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Analysis of Opportunities to Reduce Energy Waste in Distribution Transformers By Applying Time-Differentiated Tariffs

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ABSTRACT: increasing the electric power system's effectiveness, avoiding distribution transformer overloads, lowering the amount of electricity wasted in transformers, enhancing the ASECA system's dependability in the power system, and improving it. Analysis of the impact of leveling electricity load graphs on enhancing the electric power system's tariff structure, implementing the differentiated tariff structure in residential areas, reducing energy waste in transformers as a result of implementing the differentiated tariff structure, and raising system reliability.

KEYWORDS: increasing efficiency, differentiated tariffs, ASECA-automated systems of electricity control and accounting, reducing energy waste, electricity load graphs, increasing reliability, reducing waste.

I.INTRODUCTION

A number of initiatives are being put into place to meet the nation's demand for electricity at reasonable prices, as well as to modernize and reconstruct existing power plants, construct new production facilities based on high-efficiency energy production technologies, enhance the electricity accounting system, and expand the use of renewable energy sources.

As in many countries of the world, in our country, the electric power sector is one of the areas of natural monopolies. In other words, due to the absence or slowness of the competitive environment in the market, electricity generation, transmission and delivery to consumers is regulated and managed by the government, entered into the register of natural monopolies.

The article provides information on the analysis of the consumption of distribution transformers with a capacity of 630 kVA installed in residential areas and the part of the consumed electricity that is wasted.

II.MATERIALS AND METHODS

Consumers' demand for electricity is very high during the morning and evening rush hours. This creates a very large fluctuation of the electrical load graphs. In this case, the fluctuations that occur have a negative effect on the operation mode of distribution transformers. Table 1 shows information about the electricity consumed by consumers of the distribution transformer with a capacity of 630 kVA in 5 periods of the day.

Table 1

Share of consumers in total consumption					
	Period 1 From (00:00 to 06:00	Period 2 From 06:00 to 09:00	Period 3 From 09:00 to 17:00	Period From 17:00 to 22:00	Period 5 From 22:00 to 00:00
kW hour	514 kW hour	1308 kW hour	930 kW hour	1308 kW hour	314 kW hour
Percentage of total	11,2 %	28,5 %	27,14 %	20,3 %	11,2 %

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Vol. 10, Issue 10, October 2023

consumption %					
Total:	**4574** kW hour				

The máximum daily energy consumption of consumers is 4574 kW·h and consists of a total of 169 consumers. 4 of the consumers are production enterprises (450 sums/kWh, compared to 2023), 165 are residential buildings (295 sums, compared to 2023).

Based on the indicators of the balance meter installed on the distribution transformer, we determine the electricity consumed in each hour of the day in Table 2.

Table 2

$P_{1-\text{period}} = \frac{W_{1-\text{period}}}{T_1} = \frac{514}{6} = 85{,}6 \text{ kW}$
$P_{2-\text{period}} = \frac{W_{2-\text{period}}}{T_2} = \frac{1308}{3} = 436 \text{ kW}$
$P_{3-\text{period}} = \frac{W_{3-\text{period}}}{T_3} = \frac{930}{8} = 116{,}2 \text{ kW}$
$P_{4-\text{period}} = \frac{W_{4-\text{period}}}{T_4} = \frac{1308}{5} = 261{,}6 \text{ kW}$
$P_{5-\text{period}} = \frac{W_{5-\text{period}}}{T_5} = \frac{514}{2} = 157 \text{ kW}$

Here : $P_{1-\text{period}}$, $P_{2-\text{period}}$, $P_{3-\text{period}}$, $P_{4-\text{period}}$, $P_{5-\text{period}}$ – active power consumed in every hour of each period (kW).

$W_{1-\text{period}}$, $W_{2-\text{period}}$, $W_{3-\text{period}}$, $W_{4-\text{period}}$, $W_{5-\text{period}}$ – energy consumed per period (kW·h)

T_1, T_2, T_3, T_4, T_5 - time allocated to each period (hours).

