity consumption in enterprises do not require additional capital costs, then to obtain the economic effect, it is determined from the difference between the previous and subsequent total electricity prices [8]:

$$\Delta Э_e=C_1-C_2=Z_1A_1-Z_2A_2; \quad (5)$$

Where, $\Delta Э_e$ – saved cost of electricity, (kWh/sum);

C_1, C_2 – price of electricity before and after applying the research, (kW·h/sum);

Z_1, Z_2 – electricity costs, (kW·h/sum);

A_1, A_2 – annual electricity consumption in the cases under consideration (kW·h/sum).

In the development of organizational and technical measures to save electricity, the use of technological measures will be more beneficial.

In the time-classified electricity balance of electricity consumption of production enterprises, all wastes and energy consumption related to electricity consumption belong to the main technological process. But the organizational structure of the electricity balance is much deeper and comes from the period of power spent on production by each consumer.

The main part of the production enterprises' electricity balance is that most of the wasted electricity is in the network and transformers. Waste in the network cannot be determined by measurement, so the amount of waste is determined by calculations.

Daily electricity consumption modes of production enterprises are consumed depending on the periods of the day with the help of consumption graphs. Daily load graphs provide an opportunity to regulate the operation mode of the enterprise's electrical equipment and analyze it for the next periods. It will also help to develop measures to clarify electricity consumption regimes in the near future.

Time-classified tariffs are calculated on the basis of the maximum and minimum hours of electricity consumption during the day and are used to determine the capacity. The graph of electricity consumption of enterprises is characterized by a certain change of electricity consumption during the day [9].

The most complete monitoring period of the equipment that consumes electricity in enterprises helps to work with accurate calculations, to work at a uniform level of electricity consumption, and to improve the rhythm of production.

Regulation of electricity consumption in enterprises is one of the most important tasks for the electric power system: in the first place, it promotes the rational use of fuel in the production of electricity, as well as increases the reliability of the equipment at power plants [10].

It is important to monitor the consumption of electricity when tariffs are implemented, which separate payments for electricity by periods of the day, days of the week and seasons of the year.

Considering the electricity tariffs of enterprises, it is necessary to consider some important mechanisms for monitoring the peak period of the substation. That is, it is possible to change the period of stress on the electricity system by applying the system of differentiated tariffs only to consumers.

Costs per unit of production in enterprises are expressed as follows:

$$Z_i = d_i(n_i)\, b_i + \sum_{i=1}^{l} a^k \alpha_k + C; \quad (6)$$

where: Z_i –costs per unit of manufactured product (for technological processes);

$b_i > 0$ –the fixed price of 1 kW·h of electricity during the fixed tariff period, sums;

$a^1, a^2, \ldots, a^k$ –consumption of raw materials, fuel, water, etc. in production unit (for process management);

$$a^k = f\,(n_i),\ \ a^k > 0; \quad (7)$$

$\alpha_1, \alpha_2, \ldots, \alpha_l$ – unit price a^k;

$C > 0$ – fixed costs per unit of production;

It is desirable to reduce the amount of production enterprises' consumption at the time of maximum load, which ensures the reduction of the costs of the enterprise in the execution of the production plan (Δ3).

The mathematical expression of this is as follows:

$$\Delta Z = a\,\Delta P - У(\Delta P); \quad (8)$$

$$0 \leq \Delta P \leq \Delta P_{kor}; \quad (9)$$

where: a – the price of 1 kW·h of electricity during the maximum load of the electric power system;

У(ΔP) – additional costs of the enterprise related to the regulation of electric energy consumption of technological devices;

Changing the tariff price regimes for "peak" (maximum) periods of [11] consumption of electricity depends on the annual costs of the consumer:

$$Z_0 = X_0 + n_0 T_0 \gamma_0 + P_0 a + n_0 T_0 d_0; \quad (10)$$

where: X_0 – annual production costs, sum/year;

n_0 – period of change of hours in working mode, hours;

T_0 – planning of annual working hours in the enterprise;

γ_0 – the price of electricity consumed per unit product before the tariff change, sum;

P_0 – the power consumed during the period of maximum load of the electric power system before the voltage change, kW·h;

a – amount of payment for 1 kW·h during the maximum load, sum;

d_0 – consumption of electricity per product unit from mode change, kW·h.

