



Asinxron elektr motorlarni silliq ishga tushirishda kuchlanish tushuvini rostlashning va boshqarishning usullari tahlili

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Dolzarbliqi: Asinxron elektr motorlarni to'g'ridan-to'g'ri ishga tushirish jarayonida yuzaga keladigan kuchlanish tushuvi sanoat tarmoqlarida energiya samaradorligiga va uskuna ishonchligiga salbiy ta'sir ko'rsatadi. Shu sababli, silliq ishga tushirish qurilmalaridan foydalanish bugungi kunda dolzarb masala hisoblanadi.

Maqsad: Motorlarni ishga tushirish jarayonida kuchlanish tushuvini kamaytirish, elektr tarmoqlarining barqarorligini oshirish va uskunalarning xizmat muddatini uzaytirishga qaratilgan nazariy hamda amaliy yechimlarni ishlab chiqish.

Usullari: Asinxron motorlarni ishga tushirishda yuzaga keladigan muammolarni tahlil qilish, silliq ishga tushirish texnologiyalarini qo'llash samaradorligini asoslash va avtomatlashtirilgan boshqaruv tizimlari bilan integratsiyasini o'rganish.

Natijalar: Silliq ishga tushirish qurilmalari qo'llanganda kuchlanish tushuvlari kamayishi, tarmoq barqarorligi va uskuna ishonchligi ortishi, energiya tejamkorligi ta'minlanishi va sanoat korxonalarini uchun xavfsiz hamda samarali energiya tizimini shakllantirish imkoniyati aniqlangan.

Kalit so'zlar: asinxron elektr motor, silliq ishga tushirish, kuchlanish tushuvi, avtomatlashtirilgan boshqaruv, energiya samaradorligi, tiristorli regulyator.

Анализ методов регулирования и управления падением напряжения при плавном пуске асинхронных электрических двигателей

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Актуальность: Прямой пуск асинхронных электродвигателей нередко сопровождается падением напряжения, что отрицательно сказывается на энергетической эффективности и надежности промышленных электрических сетей. В связи с этим внедрение устройств плавного пуска рассматривается как особо актуальное направление современной практики.

Цель: Исследование направлено на разработку теоретических и практических подходов к снижению падений напряжения при пуске электродвигателей, повышению устойчивости энергосетей и продлению срока службы электротехнического оборудования.

Методы: В работе проведен анализ проблем, возникающих при пуске асинхронных двигателей, обоснована эффективность применения технологий плавного пуска, а также исследована их интеграция с автоматизированными системами управления.

Результаты: Установлено, что использование устройств плавного пуска снижает падения напряжения, повышает устойчивость сетей и надежность оборудования, обеспечивает энергоэффективность и способствует формированию безопасной и устойчивой энергетической системы для промышленных предприятий.

Ключевые слова: асинхронный электродвигатель, плавный пуск, падение напряжения, автоматизированное управление, энергоэффективность, тиристорный регулятор.

Analysis of voltage drop regulation and control methods during the soft starting of asynchronous electric motors

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Relevance: The direct starting of asynchronous electric motors often leads to voltage drops, which negatively impact the energy efficiency and reliability of industrial power networks. Consequently, the implementation of soft starters is regarded as a highly relevant solution in modern practice.

Aim: The study aims to develop theoretical and practical approaches to minimizing voltage drops during motor startup, enhancing power network stability, and extending the operational lifespan of electrical equipment.

Methods: The research involves analyzing the challenges associated with starting asynchronous motors, substantiating the efficiency of soft starting technologies, and examining their integration with automated control systems.

Results: Findings demonstrate that the use of soft starters reduces voltage drops, improves network stability and equipment reliability, ensures energy efficiency, and contributes to establishing a safe and sustainable energy system for industrial enterprises.

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Keywords: asynchronous electric motor, soft starter, voltage drop, automated control, energy efficiency, thyristor regulator.

1. Introduction (Введение)

Among the power quality indicators, voltage deviation is the most significant factor leading to increased energy losses in power supply systems and among consumers, causing the greatest damage. When the voltage drops, the rotational speed of asynchronous motors decreases, the current consumption increases, and consequently, the service life of the motor insulation is reduced. It is well known that in asynchronous motors, the torque is directly proportional to the square of the voltage $M \sim U^2$, therefore, a voltage drop complicates the starting process of the motor. A sharp decrease in voltage may result in the motor transitioning from operating mode to braking mode.