The balance meter installed in the transformer calculates the active and reactive energies for 5 cycles. Table 3 provides information about reactive energy consumed in each period and its percentage in relation to total consumption. Finding the reactive power consumed in each hour of each period is presented in Table 4.

Table 3

Five-cycle reactive power demand					
	1-period From 00:00 to 06:00	2-period From 06:00 to 09:00	3-period From 09:00 to 17:00	4-period From 17:00 to 22:00	5-period From 22:00 to 00:00
kVar	42 kVar	108 kVar	56 kVar	100 kVar	38 kVar
Percentage of total consumption %	10,43 %	29,5 %	20,14 %	29,5 %	10,43 %
Total:	**328 kVar**				

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 10, Issue 10, October 2023

Table 4

$Q_{1-\text{period}} = \frac{W_{1\text{p}}}{\text{T}_1} = \frac{42}{6} = 7\ \text{kVar}$
$Q_{2-\text{period}} = \frac{W_{2\text{p}}}{\text{T}_1} = \frac{108}{3} = 36\ \text{kVar}$
$Q_{3-\text{period}} = \frac{W_{3\text{p}}}{\text{T}_3} = \frac{56}{8} = 7\ \text{kVar}$
$Q_{4-\text{period}} = \frac{W_{4\text{p}}}{\text{T}_4} = \frac{100}{5} = 20\ \text{kVar}$
$Q_{5-\text{period}} = \frac{W_{5\text{p}}}{\text{T}_5} = \frac{38}{2} = 19\ \text{kVar}$

Here: $Q_{1-\text{period}}, Q_{2-period}, Q_{3-\text{period}}, Q_{4-\text{period}}, Q_{5-\text{period}}$ – reactive power consumed per hour of each period (kVar)

$\text{T}_1, \text{T}_2, \text{T}_3, \text{T}_4, \text{T}_5$ time allocated to each period (hours).

Finding the total power consumed for 5 periods of the day is given in the following formula 1. Calculation of full power is determined by the following formula 4.2.

$$S = \sqrt{\text{P}_{1\ \text{day}}{}^2 + Q_{1\ \text{day}}{}^2} \quad (1)$$

Here: $\text{P}_{1\ day}$ active power consumed during one day,

$Q_{1\ day}$ reactive power consumed during one day,

Finding the full power consumption in each period is presented in Table 5. The information in the table shows that the consumption of electricity in the morning and evening peak periods is significantly higher than in other periods of the dayThis overloads distribution transformers and switching devices, reduces the service life of electrical equipment and reduces the level of reliability of the energy system.

Table 5

	Active power kW	Reactive power kVar	Full power kVA
1-period	85,6	7	$S_{1-\text{period}} = \sqrt{\text{P}_{1-\text{period}}{}^2 + Q_{1-\text{period}}{}^2} = 86\ \text{kVA}$
2-period	436	36	$S_{2-\text{period}} = \sqrt{\text{P}_{2-\text{period}}{}^2 + Q_{2-\text{period}}{}^2} = 438\ \text{kVA}$
3-period	116	7	$S_{3-\text{period}} = \sqrt{\text{P}_{3-\text{period}}{}^2 + Q_{3-\text{period}}{}^2} = 117\ \text{kVA}$
4-period	261	20	$S_{4-\text{period}} = \sqrt{\text{P}_{4-\text{period}}{}^2 + Q_{4-\text{period}}{}^2} = 262\ \text{kVA}$
5-period	157	19	$S_{5-\text{period}} = \sqrt{\text{P}_{5-\text{period}}{}^2 + Q_{5-\text{period}}{}^2} = 158\ \text{kVA}$

