Форма № 24

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Національний університет «Запорізька політехніка»

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(повне найменування факультету)

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до дипломного проєкту (роботи)

магістра
(ступінь вищої освіти)

на тему Розробка та дослідження перетворювача
(назва теми)
частоти 120 А/380 В/25-50 Гц

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Освітня програма (спеціалізація)
Електричні та електронні апарати

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Форма № 25

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Національний університет «Запорізька політехніка»
(повне найменування закладу вищої освіти)

Інститут, факультет Електротехнічний факультет
Кафедра Електричні та електронні апарати
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Освітня програма (спеціалізація) Електричні та електронні апарати
(назва освітньої програми (спеціалізації)

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Завідувач кафедри ____________________

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З А В Д А Н Н Я
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(прізвище, ім'я, по батькові)

1. Тема проєкту (роботи) Розробка та дослідження перетворювача частоти 120 А/380 В/25-50 Гц

керівник проєкту (роботи) Поляков Михайло Олексійович, д.т.н., професор ,
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1. Розрахунок і вибір силових елементів перетворювача частоти. 2. Розрахунок енергетичних показників перетворювача частоти постійного струму. 3. Розрахунок захисних RC-ланцюгів перетворювача частоти. 4. Перевірка комплектності перетворювача частоти. 5. Дослідження електричного опору та випробування електричної ізоляції. 6. Дослідження вихідної напруги, її частоти та діапазонів їх зміни.
5. Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень)
1. Креслення загального виду з описом елементів. 2. Графік часових діаграм перетво-Рювача частоти . 3. Схема стенду випробувань перетворювача частоти.

6. Консультанти розділів проєкту (роботи)

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2	Розрахунок енергетичних показників перетворювача частоти постійного струму	19.09.2023-29.09.2023	
3	Розрахунок захисних RC-ланцюгів перетворювача частоти	29.09.2023-09.10.2023	
4	Зовнішній огляд, перевірка комплектності, габаритних, установчих і приєднувальних розмірів, монтажу та маркування перетворювача.	09.10.2023-19.10.2023	
5	Дослідження електричного опору та випробування електричної міцності ізоляції перетворювача	19.10.2023-29.10.2023	
6	Дослідження вихідної напруги, її частоти та діапазонів їх зміни.	08.11.2023-18.11.2023	
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ABSTRACT

Report: 89 p., 3 tables., 11 fig., 16 sources.

Development and Investigation of Frequency Converter with Transistor.

Object of research – development and investigation of frequency Converter with Transistor Modules. This thesis examines categorizes various types of frequency converters and scrutinizes the selection criteria guiding the choice of a specific type. The chosen focus of this work is on frequency converters utilizing transistor modules.

The primary goal of this thesis is the development and investigation of a frequency converter employing transistor modules. The research integrates theoretical analysis, simulation studies, and experimental validations to advance the understanding of transistor-based frequency converters and their applications in modern electrical systems.

The methodology encompasses a thorough review of existing literature, simulation studies using industry-standard software, and practical experiments on a prototype converter. Theoretical models will be developed to predict the converter's performance under different operating conditions, and simulations will validate these models. Practical experiments will be conducted to verify the theoretical and simulation results, providing a holistic understanding of the converter's behavior.

Anticipated results include a comprehensive analysis of the developed frequency converter's performance in terms of efficiency, control precision, and dynamic response. The research aims to identify optimal operating conditions and potential areas for improvement in future designs. The findings are expected to contribute valuable insights to the field of power electronics, guiding engineers and researchers in the design and implementation of efficient frequency converters in various industrial applications.

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INTRODUCTION

A static frequency converter is an electronic device that provides smooth speed control of three-phase alternating current electric motors by converting fixed values of mains voltage and frequency into variable values.

Although the principle has always remained the same, many changes have been made to the original frequency converters, including the use of thyristors, which are now controlled by microprocessor-controlled thyristors and digital units.

Due to the increasing degree of automation in industry, there is a constant need for additional automatic controls need for additional automatic controls, and there is a continuous increase in production speeds and improvements in the speed of production continuous increase in production speeds and improved methods in order to further improve the efficiency of industrial plants.

Electric motors are nowadays important standard industrial products. These motors are designed to operate at fixed speeds, and for many work has been ongoing for many years to optimize their operating speed control.

This was not possible until static frequency converters were introduced that could be used effectively to smoothly control the speed of three-phase AC motors.

The vast majority of static frequency converters currently used in industry to control or regulate the speed of three-phase AC motors are designed using two different principles (Figure 1):

- frequency converters without an intermediate circuit (also called direct inverters)

- frequency inverters with a variable or fixed intermediate circuit.

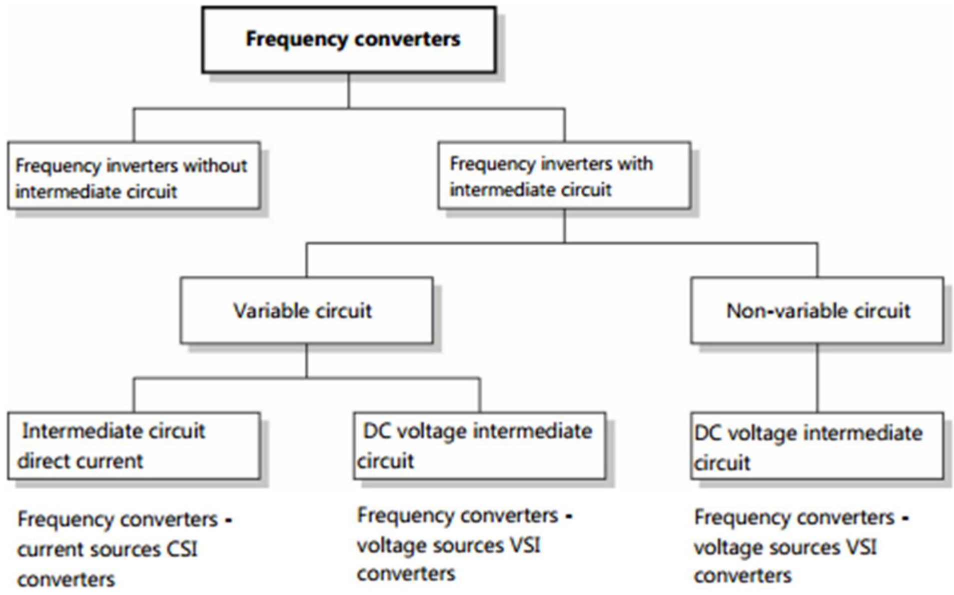

Figure 1. Frequency converter circuit on two IGBT transistors

For decades, consumer requirements for electrical energy converters have remained the same: smaller dimensions (for the same output power), higher efficiency, better functionality (including electrical parameters), lower cost.

Frequency inverters with an intermediate circuit have an intermediate circuit of either direct current or direct voltage and are called current source inverters and voltage source inverters respectively.

