Assessment of the quality of electricity by applying reactive power sources

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Abstract. In the quest to enhance electricity quality, various states and parameters play crucial roles, particularly in assessing the significance and capabilities of reactive power sources. The evolution of electricity systems in developed nations is marked by a vigorous pursuit of cutting-edge technologies to boost energy system efficiency, lower construction and operational costs of network infrastructure, and enhance power supply reliability. The issue of reactive power compensation and electricity quality is intricately linked to diverse consumer loads, voltage, and frequency considerations. This process entails elevating the system's active power factor to harmonize total power within the AC network, maintaining voltage levels, and mitigating harmonic distortions stemming from nonlinear industrial loads. Voltage stability measures are typically essential to curtail fluctuations along power transmission lines. Enhancing the system's operational reliability involves augmenting the maximum active power that reactive power compensation mechanisms can adjust.

1 Introduction

Ensuring the quality of electricity leads to the reliable operation of electrical power consumers and an increase in the efficiency of electrical power systems. The solution to the problem of the quality of electricity should be based on a technical and economic comparison of the impact of quality improvement measures and inevitable additional costs. The quality of electricity is assessed on technical and economic indicators, taking into account the damage caused. The quality of electricity is associated with reliability, since the system mode of power supply is considered normal, in which consumers are supplied with normalized quality, the required amount and uninterrupted electricity. Longitudinal compensation of reactive power-indicates a more economical achievement of the goal, which is also set for inter-system, internal systemic communications. It is known that when transmitting reactive power through conductors, electric networks pump a significant increase in current strength on their plots, creating restrictions on the transmission of active power in this. Longitudinal compensation of reactive power provides for consistent additional input with sequential loading of capacitors through voltage-increasing or separating transformers.

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2 Materials and methods

Indirect compensating reactive power sources are not only generalised compared to the installed capacitors and reactor capacities, they can also consume reactive power when switching from one flat mode to another. But relatively low-power reactive power sources combined with tristors can be achieved by the fact that controlled reactors remain sources of high harmonic currents, and their disadvantage is that the elimination of high-harmonic filters can be achieved by installation. Usually the filter is done by branching the capacitor batteries instead of the compensator [1]. To do this, the condition that small reactors with capacitors connect in series is met, and in such a connection, the resistors in the capacitor chain will be close to zero along with those of the reactor at the adjusting frequency being compensated for in high harmonica (Figure 1).

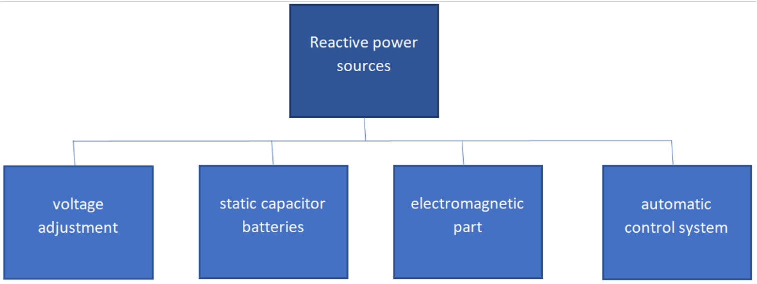

Fig. 1. Reactive power supplies.

The first two functions provide increased static and dynamic stability in the transmission of electricity. When choosing to control static thyristor compensators, it should be borne in mind that at the same time, static thyristor compensators can only perform one regulatory function. In the built-in modes of static thyristor compensators, it can basically have two or more functions, and the selection of an active function can be automatic (by external parameters or by operating conditions of the energy system), or by the orders of the substation operator. In the transition and emergency modes of static thyristor compensators, it can switch to solving local problems regulated by the priority system. For this, the voltage regulation period is carried out independently in stages. One of the parameters of the quality of electricity is the deviation of the voltage [2]. Voltage deviation is the difference between the actual voltage at the steady state of the network and its nominal value (1)

$$\delta U = \frac{U-U_{nom}}{U_{nom}} \cdot 100\% \tag{1}$$

where, U- the actual value of the voltage at the network point in question is; U_{nom}-where is the nominal voltage on this network, V. The normal allowable and maximum allowable values of the constant voltage deviation are ±5 and ±10%, respectively. For the deviation value of the voltage, the following norms are established (Figure 2).