The electric energy consumption of the three-period tariff system, classified by the time used for consumers in the electric power system, is expressed as follows:

$$C_e Э = C_e^{п} Э^{П} + C_e^{ЯП} Э^{ЯП} + C_e^{Т} Э^{Т}; \quad (11)$$

where C_e – tariff price for electricity, sum;

Э – электр энергия истеъмоли, kW·h;

$C_e^{П}$ – tariff price for electricity during the "peak" period, sum;

$Э^{П}$ – electricity consumption during the "peak" period, kW·h;

$C_e^{ЯП}$ – tariff price for electricity during "semi-peak" period, sum;

$Э^{ЯП}$ – electricity consumption during the "half-peak" period, kW·h;

$C_e^{Т}$ – tariff price for electricity at night, sum;

$Э^{Т}$ – electricity consumption during the night period, kW·h.

The use of energy audit results in enterprises and the use of a time-classified tariff system contribute to the equal distribution of electricity consumption in the power system branches, with the consumption of electricity during the night period rather than during the day.

Regulation of the use of electricity in enterprises based on the results of energy inspections, incentives for consumers at night, rational use of costs due to time-classified tariff rates are intended for the needs of electricity consumers.

The electricity consumption of the two-period tariff system, stratified by time for the day and night periods of the day, is expressed as follows:

$$C_{ur} Э = C^{К} Э^{К} + C^{Т} Э^{Т}; \quad (12)$$

Where, $C^{К}$ – tariff rate for the daytime period of the day;

$Э^{К}$ – daytime electricity consumption, kW·h;

$C^{Т}$ - tariff rate for the night period of the day;

$Э^{Т}$ – night period electricity consumption, kW·h.

The use of energy audit results for 24-hour enterprises (3-shift) and choosing one of the two- or three-period systems of the time-classified tariff system brings a number of advantages both for the electric power system and for the consumer [12].

Electricity network enterprises establish special programs for periodic calculation of existing electricity meters in enterprises on the basis of time-classified tariffs based on the contract [13].

Based on the status of the tariff system for electricity consumption in the unified electric power system of Uzbekistan, it should be noted that currently only enterprises with an installed capacity of 750 kVA and more are implementing the time-classified tariff system for electricity consumed. But in the near future, by applying this tariff system to all consumers of Uzbekistan, it will serve to eliminate extra load in the system in the morning and evening "peak" periods.

In order to eliminate morning and evening load in the electricity system in Uzbekistan [14, 15], a system of time-classified tariffs has been introduced, and the application of such tariffs and the setting of tariffs with its introduction are more transparent and understandable. Based on the situation of tariffs differentiated by use and time, in order to reduce the amount of costs in the nighttime stimulated periods, it is important to organize an accurate calculation of costs and revenues related to ensuring a certain level of reliability in the way of this introduction, in addition to dividing the commercial calculation of electricity into technical and reliability technological links.

The main features of the daily chart are as follows:

- rugged graph (the ratio of the minimum precipitation period to the maximum precipitation period during the night period) is expressed as follows:

$$\alpha_{\text{н}} = \frac{P_{min}}{P_{max}}; \quad (13)$$

The coefficient of filling the load (the ratio of the average daily load period to the maximum loading period) is expressed as follows:

$$\gamma_3 = \frac{P_{avr}}{P_{max}}; \quad (14)$$

Also, the amount of hours of the peak period is expressed as follows:

$$h = \frac{\text{Э}_{year}}{P_{max}}; \quad (15)$$

where, Э_{year} - amount of annual consumed electricity, kWh;

P_{max} –the annual maximum load period of the electric power system.