Converters with an intermediate circuit have a number of advantages over direct converters, such as converters, namely:

- Better reactive current regulation

- Reduced number of harmonics

- No limitation in terms of output frequency (but there is a limitation in terms of control and the properties of the electronic components used). control and the properties of the electronic components used). For operation at high output frequencies, mainly converters with an intermediate circuit are used.

As a rule, direct converters are cheaper than intermediate-circuit converters but they tend to have poorer harmonic suppression.

Since most frequency converters use an intermediate circuit for the voltage Since most frequency converters use an intermediate DC voltage circuit, this brochure focuses on this group of converters.

Recently developed transistor energy conversion methods, new components (IGBT transistors) and materials have made it possible, without reducing, but even increasing the efficiency, to raise the operating frequencies of commercially available pulse converters up to several hundred kilohertz, which, in turn, made it possible, in combination with new design, circuit and technological solutions, to reduce the size of the converters at the same output power.

In modern power electronics, widespread received the so-called IGBT transistors. This abbreviation is borrowed from foreign terminology and stands for as Insulated Gate Bipolar Transistor (IGBT), and in Russian it sounds like an insulated gate bipolar transistor. The IGBT transistor is an electronic power device that is used as a powerful electronic key [1].

The purpose of the ongoing research is to develop and investigate a frequency converter based on IGBT transistors with the most effective efficiency value (by reducing the number of transistors) and low cost.

It is known that at a high frequency, the stresses the dimensions of the high-frequency transformer are reduced, so the frequency converter will have low weight and size dimensions. In addition, the frequency converter is made on two transistors, and, accordingly, the electrical losses on the transistors will be less, which will increase the efficiency of the frequency converter compared with analogue and reduce the cost of the entire frequency converter.

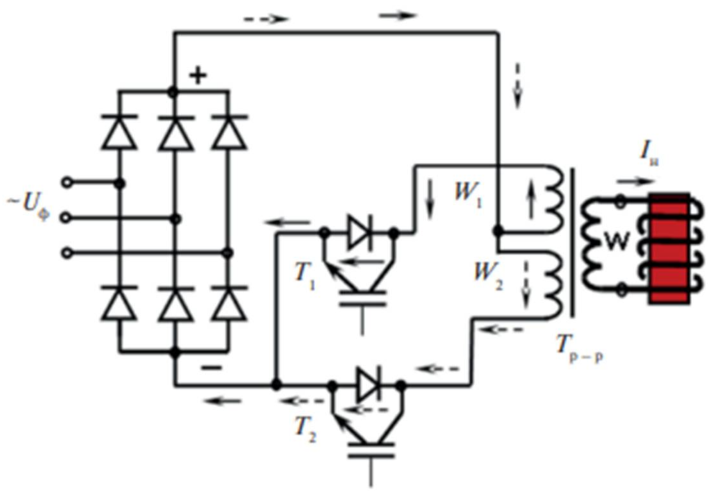

Figure 2. Frequency converter circuit on two IGBT transistors

A prototype converter was developed and manufactured frequencies. On fig. 3 shows a prototype of a frequency converter with a power of 6 kW for frequencies from 2 to 20 kHz. The frequency converter uses a three-phase power supply system as a source 380 V industrial frequency. Frequency converter implemented on IGBT transistors. The control system is implemented on the logic elements of the mathematical apparatus of the software package. The rectifier was made on the basis of a three-phase rectifier bridge circuit. For matching voltage and galvanic decoupling, a two-winding high-frequency power transformer was used.

As a load for the frequency converter was used induction heating, which is used to heat process equipment (oil pipeline, pipeline, tank, etc.), heating of metal, liquid media, for drying coatings, materials (for example, wood). The most important parameter of induction heating installations is frequency. For every process there is an optimal frequency range providing the best technological and economic performance. For induction heating of metal, frequencies from 50 Hz to 5 MHz are used.

For decades, consumer requirements for electrical energy converters have remained the same: smaller dimensions (for the same output power), higher efficiency, better functionality (including electrical parameters), lower cost.

Recently developed transistor energy conversion methods, new components (IGBT transistors) and materials have made it possible, without reducing, but even increasing the efficiency, to raise the operating frequencies of commercially available pulse converters

The cabinet of the frequency converter type IF5 (hereinafter referred to as the converter), manufactured in accordance with the documentation ATLA.654365.038, is subjected to tests.

The purpose of tests is to check the transducer on functioning, compliance with technical documentation and the present program-methodology.

During the test, Electrical circuit diagram ATLA.654365.038 PE3, the list of elements ATLA.654365.038 PE3, connection diagram ATLA.654365.038 PE5, Operation manual ATLA.654365.004 PE, Operation manual for the control terminal ATLA.656111.168 PE.

1 CALCULATION AND SELECTION OF POWER ELEMENTS

1.1 Selection of power transformer

A transformer for frequency converter, commonly known as a power transformer, serves the crucial function of converting electrical energy between different voltage levels. This is essential for efficient transmission, distribution, and utilization of electrical power in various applications. Here are some key reasons why transformers are integral components in power systems:

- Voltage Transformation: Transformers enable the conversion of voltage levels, allowing electricity to be transmitted at high voltages over long distances with minimal energy loss. At the receiving end, the voltage is then transformed back to lower levels for safe distribution and use.

- Power Distribution: Transformers play a pivotal role in power distribution networks, ensuring that electricity is distributed to homes, businesses, and industries at suitable voltage levels for diverse applications.

- Energy Transmission: Power generated at power plants is typically at high voltages to reduce energy loss during transmission. Transformers facilitate the efficient transfer of energy over long distances through power lines.

- Isolation: Transformers provide electrical isolation between the input and output, enhancing safety by preventing direct electrical connection. This is crucial for protecting equipment and ensuring the safety of personnel.

- Impedance Matching: Transformers help match the impedance between the power source and the load, optimizing power transfer and improving the overall efficiency of the electrical system.

- Voltage Regulation: Some transformers include tap changers or other features to regulate the output voltage, ensuring a consistent and stable supply to electrical devices.

In summary, transformers are essential components in electrical systems for voltage transformation, power distribution, energy transmission, safety, impedance matching, and voltage regulation. Their versatile applications make them fundamental in ensuring the reliable and efficient operation of power networks.

The power transformer is intended for transfer from electric power system of electric power to the transistor converter and creation at input of TP of necessary value of linear (U_{2l}) supply voltage.

1.1.1 Simplified selection of the secondary voltage of the power transformer

The simplified selection of the secondary voltage of a power transformer is a critical step in designing an electrical system.

In summary, the simplified selection of the secondary voltage of a power transformer is a critical aspect of electrical system design, encompassing considerations of compatibility, efficiency, safety, regulatory compliance, load distribution, and system stability.

Finding the required linear U_{2l} voltage of the active secondary voltage of the specified transformer is carried out by the ratio:

$$U_{2l} = (0{,}9 - 1{,}0)U_n - for\ FR; \quad (1.1)$$

$$U_{2l} \approx 1{,}0 \cdot 380 = 380\ (V)$$

Accepted 380 (V)

1.1.2 Calculation of power transformer power

The calculation of power transformer power is a fundamental step in electrical engineering and design.