One of the main causes of voltage fluctuations is the abrupt change in loads at certain sections of the network. For example, the operation of welding machines, the starting of large squirrel-cage asynchronous motors, the operation of controlled rectifier devices, and so on. As a result of voltage fluctuations, the insulation of operating electrical equipment and networks deteriorates rapidly, power and energy losses increase, and the integration of capacitor banks into the network is restricted.

If, during startup, the voltage supplied to the electric motor is insufficient, it cannot reach the required speed, while both starting and operating currents rise sharply, which may lead to conductor overheating, contact burning, and relay failures.

It should be emphasized that in industrial enterprises, particularly in facilities utilizing high-power asynchronous motors, voltage drops occurring during motor startup can lead to improper functioning or failure of various electronic control devices and automated systems. This, in turn, results in process interruptions, substandard products, and economic losses. Furthermore, such issues cause network unreliability, overheating, rapid insulation aging, increased maintenance costs, and heightened demand for backup power sources.

To address these problems, it is essential to implement automatic control systems for regulating voltage drop during the startup of asynchronous electric motors in power supply systems - including the use of contactless voltage relays, soft starter devices, and intelligent control algorithms. Through such solutions, it becomes possible to achieve efficient energy use, restore full operational capacity, and establish a reliable power system.

Let us consider the most widely used methods for connecting asynchronous motors, along with their advantages and disadvantages [1].

When operating asynchronous electric motors, it becomes necessary to limit the starting current in order to prolong the service life of the motors. By limiting the starting current, one can prevent disturbances in voltage parameters, which is achieved by properly selecting the motor starting scheme.

In practice, the most commonly employed options for starting asynchronous electric motors are as follows:

1. Direct-on-line starting;
2. "Star-delta" (Y- Δ) starting scheme;
3. Starting using a soft starter device;
4. Starting using a frequency converter.

The selection of a soft starting scheme for an asynchronous motor is carried out based on an analysis of the requirements imposed on the equipment and the characteristics of the electrical network.

2. Main Part. (Основная часть)

In this article, we will examine the soft starter device, which is one of the four starting methods for asynchronous motors mentioned above.

Squirrel-cage asynchronous electric machines are relatively inexpensive and possess an optimal "power-to-weight" ratio. In addition, they feature a simple design, are easy to maintain and repair, and are highly reliable. However, one of the main drawbacks of motors with this design is that, during startup, the current can increase to as much as 5–7 times the nominal value. This, in turn, leads to a significant voltage drop in the electrical network. To eliminate such undesirable effects, various devices—including soft starter devices for electric motors—are employed.

The need for a Soft Starting. By employing soft starting for asynchronous motors, it is possible to eliminate the shortcomings of these electric machines and achieve the following advantages:

- high starting currents during startup can cause overheating of the windings, which significantly reduces the operational life of the machine and decreases maintenance costs;
- abrupt starting of the motor leads to rapid wear of gear transmission systems, hydraulic shocks in fluid supply systems, and other undesirable consequences; soft starting helps to prevent these effects;
- direct-on-line starting results in additional energy consumption. Moreover, in conditions where the network power is limited, voltage drops negatively affect all connected devices, so soft starting serves

to reduce the amount of electrical energy consumed;

- electrical equipment for asynchronous drives is usually selected with a large power reserve. The use of a soft starter makes it possible to employ less expensive switching and protective devices, thus reducing expenditures on switching equipment.

Soft starting methods considerably expand the areas of application for asynchronous electric motors.

Soft Starter Devices. A soft starter device is an electrical engineering apparatus designed to start and accelerate an electric motor while coordinating the starting torque at the shaft with the load. The soft starter circuit is usually based on powerful thyristors or triacs. Such a device functions as a transformerless, stepless voltage converter.

Soft starter devices are used in the following situations:

- when connecting high-power asynchronous motors to low-capacity networks;
- when it is necessary to start, accelerate, and stop electric machines smoothly;
- when starting the motor under load is required;
- to reduce starting currents.

Soft starter devices enable the abandonment of expensive and inefficient starting schemes and significantly expand the scope of application for inexpensive and functional squirrel-cage asynchronous machines.

The device presented in the scientific patent development titled “A motor control controller system and methods” by inventors L. Bowman and A. Cheeseman can be used for soft starting of commonly used asynchronous electric motors [2].