Impulse voltage is one of the qualitative indicators of electricity, which is characterized by a sudden jump in the volt-ampere properties of the network (2)

$$\delta U \frac{U_{im}}{\sqrt{3 \cdot U_{nom}}_{Im}} \tag{2}$$

where, δU_{IMP} - Pulsed voltage, V

Voltage fluctuations are rapidly changing voltage deviations that last up to a few seconds (3)

$$\delta U_t = \frac{U_i - U_{i+1}}{U_{nom}} \cdot 100\% \tag{3}$$

where, $U_i,\ U_{i+1}$ - values of subsequent voltage levels. The voltage Flicker dose in square percentage is calculated with the following expression (4)

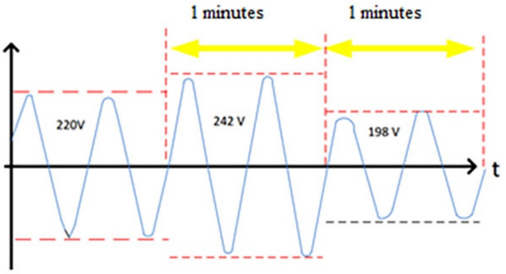

Fig. 2. Voltage deviation graph.

$$P_t = \frac{1}{T_{osp}} \int \sum g_f^2 \int \delta U_f^2 \, dt \qquad (4)$$

where, δU_f^2– Current values of the components of the division of voltage changes in the Fourier series.

The resistance of the filter connection with high harmonic currents is equal to the following (5)

$$K_u = \frac{U_{amax}}{\sqrt{2 \cdot U_{nom}}} \qquad (5)$$

where, U_{amax}- the maximum amplitude value of the voltage during the time when where is a temporary super-high voltage, V; U_{nom}- Rated voltage, V; Two normalized indicators of the sinusoidality characteristic are: the sinusoidality distortion coefficient of the voltage curve and the coefficient of the N-harmonic component of the voltage (6)

$$K_u = \frac{\sqrt{\sum_{n=2}^{N} U_{(n)}^2}}{U_{nom}} \cdot 100\% \qquad (6)$$

The breakdown coefficient of the sinusoidality of the stress curve is determined by the expression above, %.

where, $U_{(n)}$ – the current value of the N-harmonic component of the voltage, V;

n – the order of the harmonic component of the voltage;

N – The final order of the harmonic components of the voltage taken into account is determined by the standard.

N = 40;

U_{nom}- Rated voltage on the network, V.

Economic advantages, based on the above in the facilities of the power grid complex, the advantages of a controlled transformer-type shunt reactor over a controlled magnetized shunt Reactor are undeniable and should be taken into account and used in the organization of competitions for the supply of this type of equipment for high-voltage networks [3]. The use of static thyristor compensators of reactive power in substations of high voltage power transmission lines allows you to stabilize the voltage, reduce losses in the transport of electricity and increase the transmission level and electrical conductivity by increasing its static stability.

The sinusoidality of the stress curve is the values of the distortion coefficient Table 1.

Table 1. Voltage values in the network.

Network voltage, kV	**0.38**	**6-20**	**35**	**110 and higher**
Fixed face value , K_r	8	5	4	2
Continuous face value , K_d	12	8	6	3

The coefficient of the N-harmonic component of the voltage is the ratio of the N-harmonic component of the voltage to the current value of the harmonic component of the fundamental frequency (7)

$$K_{U(n)} = \frac{U_{(n)}}{U_{nom}} \cdot 100\% \tag{7}$$

Where the maximum allowable Ku (n) values set by the standard are listed in table 2

Table 2. Values of the coefficient of the N-harmonic component of the voltage.

Network voltage, kV	**0.38**	**6-20**	**35**	**110 and higher**
Order of odd harmonics , K_t	6	5	4	2
Order of double harmonica , K_j	3	2.5	2	1

Primarily in low load and load distortion, shunt-guided reactors are used to increase voltage by compensating reactive power as well as, to compensate for capacitive loading of the overhead power line. Shunt-controlled reactors allow the following functions to be performed:

- distribution of parallel connected transformers;
- switch off power lines;
- disable download;