In summary, the calculation of power transformer power is essential for load sizing, efficiency optimization, prevention of overloading, voltage regulation, system safety, compliance with standards, and consideration of future load growth. It is a critical step in ensuring the reliability, safety, and longevity of the electrical power distribution system.

Given that this transformer feeds only one of our loads, we calculate the power of the transformer approximately by the ratio:

$$S_{ts} \geq 1{,}05 \cdot \mathrm{P}_n$$

(1.2)

$$S_{ts} \geq 1{,}05 \cdot 38000 = 39900\ (V\mathrm{A})$$

This uses a two-winding power transformer.

1.1.3 Selection of nominal values of power and secondary voltage of the power transformer

The selection of nominal values for power and secondary voltage of a power transformer is a crucial aspect of electrical system design.

In summary, the selection of nominal values for power and secondary voltage of a power transformer is a comprehensive process that considers load requirements, voltage compatibility, efficiency optimization, system stability, safety, compliance with standards, and future load growth planning. It is a critical step in designing a robust and reliable electrical power distribution system.

For the nominal value of the secondary voltage we take the closest to the value of linear operating U2ln calculated from (1) - for a three-phase transformer, which is a multiple of ten.

$$U_{2ln} = 400\ \ (V\mathrm{A})$$

For the nominal value of the transformer power we take the nearest largest value of table 1 (data of power transformers).

$$S_n = 63000\ (VA)$$

1.1.4 Calculation of active resistance and rated load current

The calculation of active resistance and rated load current is essential for equipment sizing, voltage drop and power loss analysis, circuit protection, equipment longevity, system efficiency, compliance with standards, and preventing overheating. It is a fundamental aspect of designing a safe, reliable, and energy-efficient electrical system.

$$\left.\begin{aligned} R_n &= {}^{U_n}/_{I_{dn}} \\ I_{dn} &= {}^{P_n}/_{U_n} \end{aligned}\right\} \qquad (1.3)$$

$$I_{dn} = \frac{38000}{380} = 100\ (\text{A})$$

$$R_n = \frac{380}{100} = 3.8\ (Ohm)$$

1.1.5 Checking the correct choice of power of the power transformer, based on the allowable load of its primary winding with currents of non-sinusoidal shape (when powered by a transistor converter)

Checking the correct choice of power for a power transformer when dealing with non-sinusoidal currents from a transistor converter is vital for addressing issues related to harmonic content, transformer heating, efficiency, voltage distortion, equipment compatibility, compliance with standards, and long-term reliability. It ensures the transformer operates safely and efficiently in real-world conditions.

This test is performed from the following ratios for the required rated power of the power transformer:

$$S_n \geq 1{,}49 \cdot U_{2ln} \cdot I_{dn}$$

(1.4)

$$S_n = 1{,}49 \cdot 400 \cdot 100 = 59600 \ \ (VA)$$

Since the previously selected in paragraph 1.1.3 of the rated power S_n = 63000VA power transformer satisfies the test condition (4), we choose from table. 1 three-phase two-winding transformer ТСПЭ-0,12 (specified nominal power 63000VA, primary voltage 380 V) with the following parameters:

S_n =59600VA; ΔP_{xx} = 0,8 kWt; U_{2ln} = 380 V; ΔP_{kz} = 1.8 kWt; U_1 =220 V; I_{xx} = 1,8 %; U_k = 3,6 %,

where I_{xx} and U_k — relative values according to the no-load current and the short-circuit voltage of the power transformer.

1.1.6 Calculation of phase values of active resistance and scattering inductance of a power transformer

The calculation of phase values of active resistance and leakage inductance for a power transformer is essential for system modeling, transient analysis, fault analysis, voltage regulation, efficiency optimization, harmonic analysis, equipment sizing, and compliance with standards. It forms a critical part of the design and analysis process to ensure the transformer's reliable and efficient performance within the broader electrical infrastructure.

$$R_{ts.f} = \frac{\Delta P_{kz}}{3 \cdot (I_{2fn})^2} \quad (1.5)$$

$$L_{ts.f} = \frac{U_{2ln} \cdot U_k}{\sqrt{3} \cdot \omega_1 \cdot I_{2fn}} \quad (1.6)$$

where $U_{2fn} = U_{2ln}/\sqrt{3}$ — nominal phase current value of the voltage of the secondary winding of the power transformer;

$\omega 1 = 2\pi f_1 = 314\ c^{-1}$ - angular frequency of an industrial three-phase alternating current network (f_1 = 50 Hz);

I_{2fn} - nominal phase current value of the current of the secondary winding of the power transformer, calculated from the dependence:

$$I_{2fn} = \frac{S_n}{\sqrt{3} \cdot U_{2ln}} \tag{1.7}$$

$$I_{2fn} = \frac{59600}{\sqrt{3} \cdot 400} = 86{,}025\ (A)$$

$$R_{ts.f} = \frac{1800}{3 \cdot (86.025)^2} = 0.081\ (Ohm)$$

$$L_{ts.f} = \frac{400 \cdot 3{,}6 \cdot 10^{-2}}{\sqrt{3} \cdot 314 \cdot 86{,}025} = 0.307 * 10^{-3}\ (Hn)$$

1.2 Selecting the switch

An automatic circuit breaker, also known as an automatic shutdown or switch, is a crucial component in the context of a frequency converter or inverter for several reasons. Here are some key purposes and benefits of having an automatic circuit breaker in conjunction with a frequency converter:

- Overcurrent Protection: Automatic circuit breakers are designed to protect electrical circuits from excessive current. In the context of a frequency converter, they can detect and interrupt the circuit if there is an overcurrent condition, which may occur due to a fault in the system or an unexpected surge in power demand.

- Short Circuit Protection: In the event of a short circuit, where a low-resistance path forms between the conductors, an automatic circuit breaker can quickly and automatically disconnect the circuit. This helps prevent damage to the frequency converter and other connected equipment.

- Equipment Protection: Automatic circuit breakers contribute to the overall protection of the frequency converter and connected devices by interrupting the power supply in the presence of abnormal conditions. This safeguarding helps extend the lifespan of the equipment and reduces the risk of costly repairs.

- Fire Prevention: Overcurrents and short circuits can generate excessive heat, posing a fire hazard. By promptly disconnecting the power supply, automatic circuit breakers contribute to fire prevention in the frequency converter system.

- Operational Safety: The presence of an automatic circuit breaker enhances the safety of the overall electrical system. In case of a fault, it ensures a rapid response to isolate the problematic section, reducing the risk of electrical accidents and minimizing downtime.

- Compliance with Standards: Many electrical codes and standards mandate the use of automatic circuit breakers for safety and regulatory compliance. Integrating these devices ensures that the frequency converter setup adheres to industry standards and regulations.

