Possibilities of applying time-classified tariffs in "smoothing" the loading graph of the electric energy system

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Abstract. In this paper, the impact of the use of time-classified tariffs on the electricity system is considered. That is, the possibility of adjusting the loads on the existing substation in the morning and evening "peak" periods was assessed. In exchange for using the results of the energy audit and applying the system of time-classified tariffs, it will be possible to achieve smoothing of the load schedule of the electric power system during "peak" periods. Consumers' use of the time-classified tariff system will reduce the loading period of the electric power system and change its regimes.

1. Introduction

In order to ensure the stable development of Uzbekistan's electric power system, it is important to develop effective solutions for the use of tariffs, form and regulate the existing ones.

Different methods are used to smooth the load graph in the electric power system. In particular, if some consumers are limited to a certain amount of electricity in "peak" periods, it will be possible to manage other consumers through different tariffs [1].

The main goal of electricity suppliers and consumers in electricity consumption is mutual efficiency. Regulation of tariffs in the electric energy system is one of the methodological aspects of sustainable development of the energy industry.

Due to the fact that the electricity consumption of consumers is different at different times of the day, rugged load graphs in the electric power system arise [2]. For this reason, the ruggedness of load graphs in the electric power system in many countries is a specific problem and causes the use of various methods to solve it [2, 3].

Consumer demand for electricity varies daily, weekly, monthly, quarterly and annually. At the same time, one of the factors that negatively affect the performance of the system is the ruggedness of the daily "peak" period in electricity consumption [4, 5, 6].

In addition, in the period from the beginning of 2020 to October 1, the indicator of electricity delivery to consumers was 44.9 billion. kWh, and it can be observed that the indicator was 1.3 billion kWh more than the corresponding period of 2019.

According to forecasts, the demand for electricity is expected to increase by 70 percent by 2030 compared to 2020.

In the near future, measures are being developed to introduce modern technologies that have been successfully tested in developed countries into practice in Uzbekistan [7].

52.1 billion kWh of electricity was supplied to consumers in 2019, and the average daily consumption in the autumn-winter season was 149.4 mln. kWh (including 47.9 million kWh for the population). In summer, the daily consumption is 162.7 mln. kWh (from which it was 29.2 kWh for the population) (Fig. 1).

It is important to determine the volume of delivered and consumed electricity, current technical condition of power transmission networks, and the amount of technical losses. "Smart networks" aimed at automatic management of network work and quick elimination of detected faults in electrical equipment are being expanded. Research is being conducted on the implementation of the necessary measures to divide the consumed electricity into tariffs depending on the periods of the day [8].

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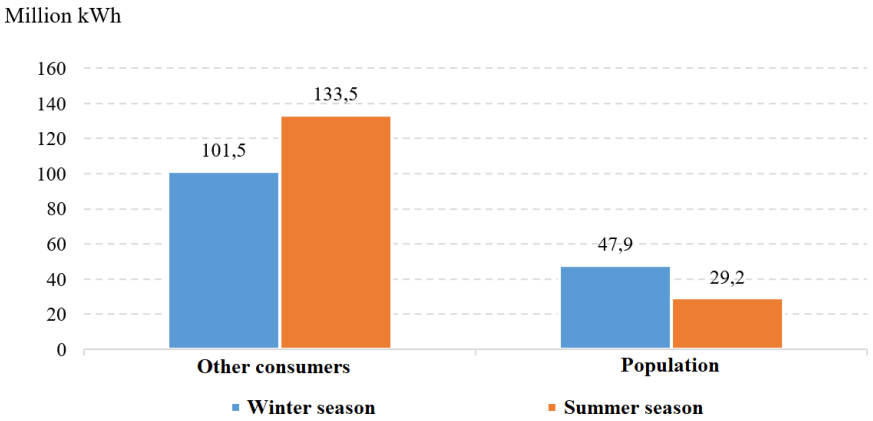

Fig. 1. Average daily consumption in 2019

It is important to regulate the load schedules of the electric power system, that is, to reduce the load during the "peak" periods of the day. It is necessary for the electricity transmission organization to form a real daily electricity load schedule for all consumers in a prescribed manner.