1. Much higher speed. The presence of a direct electromagnetic bond between the chimneys ensures the absence of magnetizing elements in the reactor's magnetic system. If the reaction rate and the controlled shunt reactor magnetization process is at least 300 ms, and the line's switching modes require pre-magnetization from its external 10 kV power source, then the voltage regulation mode controlled shunt reactor has a transformer type speed above 30 ms, and in line transition modes its power occurs before 0 ms nominal or vice versa, within a time not exceeding 10 ms. Thus, we see that the efficiency of a controlled transformer-type shunt reactor in terms of increasing the dynamic stability of electrical transmission and reducing the switching voltage is significantly higher than that of a magnetically controlled shunt reactor.
2. Minimum additional losses in the reactor at the project elements. The properly selected construction of reactor shunts is provided by an understanding of the localization and distribution issues of magnetic-link marshmallows. It is this situation that to date poses a number of difficulties in the development of this direction.
3. Minimum level of harmonica. The current value of all high harmonic currents is less than 2% of the nominal current in all operating modes of the device, and the controlled shunt reactor does not require the use of special high harmonic filters for the transformer.
4. Small dimensions and mass of the active part of the reactor. In the magnetic system of the reactor does not cause the rust of additional contacts that serve to distribute the constant magnetic flux.
5. Increase the operational reliability of the reactor. The controlled shunt reactor of a transformer is the nominal short circuit mode in secondary troughs.
6. Low level of noise and vibration. Tbutunlay of the active part of the reactor without sources of noise and vibration has been cited as being related to the choice of a new project [4,5,6].

The main functions of static thyristor compensation in ultra-high voltage networks include:

- Voltage stabilization in the substation tire;
- reactive power compensation;
- reduction of voltage deviations with large disruptions in the system;
- depreciation of active power on the line;
- reduced internal supercharging (connecting static thyristor compensators directly to the power transmission line).

Note that fixed power transmission modes do not require higher speeds than static thyristor compensators. Depending on the parameters of the energy system, the optimal reaction time to the controlled parameter change of static thyristor compensators is 30-100 ms. Controlled by weight issues, shunt reactor transformer equipment is 10-15% less due to abundant use compared to controlled magnetic-link shunt reactors, and the regulator containing the control system, controlled shunt reactor transformer is a process involving less thyristor converter than a three-phase transformer. Setting the voltage is a field with a voltage of 220 kV and a power of 60 MVA is 22×16 m. In addition, the electromagnetic part of magnetic bond shunt reactors has a much higher noise and vibration level than the controlled shunt reactor transformer, which is due to the presence of gaps in its magnetic deserts.

At the same time, the reaction time of static thyristor compensators in transition and especially emergency situations should not exceed 5-10 ms (Figure 3).

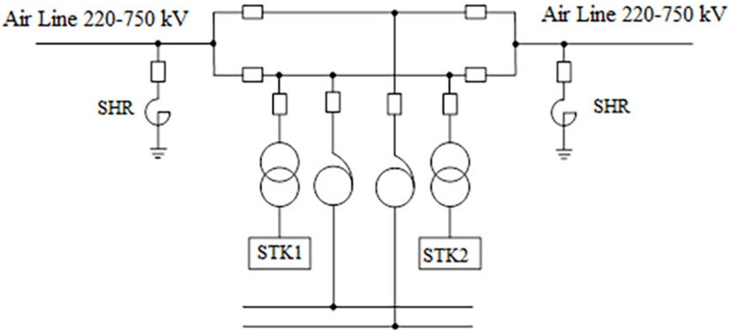

Fig. 3. The nimstances of the high voltage overhead power transmission line are shown as shunt reactors as well as the connection of static thyristor compensation.

The traditional method of regulating reactive power in electrical transmission above high voltage-line shunt switching reactors and synchronous (in the past) or static compensators mounted on high tires are connected to the marshlands of voltage or medium substations or connected network autotransformers (Figure 4).

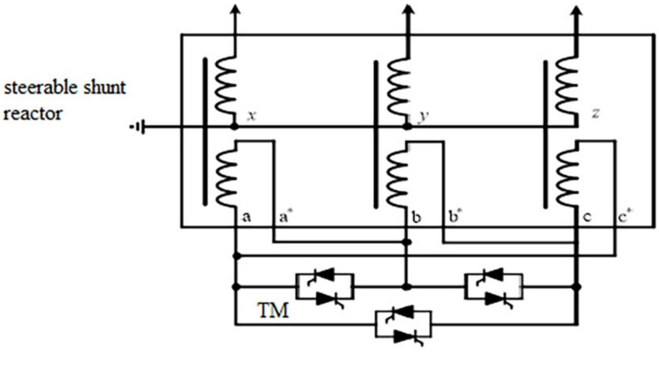

Fig. 4. The connection scheme of a reactor-transformer controlled using a shunt.