In summary, an automatic circuit breaker is an essential protective device in a frequency converter system, serving to prevent overcurrents, protect against short circuits, ensure equipment longevity, contribute to fire prevention, enhance operational safety, and comply with relevant industry standards.

The automatic switch is intended for removal and supply of supply voltage on TP, and also for protection of the last at short circuits or overloads on current. The circuit breaker is selected on operating voltage and working current.

1.2.1 Voltage selection condition:

In summary, the voltage selection condition is crucial for equipment compatibility, system efficiency, safety, voltage drop mitigation, regulatory compliance, equipment longevity, load distribution, compatibility with power sources, and future expansion considerations. It is a fundamental step in designing a reliable and efficient electrical system.

$$U_{Qn} \geq U_{2ln} \tag{1.8}$$

where U_{Qn} — operating voltage of the circuit breaker.

$$U_{Qn} \geq 400\ (V)$$

1.2.2 Current selection condition:

In summary, the current selection condition is critical for equipment rating, system safety, circuit protection, voltage drop considerations, efficiency optimization, compliance with standards, equipment longevity, load distribution, and future expansion considerations. It is a fundamental step in designing a safe, reliable, and efficient electrical system.

$$I_{Qn} \geq k_{\phi} \cdot k_{\mathrm{I}} \cdot k_{dn} \tag{1.9}$$

$$I_{Qn} \geq 1{,}05 \cdot 0{,}817 \cdot 86{,}025 = 73{,}796\ (\mathrm{A})$$

where I_{Qn} — long-term allowable operating current of the circuit breaker.

1.2.3 Selecting the type of circuit breaker

Selecting the type of circuit breaker is essential for providing effective overcurrent protection, ensuring fault clearance, meeting application-specific requirements, accommodating voltage levels and current ratings, achieving selective coordination, considering environmental conditions, addressing maintenance considerations, and ensuring regulatory compliance in the electrical system.

Choose from table 2 circuit breaker series FD160 for nominal operating voltage 690V with parameters

U_{Qn} = 690 V>$U2_{ln}$ = 400; I_{Qn} = 160A> k_f k_I I_{dn} =74A;

I_{Qmax} = 25 кА — current switching capacity of the switch.

1.3 Calculation and selection of power elements

The calculation and selection of power elements, such as transformers, generators, or other electrical components, are performed for several critical reasons:

- Load Sizing: Calculating and selecting power elements involve determining the appropriate capacity to meet the electrical load requirements. This ensures that the power elements can provide sufficient power to meet the demands of connected devices and equipment.

- System Efficiency: Properly sizing power elements contributes to the overall efficiency of the electrical system. Matching the capacity of transformers, generators, or other elements to the load helps minimize energy losses, promoting efficient energy transfer within the system.

- Voltage Regulation: Power elements play a crucial role in maintaining stable voltage levels within the system. Proper calculation and selection help ensure that the voltage regulation meets acceptable standards, preventing issues such as overvoltage or undervoltage conditions.

- System Reliability: Accurate calculation and selection of power elements enhance the reliability of the electrical system. Adequately sized components are less likely to be overloaded, reducing the risk of equipment failures, downtime, and potential damage.

- Safety Considerations: Ensuring that power elements are correctly sized contributes to system safety. Properly sized components are less likely to experience overheating or overloading, minimizing the risk of electrical hazards and enhancing the safety of the overall system.

- Compliance with Standards: The calculation and selection of power elements align with industry standards and regulations. Adhering to these standards is crucial for ensuring the safety, reliability, and legal compliance of the electrical system.

- Equipment Longevity: Properly sized power elements contribute to the longevity of electrical equipment. Avoiding overloading conditions and ensuring components operate within their specified capacity helps extend the operational life of transformers, generators, and other power elements.

- Environmental Impact: Efficiently sized power elements contribute to reduced energy consumption, which aligns with sustainability goals and minimizes the environmental impact of the electrical system.

- Future Expansion: Anticipating future load growth and system expansion is part of the calculation and selection process. Choosing power elements with scalability in mind allows for the integration of additional equipment or increased power demand without the need for frequent upgrades.

In summary, the calculation and selection of power elements are essential for load sizing, system efficiency, voltage regulation, system reliability, safety considerations, compliance with standards, equipment longevity, environmental impact, and future expansion planning in the design and operation of electrical systems.

1.3.1. Calculation and selection of transistors of the controlled rectifier:

The calculation and selection of transistors for a controlled rectifier are essential for addressing current and voltage requirements, power handling capacity, switching speed, efficiency optimization, temperature considerations, voltage drop, system reliability, compatibility with control circuitry, and compliance with industry standards. These considerations collectively contribute to the effective design and performance of the controlled rectifier.

a) Calculation of transistors by current

The calculation of transistors by current is crucial for managing current handling capacity, preventing overcurrent conditions, optimizing efficiency, addressing thermal considerations, managing voltage drop, achieving current balancing, complying with specifications, ensuring system reliability, and maintaining safety in electronic circuits.

The average value of the current flowing through the transistor s is found from the dependences:

$$\mathrm{I}_{trsr} = \frac{\mathrm{I}_{d\,max}}{3} \tag{1.10}$$

$$\mathrm{I}_{trsr} = \frac{2 \cdot 100}{3} = 66.66\ (\mathrm{A})$$

b) Calculation of transistors voltage

The calculation of transistors voltage is crucial for selecting transistors that can safely handle the voltage levels in a circuit. It contributes to overvoltage protection, efficiency optimization, thermal considerations, voltage drop analysis, voltage compatibility, compliance with specifications, system reliability, and safety in electronic circuits.

The maximum value of the voltage applied in operating modes to the transistor is determined by the dependences:

$$U_{trmax} = \sqrt{2} \cdot \mathrm{K}_{cmax} \cdot U_{2ln} \tag{1.11}$$

$$U_{trmax} = \sqrt{2} \cdot 1{,}1 \cdot 380 = 591.141\ (V)$$

c) Choice of type and basic passport data of transistors

The choice of transistor type and obtaining basic passport data is crucial for ensuring the suitability, reliability, and performance of transistors within electronic circuits. It enables engineers to make informed decisions based on the specific requirements of the application and ensures compliance with standards for a safe and efficient operation.