2. Research Methods

If the power consumed in peak periods (ΔP) is reduced by changing the operating mode of the enterprise, the annual consumption power ($a\Delta P$) of the enterprise is also reduced. However, this may lead to a decrease in the production volume of the product. In order to maintain the overall production plan, underproduction during periods of peak consumption can be compensated by more production during nighttime periods.

$$n_0 T_0 = n_1(T_0 - T_3) + n_3 T_3 = n_0 \alpha_1 (T_0 - T_3) + n_3 \alpha_3 T_3; \quad (1)$$

where: T_3 – duration of the enterprise's electricity consumption during the "peak" period of the electric power system, kWh;

α_1 – coefficient of electric energy used for the maximum product that is produced hourly in the maximum periods the electric power system;

α_3 – coefficient of electric energy consumed for the minimum hourly produced product in the maximum periods of the electric power system.

Changing the operating mode of the enterprise leads to a change in the total annual costs. These costs can be expressed as follows:

$$3_1 = \Delta K(E + p) + \Delta\Phi + X_0 + n_0\gamma_0 \times [\alpha_1\beta_1(T_0 - T_3) + \alpha_3\beta_3 T_3] + \\ +(P_0 - \Delta P)a + n_0 d_0[\alpha_1\beta_4(T_0 - T_3) + \alpha_3\beta_6 T_3]b; \quad (2)$$

where: ΔK – additional capital values after the change in the mode of operation;

E – efficiency ratio of capital investments, taking into account the payments;

p – depreciation rate;

$\Delta\Phi$ – change of work mode;

β_1 – coefficient that takes into account the volume of consumption of raw materials and materials in the production unit during the changed working hours;

β_3 – the coefficient that takes into account the volume of consumption of raw materials and materials in the production unit at the time of maximum load;

β_4 – Coefficient that takes into account the change in electricity consumption when production is changed in the interval T_0-T_3;

β_6 - Coefficient that takes into account the change in electricity consumption when production is changed at time T_3;

The annual economic effect of reducing the load at peak times of the electric power system is determined by the following expression:

$$\Delta 3 = a\Delta P + n_0\gamma_0[T_0(1 - \alpha_1\beta_1) + T_3(\alpha_1\beta_1 - \alpha_3\beta_3)] + n_0 d_0[T_0(1 - \alpha_1\beta_4) + \\ +T_3(\alpha_1\beta_4 - \alpha_3\beta_6)]b - \Delta K(E + p) - \Delta\Phi; \quad (3)$$

If $\Delta 3 > 0$, it is appropriate for the enterprise to reduce the amount of electricity consumption during the maximum load of the electric power system.

After a series of transformations, the appropriateness of the electric power system for the enterprise during periods of maximum load is expressed as follows:

$$a > \frac{\Delta K(E+p)+\Delta\Phi}{\Delta P} + \frac{n_0\gamma_0}{\Delta P}[T_0(\alpha_1\beta_1 - 1) + T_3(\alpha_3\beta_3 - \alpha_1\beta_1)] + \frac{n_0 d_0}{\Delta P}[T_0(\alpha_3\beta_4 - 1) + +T_3(\alpha_3\beta_6 - \alpha_1\beta_4)]b; \quad (4)$$

The decrease in electricity consumption during the night or semi-peak periods ($T_0 - T_3$) changes the electricity consumption:

$$\Delta Э_{1,2} = n_0 d_0 (T_0 - T_3)(1\text{-}\alpha_1\beta_4); \quad (5)$$

During the period of maximum consumption (T_3) of the electric power system

$$\Delta Э_3 = n_0 d_0 T_3 (1 - \alpha_3\beta_6); \quad (6)$$

Change in total electricity consumption

$$\Delta Э_\Sigma = n_0 d_0 [(T_0 - T_3)(1 - \alpha_1\beta_4) + T_3(1 - \alpha_3\beta_6)]; \quad (7)$$

If ΔE>0, then the volume of the load in the operating mode, that is, the consumption of electricity, decreases, if ΔE<0, the consumption of electricity increases.