A rotor of a motor coupled to an energy management system is either (i) stationary (ii) accelerating or rotating at constant speed or (iii) decelerating. In response to determining that the rotor is stationary a supply voltage is reduced and the supply voltage waveform to the motor modified to achieve a starting torque or speed of the rotor. A back emf from the motor is determined at a certain threshold and the voltage waveform of the supply voltage to the motor is increased and modified to achieve a desired operating torque or speed of the rotor. In response to an increased torque demand or required rotor speed, the voltage waveform of the supply voltage to the motor is increased and modified to achieve a desired torque or speed of the rotor. In response to determining that the rotor is decelerating a voltage generated from the motor is compared to the supply voltage and determined whether to increase or decrease the supply voltage based on the comparison. The motor may be an electrically commutated brushless motor. The energy management system 200 may be four quadrant motor drive control system, or a charging system for a battery coupled to the motor.

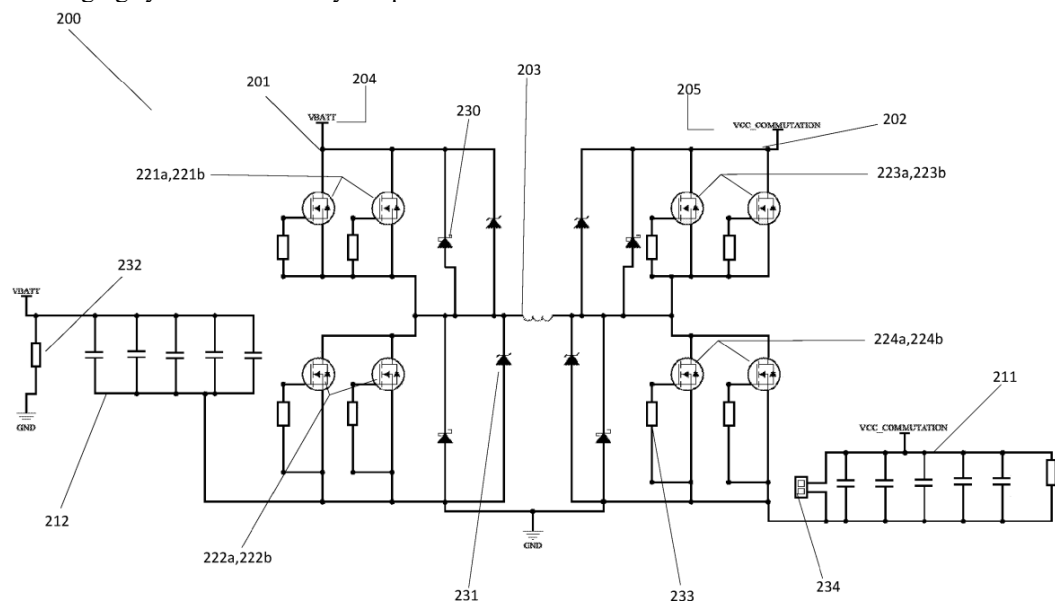


Fig.1. Shows an exemplary energy management system comprising a bi-directional energy converter circuit.

In simpler terms, this scheme pertains to a high-efficiency motor control system designed to efficiently manage energy usage, initiate motor motion, and coordinate braking processes. It incorporates four-quadrant operational modes (automatically enabling functions such as stopping, acceleration, reversal, and braking of the electric motor) and supports bidirectional energy flow capabilities.

The complete inverter system is powered through the VBATT supply. MOSFET transistors—which are highly efficient and fast-switching electronic components used as amplifiers or switches in electrical circuits, controlling current conduction by means of an electric field—generate precise waveform



signals to drive the motor rotor. Through the commutation block, the direction and speed of the motor are controlled. Depending on which channel is activated, the motor will rotate or come to a stop. During the commutation process, current suppression and stabilization are provided by capacitors and diodes. The present invention relates to motor power control signals and systems. More particularly, but not exclusively, the present invention relates to an energy management system for a motor controller system for optimising power signals for different operating voltages of electrically commutated motors.

Background. There has been a significant drive to make electric motors more compact and efficient. An electric motor comprises a stator and a rotor and can be put into two categories: a brushed motor and a brushless motor. In a brushed motor the stator may comprise permanent magnets and the rotor may comprise a coil assembly. When a current is passed through the coils of the rotor a magnetic field is generated causing a torque in the rotor that is tangential to the current flow in the coils. In order for the rotor to rotate in a constant direction the polarity of the generated magnetic field needs to be changed. This is achieved by brushes (commutators) which contact the rotor to manipulate the direction of current provided to the coils which in turn manipulates the polarity of the generated magnetic field.