Carried out from the following ratios:

$$\left.\begin{aligned} I_{trn} \geq \frac{K_{zt} \cdot I_{trsr}}{n \cdot k_{\text{охл}}} \\ U_{trn} \geq k_{zn} \cdot U_{tr\ max} \end{aligned}\right\} \tag{1.12}$$

where n — the number of transistors connecting in parallel in the frequency converter;

K_{zt} — current stock ratio (taking into account the difference between the shape of this current and rectangular), equal to 1.1;

K_{zn} = (1,4 −1,5) — voltage margin factor (recommended by factories-manufacturers of power semiconductor devices for reliable operation of transistors);

k_{ohl}= 1 – for forced air cooling

$$I_{trn} \geq \frac{1{,}1 \cdot 66.66}{1 \cdot 1} = 73.326\ (\text{A})$$

$$U_{trn} \geq 1{,}5 \cdot 591.141 = 886.711\ (V)$$

1.3.2 Calculation and selection of transistors of the controlled rectifier:

The calculation and selection of transistors for a controlled rectifier are essential for addressing current and voltage requirements, power handling capacity, switching speed, efficiency optimization, thermal considerations, voltage drop management, system reliability, compatibility with control circuitry, and compliance with industry standards. These considerations collectively contribute to the effective design and performance of the controlled rectifier.

a) Calculation of transistors by current

The calculation of transistors by current is crucial for managing current handling capacity, preventing overcurrent conditions, optimizing efficiency, addressing thermal considerations, managing voltage drop, achieving current balancing, complying with standards, ensuring system reliability, and maintaining safety in electronic circuits.

The average value of the current flowing through the transistor is found from the dependences:

$$\mathrm{I}_{trsr} = \frac{\mathrm{I}_{d\,max}}{3} \quad (1.13)$$

$$\mathrm{I}_{trsr} = \frac{2 \cdot 100}{3} = 66.66\ (\mathrm{A})$$

b) Calculation of transistors voltage

The calculation of transistors by voltage is crucial for selecting transistors that can safely handle the voltage levels in a circuit. It contributes to overvoltage protection, efficiency optimization, thermal considerations, voltage drop analysis, voltage compatibility, compliance with specifications, system reliability, interchangeability, and safety in electronic circuits.

The maximum value of the voltage applied in operating modes to the transistor is determined by the dependences:

$$U_{trmax} = \sqrt{2} \cdot \mathrm{K}_{cmax} \cdot U_{2ln} \quad (1.14)$$

$$U_{trmax} = \sqrt{2} \cdot 1{,}1 \cdot 380 = 622.254\ (V)$$

c) Choice of type and basic passport data of transistors

The choice of transistor type and obtaining basic passport data is crucial for ensuring the suitability, reliability, and performance of transistors within electronic circuits. It enables engineers to make informed decisions based on the specific requirements of the application and ensures compliance with standards for safe and efficient operation.

Carried out from the following ratios:

$$\left.\begin{aligned} \mathrm{I}_{trn} &\geq \frac{\mathrm{K}_{zt} \cdot \mathrm{I}_{trsr}}{n \cdot k_{ohl}} \\ U_{trn} &\geq k_{zn} \cdot U_{trmax} \end{aligned}\right\} \quad (1.15)$$

where n — the number of transistors connecting in parallel in the frequency converter;

$К_{zt}$ — current stock ratio (taking into account the difference between the shape of this current and rectangular), equal to 1.1;

K_{zn} = (1,4 −1,5) — voltage margin factor (recommended by factories-manufacturers of power semiconductor devices for reliable operation of transistors);

k_{ohl}= 1 – for forced air cooling

$$I_{trn} \geq \frac{1{,}1 \cdot 53.03}{1 \cdot 1} = 58.333\ (A)$$

$$U_{trn} \geq 1{,}5 \cdot 622.254 = 933.381\ (V)$$

1.3.3 Calculation and selection of current-limiting reactor

The calculation and selection of a current-limiting reactor are vital for overcurrent protection, fault current reduction, voltage stability, circuit protection coordination, equipment longevity, system reliability, safety, compliance with standards, voltage drop management, and overall system optimization in electrical installations.

The current-limiting reactor is designed to limit the secondary phase current of the power transformer in the mode of internal or external short circuit in the thyristor converter (at a level not exceeding the maximum allowable pulse (shock) current through the thyristor).

a) Calculation of inductance of current-limiting reactor

The calculation of the inductance of a current-limiting reactor is integral to achieving effective current limiting, reducing fault currents, coordinating with protective devices, managing voltage drops, ensuring system stability, achieving selective coordination, optimizing system performance, and complying with industry standards in electrical installations.

$$L_{\text{TO}} = \left[\frac{\sqrt{2} \cdot k_{cmax} \cdot U_{2fn}}{\omega_1 (n \cdot \text{I}_{trmax} - I_{ust})} - L_{tsf}\right] \quad (1.16)$$

where I_{ust} = (2,3 − 2,5) I_{dn} — setting of the maximum protection of the thyristor converter (at which the command on emergency shutdown of the automatic switch on the remote release arrives).

$$L_{\text{TO}} = \left[\frac{\sqrt{2} \cdot 1{,}1 \cdot \left(\frac{380}{\sqrt{3}}\right)}{314 \cdot (1250 - 2{,}5 \cdot 86.025)} - 0.445 \cdot 10^{-3}\right]$$
$$= 1.936 \cdot 10^{-4}\ Hn$$

We issue tasks for the development and manufacture of current-limiting reactor РТСС-110-0,19 У3 with the following parameters:

− inductance $L^{*}_{\text{TO}} = 0{,}19\ mHn \geq L_{\text{TO}} = 0{,}19$ mHn
− operating current $I_{\text{TO}} = 110$ A $\geq 1{,}05 \cdot 0{,}817 \cdot 79.545 = 86.025$ A
− power losses $\Delta P_{\text{TO}} = 0{,}1 \cdot 10^{-2} \cdot 38000 = 38$ Wt

1.3.4 Calculation of equivalent (total) and inductance of the AC phase of the converter

The calculation of the equivalent inductance of the AC phase in a converter is essential for optimizing converter performance, reducing current ripple, ensuring voltage stability, managing harmonics, improving efficiency, analyzing transient responses, designing control systems, meeting standards, and achieving overall reliable and efficient operation in electrical systems.

$$L_f = L_{tsf} + L^{*}_{\text{TO}} \quad (1.17)$$

$$L_f = 0.445 \cdot 10^{-3} + 0.19 \cdot 10^{-3} = 1{,}195 \cdot 10^{-3}\ Hn$$

1.3.5 Checking the adequacy of the current switching capacity of the circuit breaker during a three-phase short circuit at the input of the FC

Checking the adequacy of the current switching capacity of the circuit breaker during a three-phase short circuit at the input of the feeder circuit is essential for fault protection, personnel safety, equipment protection, system reliability, preventing cascade failures, compliance with standards, minimizing downtime, equipment longevity, load shedding, system stability, and effective emergency response in electrical systems.

Carried out by calculating the maximum instantaneous value of the phase current $I^*_{фmax}$ of the circuit-breaker at the specified short circuit and comparison of this value with passport value by current switching capacity I_{Qmax} of the applied circuit-breaker:

$$I^*_{fmax} = \frac{\sqrt{2} \cdot k_{c\,max} \cdot U_{2fn}}{\omega_1 \cdot L_f} + I_{ustmax} \leq I_{Q\,max} \qquad (1.18)$$

$$I^*_{fmax} = \frac{\sqrt{2} \cdot 1{,}1 \cdot \left(\frac{380}{\sqrt{3}}\right)}{314 \cdot 1{,}195 \cdot 10^{-3}} + 198.864 = 1156 \text{ A}$$

$$I^*_{fmax} = 1156 \text{ A} \leq I_{Q\,max} = 5000 \text{ A}$$

1.3.6 Calculation and selection of the smoothing reactor

The calculation and selection of smoothing reactors are essential for mitigating harmonics, improving power quality, reducing voltage fluctuations, limiting inrush current, minimizing electromagnetic interference, protecting capacitors, enhancing system efficiency, ensuring compliance with standards, and customizing the solution for specific applications in electrical systems and power electronics.