By changing the consumption of electricity every hour during the day and multiplying it by the appropriate tariff, it is possible to get the daily cost of electricity for a given consumer. By dividing the amount of electricity consumed per day, it will be possible to get the average daily price of electricity. If the application of average daily tariffs of electricity is reduced compared to the single tariff determined on the basis of methodology, it can be concluded that it is appropriate to switch to a tariff stratified by the period (hours) of the day, it is expressed as follows:

$$\text{С}_{avr.} = \frac{\text{С}_{\text{т}} \cdot \text{Э}_{\text{т}} + \text{С}_{\text{ят}} \cdot \text{Э}_{\text{ят}} + \text{С}_{peak} \cdot \text{Э}_{peak.}}{\text{Э}_{soum}}; \quad (16)$$

where: С_{avr} – average electricity tariff;

$\text{С}_{\text{т}}, \text{С}_{\text{ят}}, \text{С}_{peak}$ – set tariff price of electricity consumption during the night, semi-peak and peak periods (sum);

$\text{Э}_{\text{т}}, \text{Э}_{\text{ят}}, \text{Э}_{peak}$ – the amount of electricity consumed during the night, semi-peak and peak periods (kWh);

Э_{soum} – the total amount of electricity consumed during the night, semi-peak and peak periods (kWh).

In Uzbekistan, consumers of electricity must notify the organization that supplies them of electricity at least one month in advance of the annual agreement on the application of fixed tariffs, and the agreement will come into force from the beginning of the year (as a rule, from January 1).

3. Results and Discussions

The months with the least (April) and most (September) load on the 110/10 kV “Agromir” substation were analyzed. And the graph (Fig. 3) is emerged based on the results of the analysis of the electricity consumption in the lowest (April 178467 kW·h) and the most (September 992594 kW·h) months of the year in the enterprise “Agromir” LLC, which consumed the most electricity by substation.

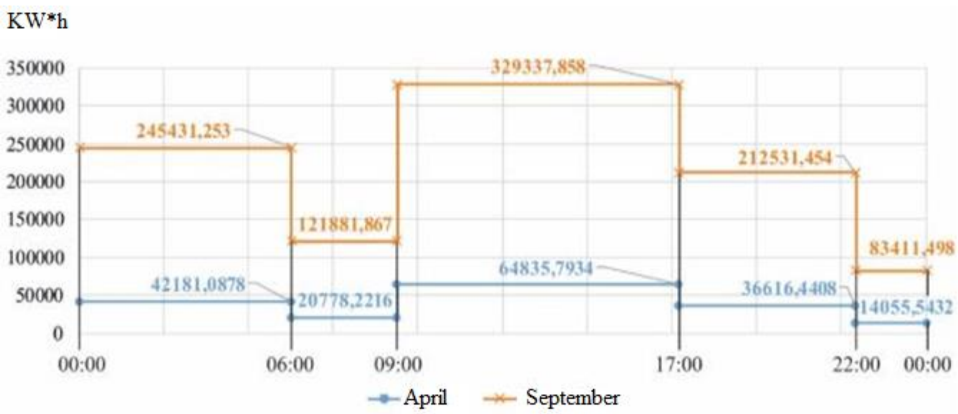


Fig. 3. Electricity consumption graph of “Agromir” LLC by time of day in April and September in 2020

Table 1 shows the calculation result of “Regional Electric Networks” JSC for the price of electricity in April and September (in 2020) for the periods of the day starting from August 15, 2019.

The calculation results of the electricity consumption of all consumers and “Agromir” LLC in the months with the least (April) and the most (September) load on the substation according to time-graded tariffs are as follows:

April report **84 788 493** sums;

The report for September is 472,583,853 sums.

The electricity consumption of “Agromir” LLC in April and September was analyzed according to the periods of the day. As a result of the analysis, the main consumption in April was 36% during the daytime, while the main consumption in September was 33% during the daytime (Figure 4).