- Finding active power dissipation in transformers depends on the following technical indicators.Qisqa tutashuv vaqtida bo‘ladigan quvvat isrofi $\Delta\text{P}_{q.t}$,birinchi davrda istemol qilinadigan umumiy to‘la quvvat S_{1-davr} , transformatirning nominal quvvati S_{nom}, transformatorga iste’molchilar ulanmagan holatdagi aktiv quvvat isrofi $\Delta\text{P}_{s.ish}$, demak transformatorda bo‘ladigan aktiv quvvat isrofini quyidagi 1-formula orqali aniqlaymiz

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Vol. 10, Issue 10, October 2023

Power loss during a short circuit $\Delta P_{q.t}$, total power consumed in the first period $S_{1-period}$, nominal power of the transformer S_{nom}, active power loss $\Delta P_{s.ish}$ when consumers are not connected to the transformer, so the active power loss in the transformer can be determined by the following formula 1 let's find out.

$$\Delta P_{oddiy} = \Delta P_{q.t}\left(\frac{S_{1-period}}{S_n}\right)^2 + \Delta P_{s.ish} \quad (1)$$

We find the active power consumed in transformers separately for 5 cycles.

Table 6

$\Delta P_{1-oddiy} = \Delta P_{q.t}\left(\frac{S_{1-period}}{S_n}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{86}{630})^2 + 1.56 = 1{,}72$
$\Delta P_{2-oddiy} = \Delta P_{q.t}\left(\frac{S_{2-period}}{S_n}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{438}{630})^2 + 1.56 = 5{,}24$
$\Delta P_{3-oddiy} = \Delta P_{q.t}\left(\frac{S_{3-period}}{S_n}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{117}{630})^2 + 1.56 = 1{,}83$
$\Delta P_{4-oddiy} = \Delta P_{q.t}\left(\frac{S_{4-period}}{S_n}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{262}{630})^2 + 1.56 = 2{,}87$
$\Delta P_{5-oddiy} = \Delta P_{q.t}\left(\frac{S_{5-period}}{S_n}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{158}{630})^2 + 1.56 = 2{,}04$

therefore, the amount of active energy wasted during one day is found as follows

$$\Delta W_{1\,kun}^{odd.tar} = 6 \cdot \Delta P_{1-odd} + 3 \cdot \Delta P_{2-odd} + 8 \cdot \Delta P_{3-odd} + 5 \cdot \Delta P_{4-odd} + 2 \cdot \Delta P_{5-odd}$$
$$= 6 \cdot 1{,}72 + 3 \cdot 5{,}24 + 8 \cdot 1{,}83 + 5 \cdot 2{,}88 + 2 \cdot 2{,}03 = 59{,}15 \text{ kW h}$$

Here, $\Delta W_{1\,day}^{odd\ tar}$ is the amount of energy wasted in a 630 kVA transformer at a normal tariff (kW·h).

By changing the consumption demand of consumers by ±14 percent, we will individually change the power indicators for energy and calculate the total full power.

We calculate the total full power in 1 transformer with a power of 630 kVA for 5 periods of the day. Table 7 shows the calculation of finding full capacities in 5 periods of the day.

Table 7

	Active power kVt	Reactive power kVar	Full power kVA
1-period	102	6	$S_{1-period} = \sqrt{P_{1-period}^{\ 2} + Q_{1-period}^{\ 2}} = 102$ kVA
2-period	374	15	$S_{2-period} = \sqrt{P_{2-period}^{\ 2} + Q_{2-period}^{\ 2}} = 375$ kVA
3-period	116	6	$S_{3-period} = \sqrt{P_{3-period}^{\ 2} + Q_{3-period}^{\ 2}} = 117$ kVA
4-period	224	21	$S_{4-period} = \sqrt{P_{4-period}^{\ 2} + Q_{4-period}^{\ 2}} = 225$ kVA
5-period	179	18	$S_{5-period} = \sqrt{P_{5-period}^{\ 2} + Q_{5-period}^{\ 2}} = 180$ kVA

Based on the results of the found calculations, we determine the consumption of active power in 5 periods of the day for the values of consumers after switching to the system of differentiated tariffs.