After changing the periods of electricity consumption (due to the increase in electricity prices in "peak" periods), the period of maximum demand decreases:

$$3_1\Delta K(E + p) + X_0 + \Delta\Phi + n_0\gamma_0(\alpha_1\beta_1 T_1 + \alpha_2\beta_2 T_2 + \alpha_3\beta_3 T_3) + +n_0 d_0(\alpha_1\beta_4 T_1 b_1 + \alpha_2\beta_5 T_2 b_2 + \alpha_3\beta_6 T_3 b_3); \quad (8)$$

where: $\alpha_1, \alpha_2, \alpha_3$ – T_1, T_2 and T_3 a coefficient that takes into account production in hourly load periods;

$\beta_1, \beta_2, \beta_3$ - T_1, T_2 and T_3 the coefficient that takes into account the change in the consumption of raw materials and materials in production during the hourly load periods;

$\beta_4, \beta_5, \beta_6$ – T_1, T_2 and T_3 a coefficient that takes into account the change in the consumption of certain energy when changing it in hourly load periods.

If the consumption of 1 kW·h during the peak period (T_3, T_2) is transferred to the less valuable time (T_1, T_2), the annual economic effect is achieved,

$$\Delta З = n_0 d_0 [T_1 b_1(1 - \alpha_1\beta_4) + T_2 b_2(1 - \alpha_2\beta_5) + T_3 b_3(1 - \alpha_3\beta_3)] + +n_0\gamma_0[T_1(1 - \alpha_1\beta_1) + T_2(1 - \alpha_2\beta_1) + T_2(1 - \alpha_2\beta_2) + T_3(1 - \alpha_3\beta_3)] - - \Delta K(E+p)\text{-}\Delta\Phi; \quad (9)$$

In this case, electricity consumption changes to the following value during the night, semi-peak and peak (T_1, T_2, T_3) periods:

$$\Delta Э_1 = n_0 d_0 T_1 (1 - \alpha_1\beta_4); \quad (10)$$

$$\Delta Э_2 = n_0 d_0 T_2 (1 - \alpha_2\beta_5); \quad (11)$$

$$\Delta Э_3 = n_0 d_0 T_3 (1 - \alpha_3\beta_6); \quad (12)$$

The total change in electrical energy is expressed as:

$$\Delta Э_\Sigma = n_0 d_0 [T_1(1 - \alpha_1\beta_4) + T_2(1 - \alpha_2\beta_5) + T_3(1 - \alpha_3\beta_6)]; \quad (13)$$

In any electricity consumers, there are certain minimum and maximum periods of consumption time. This, in turn, is directly related to time-classified tariffs.

3. Results and Discussions

It is necessary to increase the efficiency of electric energy and reduce the consumption of electric energy during the "peak" periods of the day. As a result, it is possible to reduce the load on the electric power system and increase the efficiency of consumers.

Research work was carried out in the following enterprises:

- «O'z-HANWOO» LLC JV ("Uzavtosanoat" JSC and "HANWOO GLOBAL Co.Ltd" Republic of Korea);
- «O'Z ERAE CLIMATE CONTROL» LLC JV ("Uzavtosanoat" JSC and "Erae cs Limited" Republic of Korea);
- Research work was carried out at "UzAuto Austem" LLC JV (Uzavtosanoat and AUSTEM Co.Ltd, Republic of Korea).

The months of the year with the least and most electricity consumption in the enterprises were conducted according to the periods of the day. As a result of this research, annual electricity savings and economic efficiency will be achieved due to the use of the tariff system in enterprises.

Enterprises are the main part of consumers connected to the 220/35/10 kV "Babur" substation. In terms of electricity consumption, household (population) consumers also consume almost as much as enterprises (Fig. 2).

The total number of consumers of the 220/35/10 kV "Babur" substation are 35, 5 of the cells are household consumers. The total consumption of consumers through the substation in 2020 was 182,225,314 kWh.