The smoothing reactor is designed to limit the amplitude of the ripple of the rectified current (load current) at a given level.

a) Determination of the maximum value of the output EMF of the frequency converter

Determining the maximum value of the output electromotive force (EMF) of the frequency converter is integral to the design, selection, and safe operation of the system. It influences component sizing, voltage ratings, overvoltage protection, inverter design, efficiency optimization, compliance with standards, prevention of insulation failure, system safety, and the overall performance of the frequency converter.

$$E_{d0} = 1{,}35 \cdot U_{2ln} \quad (1.19)$$

$$E_{d0} = 1{,}35 \cdot 380 = 513\ (V)$$

b) Calculation of the amplitude of the pulsations of the first harmonic of the output voltage (in the nominal mode of operation of the FC)

The calculation of the amplitude of the pulsations of the first harmonic of the output voltage in the nominal mode of operation of the Frequency Converter is crucial for harmonic analysis, power quality assessment, equipment compatibility, compliance with standards, preventing resonance issues, optimizing filter design, minimizing voltage distortion, preventing nuisance tripping, ensuring efficient operation, and avoiding thermal overloading of sensitive components in the electrical system.

$$U_{(1)м} = \frac{2 \cdot E_{d0} \cdot cos\alpha_n}{m^2 - 1} \sqrt{1 + m^2 \cdot tg^2\alpha_n} \quad (1.20)$$

where $\alpha_н$ — the control angle corresponding to the nominal mode of operation of the TP (which according to the initial data is taken equal to 25 el. deg.);

m — pulse rectification for the selected TP scheme, located from the relations:

$$m = 6$$

$$U_{(1)м} = \frac{2 \cdot 513 \cdot \cos(25^{\circ})}{6^2 - 1} \sqrt{1 + 6^2 \cdot tg^2(25^{\circ})} = 82.092\ (V)$$

c) Calculation of the required value of the total (equivalent) inductance of the DC circuit FC

The calculation of the required value of the total (equivalent) inductance of the DC circuit in a Frequency Converter is essential for current limiting, voltage ripple reduction, energy storage, harmonic filtering, preventing voltage spikes, capacitor overvoltage protection, stabilizing the DC bus, control system design, preventing system instability, and compliance with industry standards.

$$L_d \geq \frac{U_{(1)M}}{m \cdot \omega_1 \cdot \xi \cdot I_{dN}} \quad (1.21)$$

where ξ — the set value of the load current ripple factor.

$$L_d \geq \frac{83.092}{3 \cdot 314 \cdot 0{,}05 \cdot 79.545} = 0.014 \ \ (Hn)$$

d) Determination of the inductance of the smoothing reactor

The determination of the inductance of the smoothing reactor is essential for harmonic filtering, voltage stabilization, current ripple reduction, power quality improvement, protection of sensitive equipment, resonance avoidance, filter design optimization, heat dissipation management, load compatibility, and compliance with industry standards in electrical systems and power electronics.

$$L_c \geq \left(L_d - 2 \cdot L_f - L_n\right) \quad (1.22)$$

where $L_н$ — load inductance.

$$L_c \geq 0.014 - 2 \cdot 1{,}195 \cdot 10^{-3} - 0.15 \cdot 10^{-3} = 8{,}5 (mHn)$$

e) Choice of smoothing reactor

The choice of a smoothing reactor is driven by the need to mitigate harmonics, stabilize voltage, reduce current ripple, improve power quality, protect sensitive equipment, avoid resonance, optimize filter design, manage heat dissipation, ensure load compatibility, and comply with industry standards in electrical systems and power electronics.

We issue tasks for the development and manufacture of a smoothing reactor PTCM-120-0,14 with the following parameters:

− inductance $L_{с}^{*} = 0{,}14\ Гн \geq L_{то} = 0.14\ mHn$

− operating current $I_{с} = 120\ А \geq I_{dN} = 86.025\ А$

− power losses $\Delta P_{с} = 0{,}25 \cdot 10^{-2} \cdot 38000 = 95{,}5\ Wt$

f) Determination of the resulting values of the inductance of the DC circuit of the converter and the ripple factor of the load current:

The determination of the resulting values of the inductance of the DC circuit of the converter and the ripple factor of the load current is essential for current ripple analysis, power quality assessment, efficiency optimization, voltage stability, current limiting, prevention of voltage spikes, heat dissipation management, system stability, compliance with standards, and customization for application requirements in electrical systems and converters.

$$\left.\begin{aligned} L_d^* &\geq \left(2 \cdot L_f + L_c^* + L_N\right) \\ \xi &= \frac{U_{(1)м}}{m \cdot \omega_1 \cdot L_d^* \cdot I_{dN}} \end{aligned}\right\} \quad (1.23)$$

$$L_d^* \geq 2 \cdot 1{,}195 \cdot 10^{-3} + 0{,}01 + 0.15 \cdot 10^{-3} = 0{,}013\ ,(Hn)$$

$$\xi = \frac{83.092}{3 \cdot 314 \cdot 0{,}013 \cdot 100} = 4{,}4\ (\%)$$

1.3.7 Calculation of equivalent inductance of frequency converter

The calculation of the equivalent inductance of a frequency converter is essential for harmonic mitigation, voltage stability, current ripple reduction, power quality improvement, protection of components, inrush current limiting, prevention of resonance, optimization of filter design, efficiency optimization, and overall system reliability in electrical systems.

$$L_p = L_d^* - L_n \tag{1.24}$$

$$L_p = 0{,}013 - 0.15 \cdot 10^{-3} = 0{,}01\ (\,Hn)$$

1.3.8 Calculation of the fictitious active resistance of the frequency converter

The calculation of the fictitious active resistance of a frequency converter is crucial for modeling and simulation, control system design, dynamic response analysis, voltage drop considerations, power loss estimation, load flow analysis, transient stability studies, voltage regulation, efficiency optimization, and model validation in electrical engineering and power systems.

This resistance takes into account the reduction of the output voltage of the TP from the switching processes of the phase currents of the converter and is calculated from the relations:

$$R_j = \frac{3}{2\pi} L_f \cdot \omega_1 \tag{1.25}$$

$$R_j = \frac{3 \cdot 1{,}195 \cdot 10^{-3} \cdot 314}{2 \cdot 3{,}14} = 0{,}358\ (Ohm)$$

1.3.9 Determination of reactor reactances

The determination of reactor reactances is integral to impedance analysis, resonance avoidance, voltage regulation, power factor correction, load compensation, harmonic filtering, protection against transients, control of power flow, optimization of network parameters, and compliance with industry standards in electrical engineering and power systems.