Table 1. Calculation result in daily cycles of “Agromir” LLC JV in April and September 2020

Months	Tariff periods	Electricity consumed (kW·h)	Tariff prices	Sum of consumption in periods
April	Night period From 00:00 to 06:00	42181,088	300	12654326
	Morning “Peak” period From 06:00 to 09:00	20778,222	675	14025300
	Day time From 09:00 to 17:00	64835,793	450	29176107
	Evening “Peak” period From 17:00 to 22:00	36616,441	675	24716098
	Night time From 22:00 to 00:00	14055,543	300	4216663
	Total:	**178467,09**		**84 788 493**
September	Night period From 00:00 to 06:00	245431,25	300	73629376
	Morning “Peak” period From 06:00 to 09:00	121881,87	675	82270260
	Day time From 09:00 to 17:00	329337,86	450	148202036
	Evening “Peak” period From 17:00 to 22:00	212531,45	675	143458731
	Night time From 22:00 to 00:00	83411,498	300	25023449
	Total:	**992593,93**		**472 583 853**

The calculation results of the electricity consumption of all consumers and “Agromir” LLC in the months with the least (April) and the most (September) load on the substation according to time-graded tariffs are as follows:

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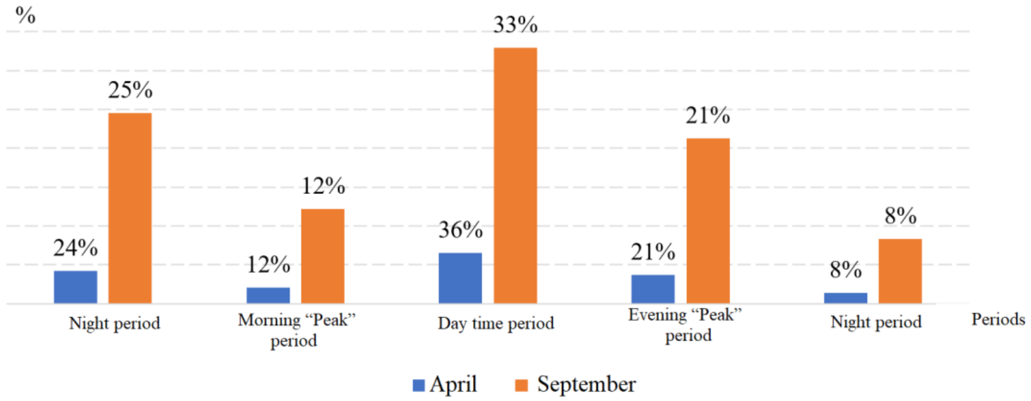

Fig. 4. Electricity consumption (%) of “Agromir LLC” per day in April and September in 2020

In order to prevent the increase of the loads in the morning and evening “peak” periods on 110/10 kV “Agromir” substation, all of the consumers, including “Agromir” LLC, should correctly consume electricity during the incentive periods of the time-classified tariff system. As a result, not only the economic efficiency of the enterprise insreases, but also it eliminates the extra loads on the substation.

During the research conducted in the enterprises connected to the 110/10 kV substation "Agromir", it was proved in the research process that "Agromir" LLC is interested in using tariffs. As a result, a graph was built on the use of this enterprise's time-classified tariff system in April and September (Figure 5).

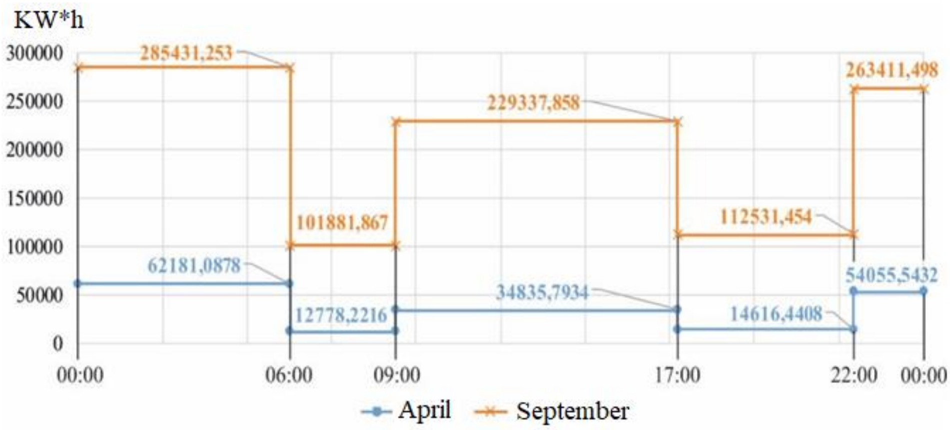

Fig. 5. Graph of using energy audit results and application time-classified tariff of "Agromir" LLC in April and September in 2020