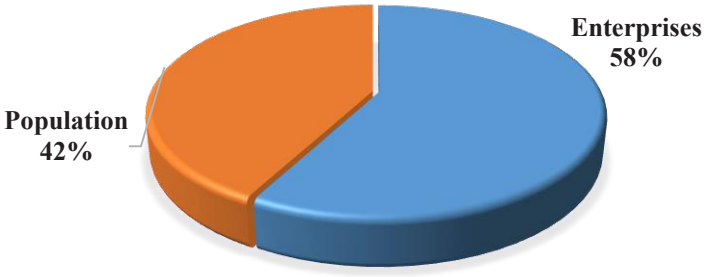

Fig. 2. 220/35/10 kV "Babur" substation's share of population and enterprises in electricity consumption (%)

Research was conducted on the lowest and highest electricity consumption months of 2020 in enterprises, i.e.:

- "Uz-HANWOO" LLC JV has the lowest in May (170,000 kWh), the highest in February (343,000 kWh);
- "O'Z ERAE CLIMATE CONTROL" LLC JV is the least in January (262784.6 kW·h), the most in February (375300.7 kW·h);
- "UzAuto Austem" LLC JV was observed to be the lowest in May (410,220 kWh), and the highest in February (548,940 kWh).

Enterprises make payments according to the tariffs, i.e. I-tariff, classified tariffs specified in the contract concluded with the municipal electric network enterprise (MENE). In 2020, the following results will be obtained if enterprises make payments according to the periods of the day in the months of the lowest and highest electricity consumption (Table 1).

Table 1. Payment indicators of enterprises by periods of the day in the months of the lowest and highest electricity consumption in 2020

Name of enterprises	**Electric energy (kWh) / Cost amounts (sums)**	**Months**	**From 00:00 to 6:00, From 22:00 to 00:00**	**From 06:00 to 09:00**	**From 09:00 to 17:00**	**From 17:00 to 22:00**	**TOTAL:**
«O'z-HANWOO» LLC	Electricity consumption (kWh)	May	39917	23943	74526	31614	**170000**
		February	83784	46700	148825	63691	**343000**
	Tariff prices (sums)		**300**	**675**	**450**	**675**	
	Tariff costs for the period of consumption (sums)	May	11975100	16161525	33536700	21339450	**83012775**
		February	25135200	31522500	66971250	42991425	**166620375**
«O'Z ERAE CLIMATE CONTROL» LLC	Electricity consumption (kWh)	January	81847,55	31781,4	93534	55621,61	**262784,6**
		February	122930,7	45557,88	130681	76131,18	**375300,8**
	Tariff prices (sums)		**300**	**675**	**450**	**675**	
	Tariff costs for the period of consumption (sums)	January	24554265	21452445	42090300	37544586	**125641596**
		February	36879207	30751569	58806450	51388546,5	**177825773**
«O'zAuto Austem» LLC	Electricity consumption (kWh)	May	115745,4	52278,75	168642,1	73553,69	**410220**
		February	154919,4	68078,75	213798,1	112143,7	**548940**
	Tariff prices (sums)		**300**	**675**	**450**	**675**	
	Tariff costs for the period of consumption (sums)	May	34 723 614	35 288 156	75 888 963	49 648 741	**195549474**
		February	46 475 814	45 953 156	96 209 163	75 696 991	**264335124**

For these consumers, it is economically efficient to consume during the night-time stimulated periods. For the electric energy system, this system of tariffs allows to eliminate morning and evening peak loads [9].
In enterprises, it is recommended to increase the consumption during the night by reducing the consumption during the day-time and "peak" periods of the day.
As a result:

firstly, the price of the produced products will be reduced due to low tariff prices in the night periods;

secondly, it is possible to reduce the load on the 220/35/10 kV "Babur" substation in the electric power system during the morning and evening "peak" periods.

Table 2 shows the results of using the results of the energy audit in the months of the year with the least and most electricity consumption and the application of time-classified tariffs.