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International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 10, Issue 10, October 2023

Table 8 shows calculations for finding energy loss in transformers. In this case, the power loss in $\Delta P_{q.t}$ −transformers in short-circuit mode, power loss in $\Delta P_{s.ish}$ transformers in the mode of operation (these values are taken from the application depending on the power of the transformer).

Table 8

$\Delta P_{1-diff} = \Delta P_{q.t}\left(\frac{S_{1-period}}{S_{nom}}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{102}{630})^2 + 1.56 = 1{,}75$
$\Delta P_{2-diff} = \Delta P_{q.t}\left(\frac{S_{2-period}}{S_{nom}}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{375}{630})^2 + 1.56 = 4{,}1$
$\Delta P_{3-diff} = \Delta P_{q.t}\left(\frac{S_{3-period}}{S_{nom}}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{117}{630})^2 + 1.56 = 1{,}83$
$\Delta P_{4-diff} = \Delta P_{q.t}\left(\frac{S_{4-period}}{S_{nom}}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{225}{630})^2 + 1.56 = 2{,}5$
$\Delta P_{5-diff} = \Delta P_{q.t}\left(\frac{S_{5-period}}{S_{nom}}\right)^2 + \Delta P_{s.ish} = 7{,}6(\frac{180}{630})^2 + 1.56 = 2{,}13$

Here: ΔP_{1-diff}, ΔP_{2-diff}, ΔP_{3-diff}, ΔP_{4-dif}, ΔP_{-diff} amount of active power consumed in 5 periods.

III.RESULTS AND DISCUSSIONS

After switching consumers to differentiated tariffs, the amount of active energy is found as follows.

$$\Delta W_{1\,day}^{diff.tar} = 6 \cdot \Delta P_{1-diff} + 3 \cdot \Delta P_{2-diff} + 8 \cdot \Delta P_{3-diff} + 5 \cdot \Delta P_{4-diff} + 2 \cdot \Delta P_{5-diff}$$
$$= 6 \cdot 1{,}75 + 3 \cdot 4{,}1 + 8 \cdot 1{,}8 + 5 \cdot 2{,}5 + 2 \cdot 2{,}1 = 53{,}9\ kW\ h$$

Here $\Delta W_{1\,kun}^{diff.tar}$ is the amount of energy wasted in a 630 kVA transformer (kW·h) according to the differentiated tariff.

So, we find the difference between the electricity consumed by the consumers under the normal tariff and the electricity consumed under the differentiated tariffs. By taking the ratio of energy waste in the transformer according to two types of tariffs, we make the difference from the previous amount of wasted electricity.

$$\Delta\eta\% = \frac{\Delta W_{1\,day}^{odd.tar} - \Delta W_{1\,day}^{diff.tar}}{\Delta W_{1\,day}^{odd\ tar}} * 100\% = \frac{59{,}15 - 53{,}9}{59{,}15} * 100 = 8{,}8\ \%$$

Here, $\Delta\eta\%$ is the difference between the parts of the consumed electricity that are wasted in the transformer according to the dual tariff system as follows

$$\Delta\eta_{benefit} = \eta - \Delta\eta\% = 100 - 8{,}8 = 91{,}2\%$$

It can be seen that the indicator of energy consumption in a transformer with a power of 630 kVA is reduced to 8.5% compared to the energy consumption in a normal tariff.

IV.CONCLUSION

- the intended outcome was attained by comparing the variance between the electrical load graphs created for the power used according to the differentiated rates and the existing tariff.
- the analysis of the power load graphs of current users in our country.
- It was shown that using renewable energy sources can boost energy efficiency.
- It was calculated that the likelihood of overloading distribution transformers may be decreased if renewable energy sources were employed during the day's busiest hours.
- It has been demonstrated that if the indications of customer demand for power during peak hours of the day are adjusted, energy waste in distribution transformers may be decreased..

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