Here the voltage at the end of the L-Bessopan line increased from 206 kV to 220 kV, an increase of 6.4%, and the average voltage on the network increased by 5.6%. Obviously, the need to use a special falling transformer for the application of Statistics thyristors compensation in high-voltage networks leads to additional losses and an increase in the installation area (Figure 5).

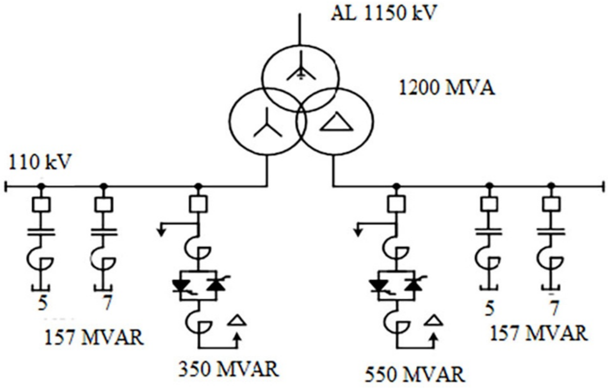

Fig. 5. Connection scheme of a compensator with a static thyristor for a power transmission line with a voltage of 1150 kV.

3 Results and discussion

The implementation of these allows the following when the control reactor maintains the active power transmitted through the lines:

- substations increase tire voltage by 11% to 220 kV voltage;
- reduction of rated current forces in power lines by 15%;
- increase static and dynamic stability limit;
- improved stability in the power transmission line due to increased throughput;
- the considered case proves that stabilizing the voltage beyond compensating the charging power of power lines in this control operation, the reactor also successfully reduces the switching voltage and prevents the system from breaking down when disposing of emergency loads (Figure 6).

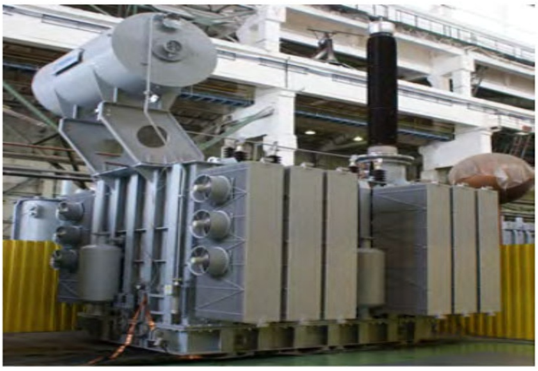

Fig. 6. Electromagnetic part of a 60 MVA controllable shunt reactor transformer with a voltage of 500 kV.

In energy, other types of controlled shunt reactors with magnetized reactors began to be widely used. These reactors have a fundamentally different principle-a control system based on changing network inductance by changing the magnetization current. Actually a controlled shunt reactor is a magnetized reactor that is a high voltage magnetic amplifier that has its own advantages and disadvantages [7]. The main advantage of controlled shunt reactors is that the reactors-transformer reactors-are small (0.2 of the rated power of the reactor) compared to the shunt reactors whose magnetized reactors are controlled...1.0%) thyristor compensator capacity and correspondingly proportionally cheap (about 20%) [8]. The main disadvantages are low speed (the transition time from the minimum to the maximum power is 1-3 seconds, and when using-0.2-0.3 seconds) and incompetence of the characteristic, which can provoke the appearance of resonance phenomena in the adjacent energy system [9].

We can see a comparison of the voltage drop before and after the introduction of reactive power sources at the end of every 220 kV voltage line of a interconnected power plant. Analyzing the data, we can draw the following conclusions about the increased voltage level after the introduction of reactive power sources [10]. A controlled shunt reactor-transformer is an effective means of covering the line's charging power and regulating voltage [11,12]. Controlled shunt reactor-transformer use 220 to increase static and dynamic stability [13,14]. It is recommended in substations of long main power transmission lines with a voltage of 750 kV. This ensures voltage stabilization, reduction of losses in power lines, and increased electrical conductivity. The analysis of the operating modes of existing electrical networks and transformers at the time of the analysis of the working order of the electrical networks and the power in the overhead power lines was carried out from the taxile. In this case, it replaces the linear shunt reactor and other voltage regulators, which significantly ensures a decrease in the volume of substation compensation equipment and active losses in it [15,16]. All of the above compensating agents are listed in Table 4.