Table 2. Indicators of using energy audit results and application of tariffs classified by time in the months of the year when enterprises consume the least and most electricity

Name of enterprises	**Electric energy (kWh) / Cost amounts (sums)**	**Months**	**From 00:00 to 6:00, From 22:00 to 00:00**	**From 06:00 to 09:00**	**From 09:00 to 17:00**	**From 17:00 to 22:00**	**TOTAL:**
«O'z-HANWOO» LLC	Electricity consumption (kWh)	May	66873	18943	44126	31514	**161456**
		February	140584	38700	92825	54691	**326800**
	Tariff prices (sums)		**300**	**675**	**450**	**675**	
	Tariff costs for the period of consumption (sums)	May	20061900	12786525	19856700	21271950	**73977075**
		February	42175200	26122500	41771250	36916425	**146985375**
«O'Z ERAE CLIMATE CONTROL» LLC	Electricity consumption (kWh)	January	98847,55	26781,4	80234	48621,61	**254484,6**
		February	129530,7	41857,88	113981	73631,18	**359000,8**
	Tariff prices (sums)		**300**	**675**	**450**	**675**	
	Tariff costs for the period of consumption (sums)	January	29654265	18077445	36105300	32819586,8	**116656597**
		February	38859207	28254069	51291450	49701047	**168105773**
«O'zAuto Austem» LLC	Electricity consumption (kWh)	May	148445,4	47578,75	128442,1	77053,69	**401520**
		February	198119,4	59378,75	168678,1	107043,7	**533220**
	Tariff prices (sums)		**300**	**675**	**450**	**675**	
	Tariff costs for the period of consumption (sums)	May	44533614	32115656	57798963	52011241	**186459474**
		February	59435814	40080656	75905163	72254491	**247676124**

The following results were obtained according to the use of the results of the energy audit of the energy consumption in the months of 2020 with the least electricity consumption of the enterprises and the tariff system stratified by time (Table 3).

Table 3. Months of 2020 with the least electricity consumption in periods of the day

kWh / Sum	«O'z-HANWOO» LLC	«O'Z ERAE CLIMATE CONTROL» LLC	«O'zAuto Austem» LLC
When not using the tariff (kWh)	170000	262784	410220
When using the tariff (kWh)	161456	254484	401520
Difference between (kW·h)	**8544**	**8300**	**8700**
Price when not using the tariff (sums)	83012775	125641596	195549474
Price when using the tariff (sums)	73977075	116656597	186459474
Difference between (sums)	**9035700**	**8984999**	**9090000**

According to the results of Table 3, in the months when enterprises consumed the least amount of electricity in 202, 8544, 8300, 8700 kWh of electricity and 9035700, 8984999, 9090000 soums were saved.
If this saved electricity and the saved amount are multiplied by 12 months of the year, the following result was obtained (Table 4).

Table 4. Annual indicators of months with the least electricity consumption in 2020

kWh / Sums	«O'z-HANWOO» LLC	«O'Z ERAE CLIMATE CONTROL» LLC	«O'zAuto Austem» LLC
Electricity saved in the month of minimum consumption (kW·h)	8544	8300	8700
One year (month)	12	12	12
Annually saved electricity (kW·h)	**102528**	**99600**	**104400**
The cost amount saved in the month of minimum consumption (soums)	9035700	8984999	9090000
One year (month)	12	12	12
Annual savings amount (sums)	**108428400**	**107819988**	**109080000**

According to the results of Table 4, based on the calculation of the months when enterprises consumed the least amount of electricity in 2020, 102528, 99600, 104400 kWh of electricity and 108428400, 107819988, 109080000 soums were saved per year.
The annual average saved electricity of the enterprises and the amount were determined. The results of the months of 2020 with the most electricity consumption in the daily periods were obtained. The results were calculated using tariffs classified by utilization and time from the results of the energy audit and were as follows (Table 5).