In a brushless motor the stator comprises the coil windings and the rotor comprises the permanent magnets. In a typical brushless motor, the rotor may incorporate a four-pole permanent magnet. The stator, on the other hand, may consist of a three phased coil winding. A sensor magnet may be used to indicate the position of a rotor shaft and a controller is able to switch current to each winding at the optimum timing point. This way semiconductor switches turn the appropriate stator winding phase “on” and “off” at the appropriate time. The direction of current flow can be in either direction when a phase is “on”. This process is called electronic commutation, borrowing on terminology used for the mechanism in dc motors, called a commutator, that switches current from winding to winding, forcing the rotor to turn.

A typical motor can operate in two modes – motoring and braking. It further comprises a motor drive configured to control the motor in both directions of rotation. In motoring mode, the machine converts the electrical energy from a source into mechanical energy, supporting its motion i.e. rotor rotation. In braking mode, the machine works as a generator and converts mechanical energy into electrical energy. The motor can work in both modes in both forward and reverse directions.

Despite its advantages, this device also has certain drawbacks. The disadvantages are as follows:

- complexity: Due to the presence of MOSFETs, diodes, and numerous passive elements, the design and commissioning of the circuit become complicated. In such a configuration, if any element does not operate reliably, it can negatively affect the entire system's performance;
- power losses: The simultaneous operation of multiple MOSFETs and diodes increases energy loss at high currents. Although Schottky diodes are efficient, they still generate heat and have inherent energy consumption at high current levels;
- protection issues: In cases where the system contains a high energy charge, discharging through resistors can be both hazardous and inefficient;
- reliability and diagnostics: The reliability of each MOSFET, diode, and resistor in the system is crucial; if any single component fails, the entire circuit may cease to function or enter a dangerous state. Each minor component requires individual monitoring;
- limitations in high-current operation: For high-power systems, proper cooling and increased physical size requirements become significant challenges;
- expensive and difficult maintenance: The overall cost is high due to the large number of active and passive components. When a failure occurs, diagnostics and repair require a high level of expertise.

While this scheme can offer high efficiency and energy savings in power management, the large number of components, along with complexity in fabrication and operation, result in increased costs and service risks. In real-world applications, more optimal and compact circuits may be proposed to achieve multiphase protection and minimize energy losses.

3. Results and discussion (Результаты и обсуждение)

Taking the above-mentioned drawbacks into account, we will consider a more optimal, compact, and cost-effective version of the soft starter device.

Control with voltage adjustment during soft starting of asynchronous electric motor.

The startup period refers to the interval during which the system increases the voltage from its initial value to the maximum. At the same time, this interval should not be excessively long, in order to prevent voltage dips and overheating during the starting phase of the electric motor. In particular, if the electric motor is heavily loaded, this parameter may exceed the set value; conversely, if the motor is unloaded, the interval can be shorter.

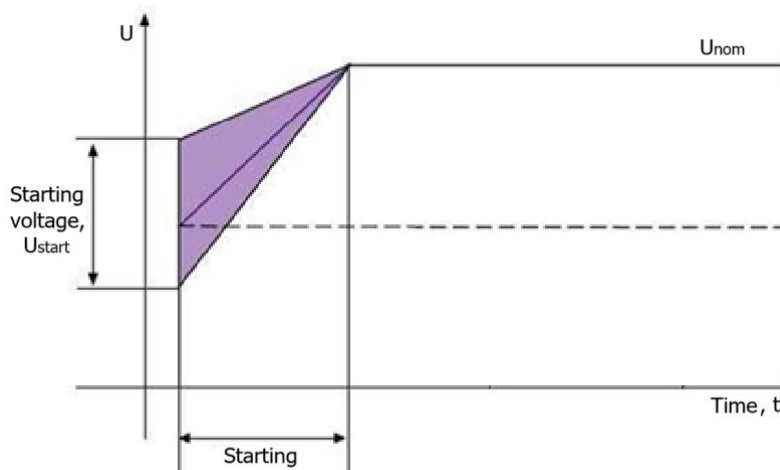


Fig.2. The variation of voltage during the soft starting process of an electric motor is depicted.

Here,

U - represents the voltage.

t - denotes the change in process over time.

U_{start} - is the initial voltage value at the moment of starting.

