where f = 50 Hz is the network frequency; C is the insulation capacity; U is the effective value of the insulation voltage; tg is the tangent of the dielectric loss angle.

The insulation of the device is heated both due to losses in the current-carrying circuit and due to losses in the dielectric.

Methods of heat transfer inside heated bodies and from their surface:

There are three types of heat transfer: thermal conductivity, convection and thermal radiation [5].

Thermal conductivity. Thermal conductivity is the process of heat propagation between directly touching particles caused by the thermal motion of molecules or atoms of a substance, and in metals - free electrons.

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Innovative technologies of electrical energy conversion system with regulation in electric drive

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This system explores innovative technologies in the field of electrical power conversion with a focus on control in the context of electric drive. The abstract covers advanced methods and tools aimed at efficient and controllable electrical energy conversion to improve the efficiency and functionality of electric drive systems.

Today, innovative technologies in the field of hydraulic and power engineering construction, as well as in water and railway transport remain in demand and relevant.

As part of the implementation of Presidential Decree No. PP-329 of 10 October 2023 aimed at radical reform of the railway transport sector, new stages of effective use of the country's transit potential are being initiated. The focus is on transformation of the railway industry, creation of a competitive environment, active involvement of business processes and introduction of modern management methods.

Electric transport plays a key role in increasing the global demand for electricity with a significant environmental impact. This makes electric transport for the movement of passengers and freight economically viable. Automatic speed control of vehicles is widely used in the railway industry. The in-depth study of automation systems based on semiconductor technology and the regulation of electric power conversion in electric drive brings significant economic benefits [1].

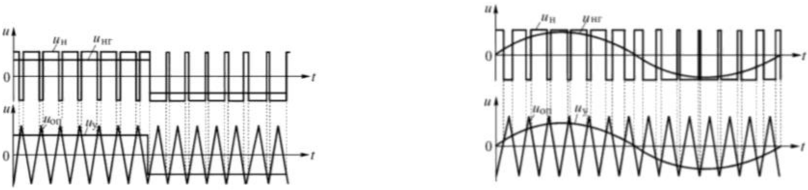
The most common type of converter devices are uncontrolled rectifiers. These devices, built on simple and affordable semiconductor diodes, stand out for their maximum simplicity, reliability, high efficiency and sufficiently high quality of the rectified voltage, as well as harmonic composition of the current consumed from the network. However, due to the lack of controllability of the energy conversion process, they cannot be used independently to create controlled electric drives. They are usually combined with other controllable devices such as voltage regulators or stand-alone inverters.

Controllable rectifiers, typically using low-frequency thyristors, are free of many disadvantages and have most of the advantages over diode rectifiers. With their high efficiency and reversible power conversion capability, they are used as the main conversion devices in DC drive systems or as part of two-stage power conversion systems [2].

Disadvantages of thyristor rectifiers are expressed in increased levels of rectified voltage ripple, reduced power factor, which decreases in proportion to the output voltage, and unidirectional flow of the output current. To enable bidirectional current flow through the load, reversible thyristor converters are used, comprising two thyristor rectifiers connected in counter-parallel. One of them is designed to flow current in the forward direction and the other in the reverse direction, thus providing full functionality of the converter.

Frequency Converters (FCs) used in AC drive systems convert the AC three-phase mains voltage, and its magnitude and frequency can be independently controlled. Despite several advantages such as the use of low-frequency thyristors, high efficiency, and the possibility of reverse power transfer, LFDs have disadvantages such as complex power circuitry, limited output frequency range, increased sensitivity to line voltage quality, significant distortion of the output voltage waveform, and low power factor. As a result of these limitations, the application of such converters is restricted fig. 1 [3].

Another type of frequency converter is a system based on a rectifier of three-phase alternating mains voltage and an autonomous inverter converting the rectified voltage into an alternating three-phase voltage The with adjustable frequency and amplitude. Despite the additional stage of energy conversion and the associated slight decrease in efficiency, such frequency converters with a DC intermediate link have found wide application in various electrical installations.



a *b*

Fig. 1. Shape of output voltage U_{out}, main harmonic U_{1AIV}:
a – single-phase AIV with PWR; *b* – single-phase AIV with PWM

In AC systems with frequency-controlled electric drives, stand-alone current inverters (AIC) and voltage inverters (AIV) are used. The AIC, which shapes the output current curves in the load, is often used with a controlled thyristor rectifier. This rectifier regulates the magnitude of the inverter input current, thereby determining the amplitude of the output currents. Frequency inverters with AIC have several advantages, such as the ability to use conventional thyristors and the ease of converting the power from the motor back to the grid via the AIC and controlled rectifier (converted to dependent inverter mode) [4; 6].

The main disadvantages include:

– low input power factor,

– deviations from the sinusoidal form of output voltages and currents,

– limited possibilities to regulate the output frequency and change the load parameters.