Table 4. The greatest effect occurs when a controlled shunt reactor-transformer connects directly to the end of a static thyristor compensator line with a switching voltage restriction function.

Device type	STC	CSHRT	CSHRM
Movement Time in static modes, ms	30-100	30-100	1000-3000
Movement Time in transition modes, ms	5-10	5-10	200-300
Daily voltage regulation	Available	Available	Available
Damping oscillations of active power	Available	Available	Limited
Phase-by-Phase regulatory capabilities	Available	Limited	Available
Decrease in switching extreme voltages	Available	Available	Limited
Structure of the electromagnetic part	Not available	Simple	Ink
Vibration and noise level of the electromagnetic part	Not available	Low	high
Active power waste	1.0	0.4….0.6+0.2	0.4…….0.6

Since the installation of the sources reactive scrotum partially or completely solved several problems such as: stabilization and increase of the voltage level at the control points of the power unit, thereby increasing the capacity of power transmission lines, stabilization of modes in case of accidents; increasing the reliability of the electric networks (Figure 7).

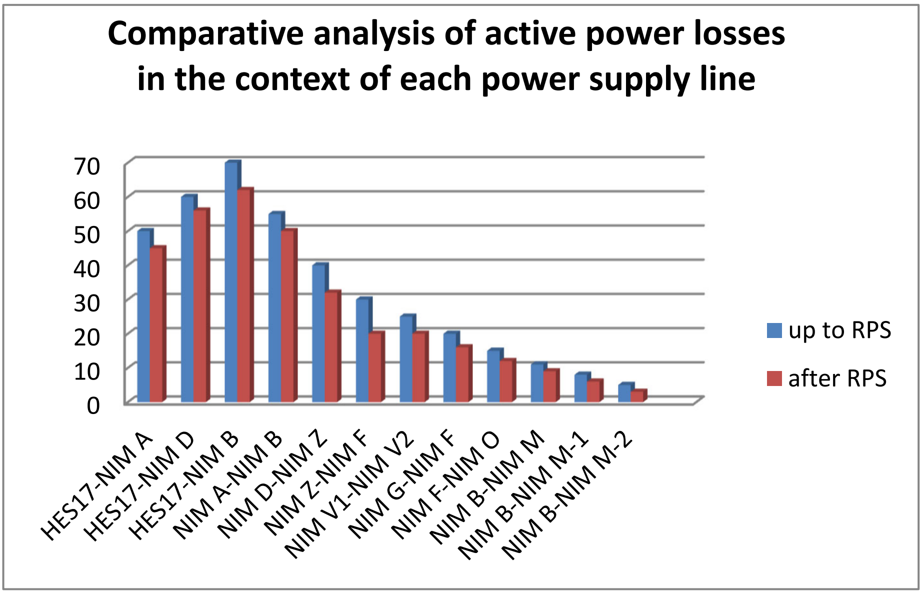

Fig.7. Comparative analysis of active power losses in the context of each power supply line.

The quality of power supply is very important in any power grid, especially for electricity consumers. The quality of electricity includes the availability of the power source, the frequency and magnitude of the voltage, as well as the characteristics of the power source's waveform [17-20]. Power is described as of good quality if the power supply is constant at acceptable, stable voltage and frequency values; and has a smooth sinusoidal waveform. Shunt reactors are connected to the line for compensation (Figure 8).