In April and September 2020, consumers connected to the 110/10 kV "Agromir" substation, using the results of the energy audit and using the time-classified tariff, consumption amounts by periods of the day and payment amounts for tariff periods are given in Table 2.

Table 2. The calculation result of "Agromir" LLC for April and September in 2020

Months	Tariff periods	Electricity consumed (kW·h)	Tariff prices	Sum of consumption in periods
April	Night period From 00:00 to 06:00	62181,088	300	18 654 326
	Morning "Peak" period From 06:00 to 09:00	12778,222	675	8 625 299
	Day time From 09:00 to 17:00	34835,793	450	15 676 107
	Evening "Peak" period From 17:00 to 22:00	14616,441	675	9 866 097
	Night time From 22:00 to 00:00	54055,543	300	16 216 663
	Total:	**178467,09**		**69 038 493**
September	Night period From 00:00 to 06:00	285431,25	300	85 629 376
	Morning "Peak" period From 06:00 to 09:00	101881,87	675	68 770 260
	Day time From 09:00 to 17:00	229337,86	450	103 202 036
	Evening "Peak" period From 17:00 to 22:00	112531,45	675	75 958 731
	Night time From 22:00 to 00:00	263411,5	300	79 023 449
	Total:	**992593,93**		**412 583 853**

The calculation results of the electricity consumption of 110/10 kV "Agromir" substation during the months of the year with the least (April) and most (September) load of all consumers connected to the substation, including "Agromir" LLC JV, using tariff periods classified by time, were as follows :

April account result is 69,038,493 sums;

The account of September amounted to 412,583,853 sums.

Consumption during the "peak" and daytime periods of the day is transferred to the stimulated periods of the night in exchange for the use of a time-classified tariff and the use of the results of the energy audit in the electricity consumption of April and September of all consumers connected to the substation, including "Agromir" LLC. As a result, the loadings on the substation are eliminated (Fig. 6)

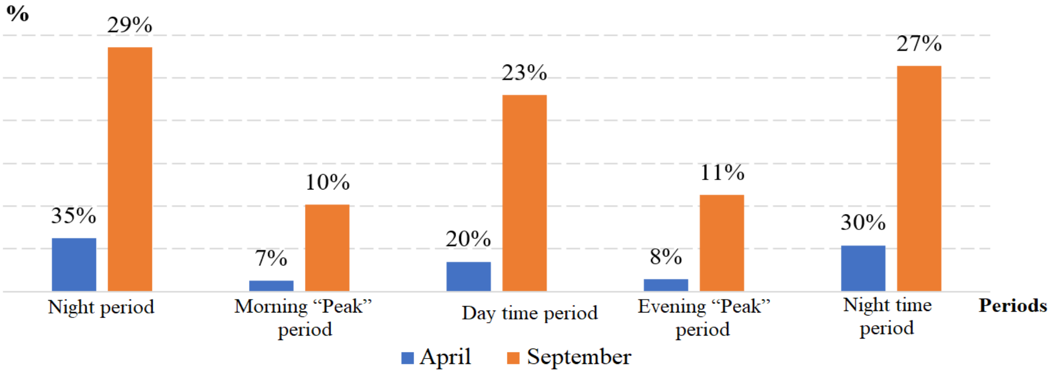

Fig. 6. Use of energy inspection results and application of time-classified tariffs on "Agromir" LLC during the April and September periods of the day in 2020

