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The Role of Time-Stratified Tariffs in Alignment of the Load Graph of the Electric Energy System

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ABSTRACT: In this article, the effective use of time-of-day tariff systems is of significant importance in leveling out the irregularity of the load schedules of the electric power system and in adjusting the load schedules of electricity consumption by consumers. Specifically, the role of tariffs in the energy system and methods of managing and improving electricity consumption modes by correctly utilizing tariff periods in electricity consumption are also discussed. Additionally, the time-of-day tariff system has been analyzed as a tool for adjusting the load schedules and leveling out the load schedules of consumers in the electric power system.

KEY WORDS: electric energy systems, electric energy, tariff, time-differentiated tariff system, consumers, Electrical energy.

I. INTRODUCTION

Economic relations between electric energy systems - producers of electric energy and its consumers - sectors of the national economy are regulated by tariffs for electric energy. The economy of the entire national economy essentially depends on the perfection of these relations [1; p.5].

Consumption and costs in the electric energy system are not the same, the increase in the demand for electric energy in "peak" periods causes an increase in the load in the system. However, the amount of payment for electricity consumed by consumers for these periods is the same according to the tariff, which leads to an increase in expenses of the supplying organizations [2;pp.190-193].

II. LITERATURE SURVEY

A system of certain tariffs is needed to make financial settlements between electricity producers and consumers [3; p.19-29]. Without going into the details of electricity price calculation, we can formulate the following basic requirements for tariffs [4]:

• tariffs should reflect all types of expenses related to further development, production and transmission of electric energy;
• reducing the economic costs related to the production and supply of electricity should be reflected in the tariffs;
• tariffs should be differentiated depending on consumption periods, time of day, days of the week and seasons [3; pp.19-29, 4; pp.50-58];
• the expediency of introducing tariffs differentiated by regions of the country should be considered;
• tariffs should encourage consumers to reduce their consumption during peak hours and increase their consumption during night hours;
• tariffs should take into account electricity consumption as much as possible and simplify calculations with consumers [1; pp.66-67].

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III. RESEARCH MATERIALS AND METHODS

In Uzbekistan, until January 1, 2018, settlements with consumers who have several tariff groups (10 groups) were carried out according to the indicators of the metering devices installed in each tariff group (Table 1) [5, 6; pp.20-25]. The disadvantage of this tariff system was that the electricity system did not have an economic incentive for electricity consumers to participate in grid balancing, and it is understood that electricity consumers were not interested in participating in grid balancing.

Table 1
It was in the Republic of Uzbekistan until January 1, 2018
tariff system for electricity

Group I	Industrial and equivalent consumers with a connected capacity of 750 kVA and above. Two-rate tariff: payment for 1kW of peak load per year. Payment for 1kW·h of consumed energy.
Group II	Industrial and equivalent consumers, connected power up to 750 kVA. One-rate tariff: payment for 1kW·h of consumed energy.
Group III	Production agricultural consumers, including pumping stations financed from the budget.
Group IV	Electrified railway and transport (electric traction).
Group V	Non-industrial consumers, budget organizations, city street lighting.
Group VI	Trade organizations, cafes, restaurants and service industry enterprises.
Group VII	Population, settlements
	Residents of residential areas equipped with electric plates.
Group VIII	Electricity used for heating, hot water supply and cooling (air conditioning) needs.
Group IX	Advertising, illumination.
Group X	To economic affairs of the energy system.

In order to achieve significant results in the balancing of load schedules in the electric power system, economic stimulation of the participation of electricity consumers in balancing the load schedules is the main condition, and the main tool for its creation is the time-differentiated tariff system.

Differentiating tariffs by 24-hour zone by encouraging night-time electricity consumption encourages the participation of daily electricity consumers in equalizing load schedules, thereby contributing to fuel savings by improving equipment performance. Due to such time stratification of tariffs, the cost of electricity for consumers will decrease. The use of differentiated tariffs by consumers leads to the flattening of the load graphs of the electric power system and the reduction of electricity prices [3; pp.19-29].

Starting from January 1, 2018, the number of consumer groups in the Republic of Uzbekistan was reduced from 10 to 4.

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Table 2
Electricity Tariff System in the Republic of Uzbekistan
After January 1, 2018

Group I	Consumers with a connected capacity of 750 kVA or more who settle payments for electricity based on differentiated tariffs (excluding budget organizations, farms, pump stations of water consumer associations, as well as pump stations financed by the state budget).
Group II	Consumers, other than residential consumers, who settle payments for electricity based on a single-rate tariff.
Group III	Residential consumers.
	For residential consumers living in multi-apartment buildings and dormitories equipped with electric stoves and having more than ten floors.
Group IV	For electricity used by consumers in Tariff Groups I and II for technological purposes, including heating buildings, hot water supply, and food preparation.

One of the most important requirements for tariff systems is to focus on solving the most important system-wide problem of matching tariffs to the cost structure of electric power systems and equalizing the load schedule of electric power systems.

As stated in paragraph 2 "a" of the decision of the President of the Republic of Uzbekistan "On measures to ensure the rational use of energy resources" No. a large amount») payments for the used electric energy have an increasing coefficient of 1.5 times compared to the established tariff by application, and in the hours with the lowest load (night time of the day) [7; pp. 536-562, 9] is carried out by applying a reduction factor of 1.5 times compared to the set tariff and at the set tariff during half-"peak" time (daylight hours) [5; 8; 7; 89, 93, 7; pp.536-562].