Table 5. Consumption in periods of the day in months with the most electricity consumption in 2020

kWh / Sums	«O'z-HANWOO» LLC	«O'Z ERAE CLIMATE CONTROL» LLC	«O'zAuto Austem» LLC
When not using the tariff (kWh)	343000	375300	548940
When using the tariff (kWh)	326800	359000	533220
Difference between (kW·h)	**16200**	**16300**	**15720**
Price when not using the tariff (sums)	166620375	177825773	264335124
Price when using the tariff (sums)	146985375	168105779	247676124
Difference between (sums)	**19635000**	**9719994**	**16659000**

According to the results of Table 5, in the months when enterprises consumed the most electricity in 2020, 16200, 16300, 15720 kWh of electricity and 19635000, 9719994, 16659000 soums were saved.
The following result was obtained by multiplying the amount of electricity saved in the months when enterprises consumed the most electricity in 2020 and the amount saved by 12 months of the year (Table 6).

Table 6. Annual indicators of the months with the most electricity consumption in 2020

kWh / Sums	«O'z-HANWOO» LLC	«O'Z ERAE CLIMATE CONTROL» LLC	«O'zAuto Austem» LLC
Electricity saved in the month of minimum consumption (kW·h)	16200	16300	15720
One year (month)	12	12	12
Annually saved electricity (kW·h)	**194400**	**195600**	**188640**
The cost amount saved in the month of minimum consumption (soums)	19635000	9719994	1665900
One year (month)	12	12	12
Annual savings amount (sums)	**235620000**	**116639928**	**199908000**

According to the results of Table 6, based on the calculation of the months in which enterprises consumed the most electricity in 2020, 194400, 195600, 188640 kWh of electricity and 235620000, 116639928, 199908000 soums were saved per year.

It is necessary to use the results of energy audits in enterprises and to distribute electricity consumption in tariff periods classified by time. Increasing the consumption of enterprises during the stimulated periods of the night is beneficial to the "electricity supplier-consumer" system [10].

In recent years, the system of time-classified tariffs has been introduced in the republic only for consumers with an installed capacity of 750 kVA and above. The culture of using these tariffs has not yet been fully formed among consumers. But the research conducted in enterprises on this tariff system gave its results.

In enterprises, it is important to use the results of energy audits and apply time-classified tariffs. Shifting the consumption of electricity during the "peak" periods of the day to the stimulating periods of the night increases the possibility of obtaining significant results [11, 12, 13].

Table 7 shows the results of using the results of the energy audit and the use of tariffs classified by time in the months when the enterprises consume the least and the most electricity.

Table 7. Performance indicators of using energy audit results in enterprises and the application of time-classified tariffs in 2020

Name of enterprises	Electricity saved in the month of minimum consumption (kWh)	Electricity saved in the month of highest consumption (kWh)	The sum of the lowest and highest consumption months (kWh)	Average monthly figure of the lowest and highest consumption months (kW·h)	**Annually saved electricity (kW·h)**	The average tariff price (15.08.2019) It is set by price (soum)	**Annual amount of electricity saved (soums)**	Consumed electricity (kW·h)	**Annual percentage of electricity saved (%)**
«O'z-HANWOO» LLC	8544	16200	24744	12372	**148464**	450	**66808800**	3213000	**4,6**
«O'Z ERAE CLIMATE CONTROL» LLC	8300	16300	24600	12300	**147600**		**66420000**	3686531,4	**4**
«O'zAuto Austem» LLC	8700	15720	24420	12210	**146520**		**65934000**	5432760	**2,7**
TOTAL:	25544	48220	73764	36882	**442584**		**199162800**	12332291	**11,3**

It can be seen from Table 7 that the annual saved electricity of the enterprises was 442584 kWh. The annual money of electricity saved is 199,162,800 soums. Due to the use of the results of energy audits in enterprises and the use of time-classified tariffs, the annual amount of total electricity saved was 11.3%.

The total annual savings of the enterprises as a result of using the results of the energy audit and the indicators of using time-classified tariffs was as follows (Table 8).