“Starting” - refers to the stage when the electric motor begins to operate.

At the beginning of the startup process, the voltage rises from its initial value (U_{start}). The voltage then gradually increases to its maximum value (either in a linear or accelerated fashion), thereby applying voltage to the motor without causing sudden surges. In this process, the area shown as a right triangle represents the “smooth rise” zone, which protects the electric motor from strong current surges.

This graph demonstrates that, during the startup and shutdown of electrical loads, the voltage should be increased and decreased in stages to ensure safe and shock-free operation of the electric motor. Such a startup scheme is primarily implemented in devices that provide soft starting functionality.

The soft starting process is usually modeled mathematically. For example, the voltage $U(t)$ and the current $I(t)$ supplied to the motor are defined by functions of the following form:

$$U(t) = U_{ном} \cdot \alpha(t);$$

бунда, $\alpha(t)$ - 0 дан 1 гача қиймат оладиган функция (вақт бўйича ўзгарувчан коэффициент).

Масалан, электр моторнинг номинал кучланиши $U_{ном}$ 380В, юмшоқ ишга тушириш жараёни 5 секундга соналган. Кучланишнинг ошиш функцияси: $\alpha(t)=t/5$,

here, $\alpha(t)$ is a time-dependent coefficient that takes values from 0 to 1.

For example, if the nominal voltage of the electric motor, $U_{ном}$, is 380V and the soft starting process is set to 5 seconds, the voltage rise function can be defined as: $\alpha(t) = t/5$,

$$\alpha(t) = \frac{t}{5};$$

яъни ишга тушириш бошида $t=0$ секундда 0 га, ишга тушириш охирида $t=5$ секундда 1 га тенг булади.

That is, at the beginning of the startup $t=0$ seconds, $\alpha(t)$ equals 0, and at the end of the startup $t=5$ seconds it equals 1.

$$U(t) = 380 \cdot \frac{t}{5};$$

at 1 second, $U(1)=380 \cdot 0,2=76V$;

at 3 seconds, $U(3)=380 \cdot 0,6=228V$;

at 5 seconds, the motor reaches its full nominal voltage: $U(5)=380 \cdot 1=380V$.

Table 1. The voltage values at various time intervals during the soft starting process:

t (seconds)	$\alpha(t)$	U(t), V
1	0.2	76V
2	0.4	152V
3	0.6	228V
4	0.8	304V
5	1.0	380V

The following block diagram illustrates the soft starting process of an electric motor. The components and their sequence in the diagram are as follows:

- U represents the input voltage, which refers to a 380V three-phase power supply;

- the voltage first passes through an automatic circuit breaker. The automatic circuit breaker ensures electrical safety and protection by disconnecting the motor in cases of overcurrent or emergency situations;
- after the automatic circuit breaker, the voltage is directed to the soft starter device. This device ensures that the motor is started gradually and without stress;
- after passing through the soft starter, the voltage is supplied directly to the electric motor (once full voltage is reached, the thyristors may be bypassed by a contactor to connect the motor directly to the network).

With this scheme, when the motor is started, both the voltage and current are supplied without surges, allowing for a smooth and trouble-free startup in a short period of time. In this way, the mechanism and electrical network are protected during the startup of the asynchronous motor.

Its main components are as follows: voltage and current sensors, which serve to measure and control the motor's current and voltage in real time; a control unit (microcontroller, PLC, or analog relay circuit), which monitors the startup duration, current and voltage dynamics, fault conditions, and other parameters; and thyristor regulators, which are connected directly to the three-phase network and ensure that the main current is supplied to the motor gradually.

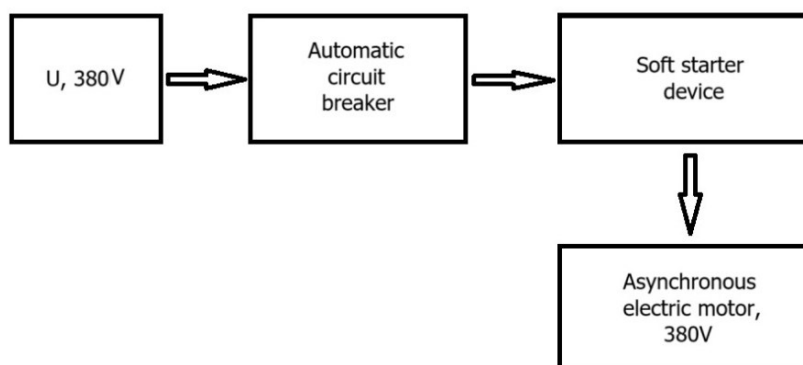


Fig.4. Example of implementing a soft starter.