Calculate the active supports of the relations:

$$R_{m0} = \frac{\Delta P_{m0}}{3I_{mo}^2} \quad (1.26)$$

– for current-limiting reactor;

$$R_c = \frac{\Delta P_c}{I_c^2} \quad (1.27)$$

– for the smoothing reactor.

$$R_{m0} = \frac{38}{3 \cdot 75^2} = 0{,}002(Ohm)$$

$$R_c = \frac{95{,}5}{80^2} = 0{,}014\ (Ohm)$$

1.3.10 Calculation of the total (equivalent) active resistance of the frequency converter

The calculation of the total (equivalent) active resistance of a frequency converter is essential for efficiency analysis, heat dissipation management, voltage drop considerations, system stability, current limiting, inrush current control, optimization of power flow, voltage stability, control system design, and compliance with industry standards in electrical engineering and power systems.

$$R_p = \left[\left(R_{tsf} + R_{m.o}\right) + R_c + R_j + R_{osh} + R_{cab}\right] \quad (1.28)$$

$$R_p = (0{,}077 + 0{,}002) + 0{,}358 + 0{,}014 + 0{,}055 + 0{,}111 = 0.695\ (Ohm)$$

In the last ratios, the active resistance R_{osh} of the frequency converter bus and the active resistance R_{cab} cables should be found approximately from the relations:

$$\left.\begin{aligned} R_{osh} &= 0{,}01\left(\frac{U_N}{I_{dN}}\right) \\ R_{kab} &= 0{,}02 \cdot R_n \end{aligned}\right\} \quad (1.29)$$

$$R_{cab} = 0{,}02 \cdot 5.531 = 0{,}111, (Ohm)$$

$$R_{osh} = 0{,}01 \cdot \left(\frac{400}{86.025}\right) = 0{,}055(Ohm)$$

where U_n , I_{dn} , P_n and R_n respectively rated voltage, current, power and load resistance.

1.3.11 Checking the correct choice of the voltage of the secondary winding of the power transformer

Checking the correct choice of the voltage of the secondary winding of the power transformer is essential for load compatibility, equipment safety, system reliability, voltage regulation, preventing equipment damage, compliance with standards, efficiency optimization, avoiding voltage drop, considering load types, and optimizing the overall design of the power distribution system.

a) Calculation of the nominal effective value of the phase EMF of the secondary winding of the power transformer

The calculation of the nominal effective value of the phase electromotive force of the secondary winding of the power transformer is essential for load voltage specification, equipment compatibility, voltage regulation, system reliability, transformer sizing, voltage drop analysis, power quality assurance, protection coordination, efficiency optimization, and compliance with industry standards in electrical engineering and power systems.

$$\mathrm{E}_{2fn} = U_{2fn}(1 + U_k), \tag{1.30}$$

$$\mathrm{E}_{2fn} = \left(\frac{400}{\sqrt{3}}\right) \cdot (1 + 5{,}5 \cdot 10^{-2}) = 243.642\ (V)$$

b) Calculation of the minimum phase active value (at sedimentation of supply voltage) of EMF of a secondary winding of the power transformer

The calculation of the minimum phase active value of the EMF of a secondary winding of a power transformer during sedimentation of the supply voltage is essential for voltage stability assessment, load voltage guarantee, equipment protection, prevention of voltage sags, transient response analysis, avoidance of equipment tripping, power quality considerations, regulatory compliance, system reliability, and optimization of protection devices in electrical engineering and power systems.

$$\mathrm{E}_{2min} = \mathrm{K}_{cmin} \cdot \mathrm{E}_{2fn} \quad (1.31)$$

$$\mathrm{E}_{2fn\,min} = 0{,}9 \cdot 243.642 = 219.278\ (V)$$

c) Calculation of the maximum value of the output EMF of the thyristor converter when the voltage of the supply network

The calculation of the maximum value of the output electromotive force (EMF) of the thyristor converter when the voltage of the supply network is crucial for device rating, equipment protection, insulation design, material selection, efficiency optimization, voltage regulation, avoidance of overvoltages, compliance with standards, system reliability, and protection coordination in power electronics and electrical systems.

$$\mathrm{E}_{d0\,min} = 2{,}34 \cdot \mathrm{E}_{2fmin} \quad (1.32)$$

$$E_{d0\,min} = 2{,}34 \cdot 219.278 = 513.11(V)$$

d) Calculation of voltage drop on open valves of the converter

The calculation of voltage drop on open valves of the converter is crucial for device performance assessment, insulation design, avoidance of overvoltages, protection coordination, material selection, efficiency optimization, voltage regulation, reliability and lifespan considerations, prevention of transient effects, and compliance with industry standards in power electronics and electrical systems.

$$\Delta U_v = \Delta U_{tr\,pr} \quad (1.33)$$

$$\Delta U_v = 2\ (V)$$

e) Checking the correct choice of the voltage of the secondary winding of the power transformer

Checking the correct choice of the voltage of the secondary winding of the power transformer is essential for load compatibility, equipment safety, system reliability, voltage regulation, preventing equipment damage, compliance with standards, efficiency optimization, avoiding voltage drop, considering load types, and optimizing the overall design of the power distribution system.

$$0 \le \frac{E_{d0min} - R_{п} \cdot I_{d\,max} - \Delta U_v - U_n}{E_{d0\,min}} \le 0{,}05 \qquad (1.34)$$

$$0 \le \frac{513.11 - 0.695 \cdot 2 \cdot 79.545 - 2 - 400}{513.11} = 0{,}031$$

2 CALCULATION OF ENERGY INDICATORS OF FREQUENCY CONVERTER

The calculation of energy indicators of a frequency converter is undertaken for several important reasons in the field of electrical engineering and power systems:

- Energy Efficiency Assessment: Calculating energy indicators helps assess the overall efficiency of the frequency converter. It provides insights into how effectively the converter transforms electrical energy and helps identify areas for improvement in terms of energy conservation.
- System Optimization: The analysis of energy indicators contributes to optimizing the design and operation of the frequency converter. Engineers can identify ways to enhance the converter's performance, reduce energy losses, and improve overall system efficiency.
- Energy Consumption Monitoring: By calculating energy indicators, it becomes possible to monitor the energy consumption of the frequency converter over time. This information is valuable for evaluating the converter's energy usage patterns and making informed decisions about energy management.
- Load Profile Analysis: Energy indicators offer a detailed understanding of the load profile of the frequency converter. This includes variations in energy consumption under different operating conditions, helping engineers design systems that align with specific load requirements.
- Environmental Impact Assessment: Understanding the energy indicators allows for an assessment of the environmental impact of the frequency converter. It helps quantify energy usage and supports efforts to design more sustainable and environmentally friendly systems.
- Operational Cost Estimation: Calculating energy indicators assists in estimating the operational costs associated with the frequency converter. This information is crucial for budgeting, financial planning, and making decisions about the economic viability of the system.