Since April is the month with the least load on the substation, the electricity consumption in this enterprise in this month using the results of the energy audit and the calculation of the indicators when using and not using the time-classified tariff system is given below,

$$84\ 788\ 493 - 69\ 038\ 493 = 15\ 750\ 000 \text{ sums.}$$

Since September is the month with the most load on the substation, the calculation of the indicators of electricity consumption in this enterprise in this month when using the system of time-classified tariffs and when not using it is given below,

$$472\ 583\ 853 - 412\ 583\ 853 = 60\ 000\ 000 \text{ sums.}$$

The enterprise's electricity consumption in 2020 was 5,574,662 kWh. Average monthly consumption of annual electricity consumption by month was calculated, that is:

$$5\ 574\ 662 \div 12 = 464\ 555 \text{ kW·h}$$

If the electricity consumption of the enterprise in April is 178467 kWh, the following coefficient was obtained when this indicator was compared to the average consumption:

$$464\ 555 \div 178\ 467 = 2{,}6$$

The following result was obtained by dividing the result of the calculation of the the enterprise's indicators when using and not using the system of time-classified tariffs annual electricity consumption by months and multiplying by the average monthly consumption

$$15\ 750\ 000 \cdot 2{,}6 = 40\ 950\ 000 \text{ sums,}$$

40,950,000 sums is the monthly profit of the enterprise due to the use of the results of the energy audit and the application of the time-classified tariff. The following result was obtained if the profit made by the enterprise due to the use of the results of the average monthly energy inspection and the application of the time-classified tariff was multiplied by 12 months of the year.

$$40\ 950\ 000 \cdot 12 = 491\ 400\ 000 \text{ sums.}$$

During the year, the benefit of "Agromir" LLC due to the use of the results of the energy audit and the use of the time-classified tariff amounted to **491,400,000** sums.

In addition, due to the transfer of the consumption of April, when the company consumed the least amount of electricity of the year, to night-time stimulated periods, electricity savings were achieved due to the decrease in the demand for some equipment that worked during the day (some equipment in the auxiliary workshop).

The enterprise's electricity consumption in April 2020 was 178467.09 kWh. Due to the decrease in the demand for some equipment due to the transfer to the night-time stimulated periods, the consumption of electricity in the month with the least electricity consumption of the year was 169367.09 kWh, and the following results were obtained:

$$178467{,}09 - 169367{,}09 = 9100 \text{ kW·h}$$

Savings were achieved in the month of the year (April) when the least amount of electricity was consumed. If 9100 kWh in April is multiplied by 12 months of the year, the following result is obtained:

$$9100 * 12 = \mathbf{109200} \text{ kW·h}$$

The annual amount of electricity saved (in the example of the month of the year with the least electricity consumption). Multiplying the annual saved 109,200 kWh by the average price of the tariff, the following result is obtained:

109200 * 450 = 49 140 000 sums

The following result is obtained by adding the amount of annual saved electricity to the benefit (491,400,000 sums) that the enterprise will see as a result of using the results of the energy audit during the year and applying the time-classified tariff:

491400000 + 49140000 = **540 540 000** sums.

The result of the annual energy saving of the enterprise:

5574662 – 100%; 109200 – x%.

109200 * 100 ÷ 5574662 = **2%**.

4. Conclusions

Summarizing the research results, we can draw the following conclusions:

- The loading graphs of the "electricity supplier-consumer" system were analyzed. As a result, it was found that in the morning and evening "peak" periods, loading increases by 6% compared to the night periods, and by 4% in the daytime periods;
- using the results of energy audits and applying the classified tariffs allows to reduce the loads in the electric power system while reducing consumer costs. As a result, the consumer receives more economic benefits due to consumption during the incentive periods of the tariff system;
- the reliability of equipment operation is increased due to the use of the results of the energy audit of consumers connected to the substation and the prevention of excess loads in the morning and evening "peak" periods of the time-classified tariff system;
- in exchange for the use of the results of the energy audit and the application of the time-graded tariff system, the annual electricity consumption of "Agromir" LLC was achieved by 109,200 kWh (2%) and 540,540,000 sums.

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