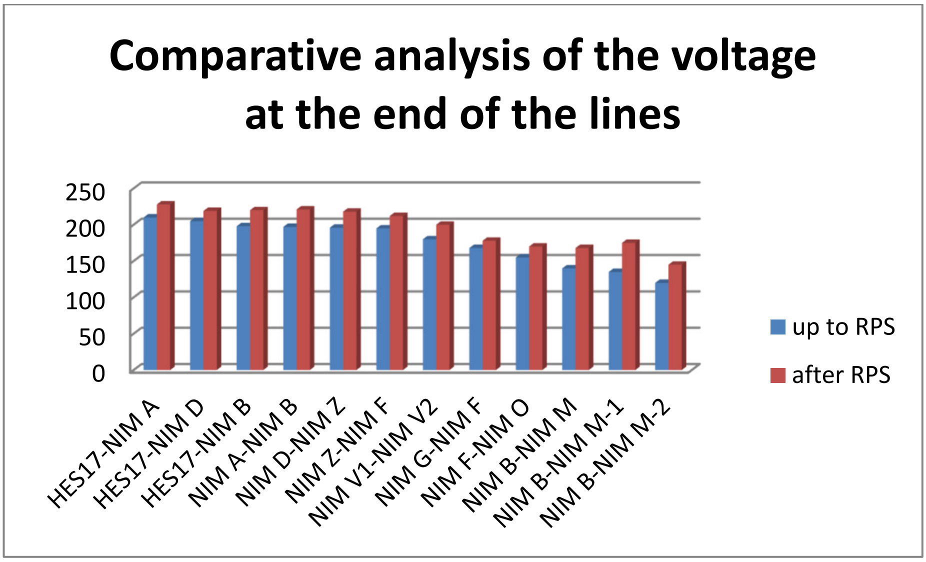

Fig. 8. Comparative analysis of the voltage at the end of the line.

4 Conclusion

The rationale behind the air was substantiated through a mathematical examination of the prevailing power parameters (active and reactive) in power lines. Recommendations were put forth to mitigate the impact on power transmission networks by proposing measures to diminish the wastage of reactive and active power. The focus extended to reactive power, its compensation, enhancing electricity quality through reactive power sources and their installation, and ensuring a continuous, reliable power supply to consumers, forming the cornerstone of modern energy systems. The study yielded the following insights:

- Reactive power losses significantly impede the efficiency and reliability of electrical circuits, with their mitigation leading to reduced losses in distribution network complexes.
- A method for analyzing contact rust was introduced to assess the impact of proposed electrical network parameters on reactive power loss.
- A statistical approach was devised for the structural analysis of electrical energy and reactive power losses in distribution networks, utilizing operational data to quantify energy losses.
- Utilizing reactive power sources, strategies were devised to identify and mitigate active power and voltage losses, thereby curbing wastage.

References

1. A.N. Tovbaev, D.Sh. Mardonov, A.X. Mamatazimov, S.S. Samatova, Journal of Physics: Conference Series **2094** 052048 (2021)
2. Oybek Ishnazarov, Jonibek Mavlonov, Davron Mardonov, E3S Web of Conferences **461** 01091 (2023)
3. J. Mavlonov, D. Mardonov, M. Eshmirzayev, I. Togayev, E3S Web of Conferences **414** (2023)
4. Akram Tovbaev, Gayrat Boynazarov, Islom Togaev, E3S Web of Conferences **390** 06032 (2023)
5. N.O. Ataullayev, D.F. Nizomova, B.Q. Muxammadov, Journal of Physics: Conference **2094** 052039 **(**2021)
6. M. Ibodulaev, A.N. Tovboyev, E3S Web of Conferences **216**, 01113 (2020)
7. A.N. Tovboyev, I.B. Togayev, I.Q. Uzoqov, G.Y. Nodirov, E3S Web of Conferences **414** 03001 (2023)
8. A.I. Karshibaev, B.Sh. Narzullaev, X.Sh. Murodov, Journal of Physics: Conference Series **1679** 022074 (2020)
9. A.O. Ataullaev, M.K. Sayidov, E3S Web of Conferences **414** 03006 (2023)
10. A. Tovbaev, M. Ibadulaev, Z. Safarov, AIP Conference Proceedings **2552** 030027 (2023)
11. Yu. S. Zhelezko, Power stations **9**, 33 (2001)
12. E.O. Bakai, Bulletin of the South Ural State University. Ser. Economics and Management **11(4),** 117-125 (2017). https://www.doi.org/10.14529/em170416
13. S.A. Sirok, Yu.V. Kasharnaya, S.A. Evgrafov et al., Promishlennaya energy **8**, 9-15 (2010)
14. A. Ovchinnikov, Electricity losses in distribution networks 0.38 - 6 (10) kV News of Electrotechnics **6(18)** (2002)

15. J. Dixon et. al., IEEE **93(12)**, 2144-2164 (2022)
16. T.J.E. Miller, *Reactive Power Control in Electric Systems* (Wiley, 1982)
17. A.T. Belenov, V.V. Kharchenko, S.A. Rakitov, Y.V. Daus, I.V. Yudaev, Applied Solar Energy **52(2)**, 105-108 (2016)
18. K. Murodov, A. Karshibayev, E3S Web of Conferences **414**, 03012 (2023)
19. N. Ataullaev, D. Nizomova, A. Norqulov, E3S Web of Conferences **414**, 03009 (2023)
20. K.S. Sanakulov, U.Z. Sharafutdinov, Tsvetnye Metally, **10** 46–49 (2019)