Two-stage frequency inverters based on autonomous voltage inverters are more widely used. Unlike Autonomous Current Inverters, which include an inductance in the DC circuit at their input, an AIV has a parallel connected capacitance at the input as a mandatory element. This allows the use of semiconductor keys to connect this capacitance to the output terminals, which enables the generation of voltage curves at the load. By using an uncontrolled rectifier, a high input power factor is achieved and the output voltage can be regulated using pulse width regulation (PWR) or the more advanced pulse width modulation (PWM) method.

There are different realizations of pulse width regulation and pulse width modulation. In the case of bipolar PWM, each half-wave of the output voltage of a single-phase stand-alone voltage inverter is a number of usually identical pairs of rectangular pulses of opposite polarity, as shown in fig. 1a. Regulation of the amplitude of the fundamental harmonic of the voltage is achieved by changing the ratio of the duration of positive and negative rectangular pulses [1,5].

Bipolar pulse width modulation is a special case of pulse width regulation, in which the change in the ratio of pulse widths of opposite polarity during each half-wave of the output voltage is adjusted so that the average value of each pair of pulses during the period of their repetition frequency corresponds to the instantaneous value of the main harmonic of the output voltage in the middle of the averaging interval. The output voltage graph of an autonomous voltage inverter for such a dual polar PWM is shown in fig. 1 b.

When forming the output voltages of a three-phase autonomous voltage inverter, each of the load phases is connected to one of the two poles of the input DC voltage at any given time. At this point, three possible combinations of connection of the other two phases are possible:

1) both phases are connected to the same pole;

2) one of the phases is connected to the same pole and the other to the opposite pole;

3) both phases are connected to the opposite voltage pole.

The frequency of the higher harmonic components of the output voltage is determined by the PWM frequency, which, when using modern IGBT-type transistors in the AIV, can be increased to a value of more than 4 kHz without a noticeable decrease in the efficiency of the converter. Therefore, despite the significant amplitude level of the higher harmonics of the AIV voltage, the currents of the active-inductive load are practically sinusoidal fig.2.

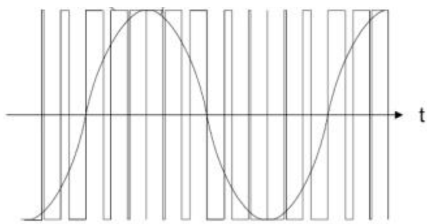


Fig. 2. The shape of the output voltage U_{out} of one phase of a three-phase AIV with PWR

In the mode of a frequency-controlled electric drive, dynamic braking can be used, in which the stator windings of the motor are powered by direct current from an autonomous voltage inverter. If the effectiveness of such braking is insufficient, generator braking is used with the transfer of active power through the AIS to the DC circuit of the frequency converter. To prevent an increase in voltage on the DC filter capacitance in the case of power transmission to the network through an uncontrolled rectifier, the capacitance is discharged using a transistor pulse regulator on a brake resistor. If the amount of energy transferred is significant and it is advisable to transfer to an alternating current network, a controlled rectifier is used. A transistor AIV with PWM at the input of the frequency converter acts as an inverter in braking modes, providing energy recovery, and in motor mode it turns into a rectifier. This ensures the sinusoidal nature of the mains currents and the regulation of the reactive power of both signs. The use of identical transistor devices at the input and output of the frequency converter is an additional advantage.

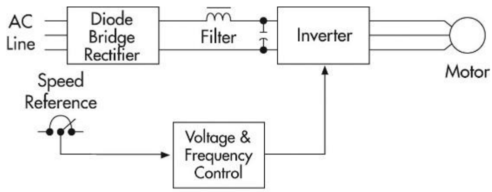


Fig. 3. Frequency–controlled electric drive: rectifier; filter; autonomous voltage inverter; frequency converter control devices [2; 7]

Thus, after the analysis, it can be concluded that the optimal structure of a modern frequency-controlled asynchronous electric drive, taking into account energy, adjustment and mechanical characteristics, involves the use of a frequency converter with a DC intermediate. This link consists of a rectifier with an inductively capacitive DC voltage filter and an autonomous voltage inverter built on IGBT type power transistors and forming the main harmonic of the output voltage by pulse width modulation. An adjustable electric drive based on the structure shown in fig. 3 has a number of advantages, including:

– wide range of regulation (D = 30−60 and more);
– high efficiency (excluding the engine reaching 0,98);
– high power factor (up to 0,98);

as well as high reliability and compactness of the converter. These factors confirm the choice of this power structure in the development of frequency-controlled drives of the AT series.

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Методы эффективного управления тяговым электроприводом

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В статье рассмотрены способ управления тяговым электроприводом, способ скалярного управления асинхронного двигателя, а также найдены векторные системы управления электроприводами с прямым измерением