The advantages of this device are as follows:

- it is not complex; the circuit design and commissioning are straightforward;
- power losses are minimal; it is energy efficient and reduces energy loss even at high currents;
- regarding high-current operation, the device remains more compact in high-power systems compared to the previously described device;
- maintenance is inexpensive and simple; since it is made of basic components, the overall cost is low. In the event of a failure, diagnostics and repairs do not require specialized skills.
- This scheme can achieve a good level of efficiency and energy savings in power management; however, the methods for controlling asynchronous motors are limited.

4. Conclusion (Заклучение)

Effective regulation of voltage drop during the starting of asynchronous electric motors in industrial and household enterprises plays a crucial role in ensuring the reliability of the power system and increasing energy efficiency. Direct-on-line starting of asynchronous motors often leads to high inrush currents and significant voltage dips, which negatively affect the power network: causing insulation degradation, increased power losses, and failures of automation systems. Therefore, it is essential to employ modern methods for limiting starting currents and managing voltage, including the implementation of soft starter devices, contactless relays, and intelligent control algorithms.

Soft starter devices provide gradual starting of the motor, smoothly increasing the voltage from its initial value to the nominal level. This process reduces inrush currents, protects the mechanism and power network, and extends the service life of the equipment. Soft starters are distinguished by their energy efficiency, high reliability, affordability, and ease of maintenance. However, the control capabilities may be limited, and some challenges can arise in systems with heavy loads and rapid dynamic requirements.

The technical solutions and mathematical models analyzed by the author take into account the dynamic changes in voltage during motor startup and make it possible to achieve optimal control and energy efficiency. Therefore, the application of automated control systems and soft starting technologies in modern asynchronous electric motor systems ensures not only reliability but also the rational use of energy resources.



REFERENCES

1. J.S. Salimov, N.B. Pirmatov, "Elektr mashinalari," Tashkent, National Society of Philosophers of Uzbekistan Publishing House, Tashkent, 2011. [1]
2. The scientific patent titled "A motor control controller system and methods" by researchers L. Bowman and A. Cheeseman. GB 2619616 A. 2023 year [2].
3. A.S. Karimov, M.M. Mirkhaydarov, G.R. Shoyokubov, B.A. Abdullaev, S.G. Bleykhman, "Fundamentals of Electrical Engineering and Electronics" Tashkent, "O'qituvchi" Publishing House, 1995.
4. B.X.Shaymatov, I.I.Xafizov, M.B.Xolmurodov, T.A.Sattorov "Elektr mashinalari" Buxoro 2021 yil.
5. I.U.Rakhmonov, N.N.Kurbonov "Analysis of automated software for monitoring energy consumption and efficiency of industrial enterprises" E3S Web of Conferences 216, 01178, 2020 y.
6. I.U.Rakhmonov, F.A.Hoshimov, N.N.Kurbonov, D.A.Jalilova, "Optimization of the modes of electric loads of power-consuming units operating in different production modes", AIP Conference Proceedings 2552 (1), 2023 y.
7. F.Mamarasulova, Y.Bobojonov, S.Djurayev, N.Karimova, "Stimulating environmental protection activities in the energy sector" E3S Web of Conferences 461, 01099. 2023 year.
8. H.F.Abidovich, R.I.Usmonovich, "Analysis of the optimal energy indicators of electric arc furnace", Austrian Journal of Technical and Natural Sciences, 52-54, 2015 y.
9. V.Y.Ushakov, A.V.Mytnikov, I.U.Rakhmonov, "High-voltage equipment of power systems" Power systems. Springer, Cham. <https://doi.org/10.1007/978-3-031-38252-9>, 2023 year.
10. S.Makhmutkhanov, J.Akhrom, S.Djurayev, I.Bozorov "Stimulating environmental protection activities in the energy sector" AIP Conference Proceedings 3152 (1), 060011, 2024 year.
11. I.U.Raxmonov, N.N.Niyozov, K.B.Nimatov, V.Ya.Ushakov, "Mathematical model for reducing active power losses by regulating reactive power at enterprises with continuous production mode" Bulletin of the Tomsk Polytechnic University Geo Assets Engineering 336 (159-171) 2025 year.