Table 8. Total annual savings of enterprises

Name of enterprises	The cost of electricity saved in the lowest consumption month of the year (sums)	The cost of electricity saved in the month of highest consumption of the year (sums)	Average cost of electricity saved per month (sums)	Annual savings cost (sums)	Use of time-classified tariffs	**Total cost saved annually (sums)**
«O'z-HANWOO» LLC	9035700	19635000	14335350	172024200	66808800	**238833000**
«O'Z ERAE CLIMATE CONTROL» LLC	8984999	9719994	9352496	112229952	66420000	**178649952**
«O'zAuto Austem» LLC	9090000	16659000	12874500	154494000	65934000	**220428000**
Total for three enterprises:	27110699	46013994	36562346	438748152	199162800	637910952

Using the results of the energy audit in the above enterprises, the effect on the 220/35/10 kV "Babur" substation was determined using time-classified tariffs. The total number of consumers is 35, and the results of which only the consumers with installed capacity of 750 kVA and above are currently received.

Due to using the results of the energy audit and the payment according to the system of time-classified tariffs:

"Uz-HANWOO" LLC JV (148464 kWh);

"OZ ERAE CLIMATE CONTROL" LLC JV (147,600 kWh);

"UzAuto Austem" LLC JV (146520 kWh) reduction was achieved.

The annual peak period of enterprises was 442,584 kWh or 0.24% of the total electricity consumption (Fig. 3).

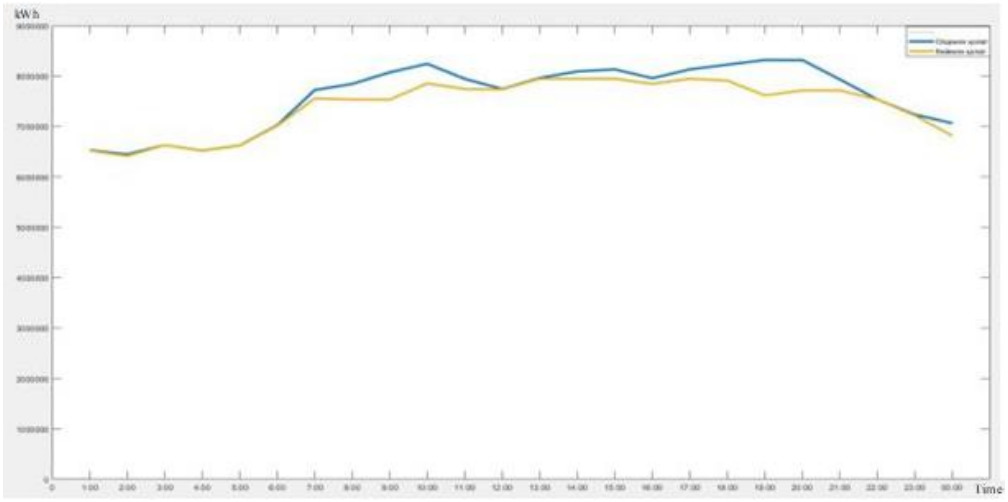

Fig. 3. Due to the use of time-classified tariffs for consumers of 220/35/10 kV "Babur" substation during morning and evening "peak" periods before and after the falling load

442 584 kWh/3 = 147 528 kWh * 30 = 4 425 840 kWh * 100% / 182 225 314 kWh 2.4% total reduction was created.

4. Conclusions

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

- Annual electricity saving of "Uz-HANWOO" LLC JV is 148,464 kWh, i.e. 4.6% per year, and due to the use of the results of the energy audit for the consumed electricity and the use of time-classified tariffs, the enterprise has achieved savings of 238,833,000 sums per year .
- Annual electricity saving of "O'Z ERAE CLIMATE CONTROL" LLC JV is 147,600 kWh, i.e. 4%, and due to the use of energy audit results and the use of time-classified tariffs for consumed electricity, the enterprise saved 178,649,952 sums per year.
- Annual electricity saving of "UzAuto Austem" LLC JV is 146,520 kWh, i.e. 2.7%, and due to the use of the energy audit results and the use of time-classified tariffs for the consumed electricity, the enterprise saved 220,428,000 sums per year.

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