According to the decision, from January 1, 2018, consumers connected to the system of time-differentiated tariffs with a capacity of 750 kVA and above (with the exception of pumping stations of budget organizations, farms and water consumer associations, as well as pumping stations financed from the state budget) [5;9] Tariff for legal entities making payments for electricity according to the second group of tariffs is carried out according to the differentiated tariff of daily hours determined in the amount [8; 5; 9; 10].

It is impossible to solve the problem of equalizing the load graphs of the electric power system using the system of differentiated tariffs by time zones without determining the reasonable boundaries of the relevant time zones (Fig.1).

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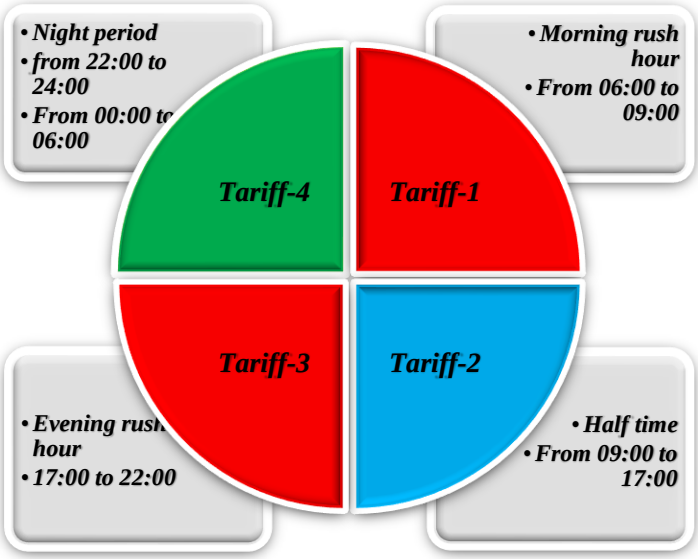

Figure-1. Time-graded tariff and its periods

The time-differentiated tariff system is distinguished by its convenience for both electricity producers and consumers. In this system, during the peak hours of the unified power system, specifically:

Peak time - Payments for electricity consumed during the designated morning and evening "maximum usage" periods are subject to a 1.5 times higher multiplier applied to the established tariff [3; 5; 6].

During the off-peak hours:

Night time - Payments for electricity consumed during the dark hours of the day are subject to a 1.5 times lower multiplier applied to the established tariff [5; 9].

Mid-peak time - Payments for electricity consumed during daylight hours are made based on the standard tariff [5; 9].

Taking into account the above tariff periods, the calculation of time-graded tariff periods for electricity for three periods (zones) of the day is expressed by the following expression [6; pp.20-25].

IV. METHODOLOGY

Determining the electricity consumption patterns of industrial enterprises involves identifying consumption during the differentiated tariff periods and developing payment periods for electricity consumption during the system's peak hours. The daily electricity consumption of the system should be thoroughly studied to identify the periods of minimum and maximum electricity usage [11; pp. 123–137, 3; pp. 19–29].

The mathematical form for each tariff period is as follows:

1. $n_{мин} \le n_i \le n_{мах}, i=\overline{1,\ m}$;
2. $0 \le d_i n_i P, i=\overline{1,\ m}$;
3. $П - \varepsilon_1 \le \sum_{i=1}^{m} n_i t_i < П + \varepsilon_2$. (1)

Where: n_i – the tariff set for the required period;

m – the number of tariff periods;

$n_{мин}$, $n_{мах}$ – minimum and maximum consumption capacities during the periods, in kW;

t_i – duration of the tariff period, in hours;

$d_i = d_i(n_i)$ – electricity consumed during the tariff period, in kWh;

P – the defined electricity supply capacity, in kW;

П – the planned daily production output [12; pp. 67–68].

The costs per unit of product manufactured are calculated as follows:

$$З_i = d_i(n_i)b_i + \sum_{i=1}^{l} a^k \alpha_k + C; \quad (2)$$

Where: $З_i$ – costs per unit of manufactured product (for technological processes);

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$b_i > 0$ – the price per kWh of electricity during the specified tariff period, in the local currency;

$a^1, a^2, \ldots, a^k$ – consumption of raw materials, fuel, water, and other inputs required per unit of production;

$$a^k = f(n_i), \quad a^k > 0; \tag{3}$$

$\alpha_1, \alpha_2, \ldots, \alpha_l$ – unit costs;

C>0 – fixed costs per unit of production.

Every consumer has specific periods of electricity consumption, namely, minimum and maximum periods, which are directly linked to time-differentiated tariffs [11; pp. 123–137].

Until January 1, 2018, the tariff system in Uzbekistan primarily focused on covering electricity supply costs, limiting consumers' ability to fully manage their electricity consumption patterns. Analyzing the experiences of developed countries demonstrates the feasibility and objective necessity of introducing a more extensive tariff system that accounts for work schedules and operational characteristics [12; pp. 67–68]. This approach is particularly suitable for industrial enterprises and organizations capable of timely adjusting their work schedules and technological processes.

V. CONCLUSION

The effective use of time-differentiated tariff systems in managing consumers' electricity consumption patterns leads to a reduction in electricity consumption during peak load periods in the morning and evening. To alleviate the demand during "congested" periods in the power system, time-differentiated tariffs are introduced into the electricity supply system. A two-period tariff system, covering daytime and nighttime rates, is utilized to manage consumption across these two distinct periods.

As mentioned above, the unevenness of the load schedule in the electricity system is determined by electricity consumption patterns. Electricity tariffs significantly influence the load schedules of electricity consumption. By improving the tariff system, it is possible to incentivize a reduction in electricity consumption during peak load hours and an increase in consumption during off-peak hours. This serves as one of the most critical factors affecting electricity consumption patterns.

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