- Efficiency Standards Compliance: Energy indicators are often used to assess compliance with energy efficiency standards and regulations. Ensuring that the frequency converter meets or exceeds these standards is important for regulatory compliance and certification.

- Performance Monitoring: Energy indicators serve as key performance metrics for the frequency converter. Monitoring these indicators allows engineers to identify deviations from expected performance and implement corrective measures to maintain optimal operation.

- Loss Analysis: Energy indicators help in analyzing losses within the frequency converter. This includes both electrical losses (e.g., resistive losses) and losses associated with the conversion process. Identifying and minimizing these losses are essential for improving overall efficiency.

- Life Cycle Assessment: Calculating energy indicators supports a comprehensive life cycle assessment of the frequency converter. This involves evaluating the environmental and energy-related aspects of the converter from its production to its end-of-life disposal.

In summary, the calculation of energy indicators of a frequency converter is performed for energy efficiency assessment, system optimization, energy consumption monitoring, load profile analysis, environmental impact assessment, operational cost estimation, efficiency standards compliance, performance monitoring, loss analysis, and life cycle assessment in the field of electrical engineering and power systems.

The most important energy indicators of converters are: efficiency and input power factor (work of converters calculated for a nominal mode,).

2.1 Calculation of frequency converter efficiency

The calculation of frequency converter efficiency is performed for several important reasons in the field of electrical engineering and power systems:

- Performance Evaluation: Calculating the efficiency of a frequency converter is essential for evaluating its overall performance. Efficiency provides a quantitative measure of how effectively the converter transforms electrical energy, allowing engineers to assess its effectiveness in converting input power to useful output power.

- Energy Conservation: Efficiency calculations help identify areas where energy losses occur within the frequency converter. By understanding these losses, engineers can implement measures to improve efficiency, reduce waste, and conserve energy resources.

- Operational Cost Reduction: Efficient frequency converters typically result in lower energy consumption. Calculating efficiency allows for the estimation of operational costs associated with running the converter. Identifying opportunities for efficiency improvements can lead to cost reductions over the operational life of the system.

- Heat Dissipation Management: Inefficient converters tend to generate more heat due to higher energy losses. The calculation of efficiency is crucial for managing heat dissipation within the system. Efficient converters generally require less cooling and contribute to a more reliable and sustainable operation.

- System Optimization: Efficiency calculations contribute to the optimization of the frequency converter and the overall power system. Engineers can use efficiency data to fine-tune the design, select appropriate components, and optimize control strategies to achieve better overall system performance.

- Environmental Impact Assessment: Understanding the efficiency of a frequency converter is vital for assessing its environmental impact. More efficient converters result in lower energy consumption, reducing the overall carbon footprint and environmental stress associated with power generation.

- Compliance with Standards: Many industries and regions have established energy efficiency standards and regulations. Calculating converter efficiency helps ensure compliance with these standards, which is essential for obtaining certifications and meeting legal requirements.

- Load Profile Analysis: Efficiency calculations provide insights into the converter's performance under different load conditions. Analyzing efficiency across various operating points helps engineers understand how well the converter adapts to changing load requirements.

- Reliability and Longevity: Inefficient converters may experience higher levels of stress due to increased heat generation. Calculating efficiency is crucial for assessing the converter's reliability and longevity, as efficient operation often contributes to reduced wear and tear on components.

- Optimization of Control Strategies: Efficiency data is valuable for optimizing control strategies of the frequency converter. By understanding the relationship between input and output power, engineers can develop control algorithms that enhance efficiency under different operating conditions.

In summary, the calculation of frequency converter efficiency is performed for performance evaluation, energy conservation, operational cost reduction, heat dissipation management, system optimization, environmental impact assessment, compliance with standards, load profile analysis, reliability and longevity considerations, and the optimization of control strategies in electrical engineering and power systems.

Calculation of the efficiency of the frequency converter taking into account the losses in the power transformer, reactors and supply cables.

2.1.1 Calculation of power losses in the protective RC-circuits of the frequency converter

The calculation of power losses in the protective RC circuits of the frequency converter is performed for safety and reliability, overvoltage protection, thermal management, energy efficiency, component sizing, voltage transient analysis, system stability, cost considerations, compliance with standards, and the optimization of protection strategies in electrical engineering and power systems.

$$\Delta P_{RC} \approx 0{,}001\ P_{Н} \tag{2.1}$$

$$\Delta P_{RC} \approx 0{,}001 \cdot 38000 = 38\ (Wt)$$

2.1.2 Calculation of power losses in the circuits of the TP control system

The calculation of power losses in the circuits of the TP control system is performed for efficiency assessment, heat dissipation analysis, transformer protection optimization, energy conservation, operational cost estimation, fault detection improvement, component sizing and selection, voltage and current stress analysis, environmental impact assessment, and compliance with standards in electrical engineering and power systems.

$$\Delta P_{su} \approx 100 \text{ Вт, when } 10 \text{ кВт} \leq P_n < 100 \text{ кWt} \quad (2.2)$$

$$\Delta P_{su} = 100 \text{ (Wt)}$$

2.1.3 Calculation of total power losses of FC (in nominal mode)

The calculation of total power losses of a frequency converter in its nominal mode is performed for efficiency assessment, energy conservation, heat dissipation management, optimization of system design, operational cost estimation, voltage and current stress analysis, load profile analysis, environmental impact assessment, compliance with standards, and system reliability in electrical engineering and power systems.

$$\Delta P_{tp} = \Delta U_{в}\, I_{dн} + (R_p - R_j) I_{dн} + \Delta P_{RC} + \Delta P_{su} + \Delta P_{xx} \quad (2.3)$$

where ΔPxx — no-load losses of the power transformer (given in the passport data on the transformer).

$$\Delta P_{tp} = 2 \cdot 79.545 + (0.695 - 0.358) \cdot (86.025)^2 + 35 + 100 + 330 = 2756 \text{ (Wt)}$$

2.1.4 Calculation of efficiency of the converter (in the nominal mode)

The calculation of the efficiency of the converter in the nominal mode is performed for performance evaluation, energy conservation, operational cost estimation, heat dissipation management, environmental impact assessment, compliance with standards, optimization of system design, load profile analysis, reliability and longevity considerations, and the optimization of control strategies in electrical engineering and power systems.

$$\eta_{тр} = \frac{P_N \cdot 100}{P_N + \Delta P_{тр}} \ (\%) \tag{2.4}$$

$$\eta_{тр} = \frac{38000 \cdot 100}{38000 \cdot 2756} = 92.7 \ (\%)$$

2.2 Calculation of the input power factor of the frequency converter

The calculation of the input power factor of a frequency converter is undertaken for several important reasons in the field of electrical engineering and power systems:

- System Efficiency Assessment: Calculating the input power factor is crucial for assessing the overall efficiency of the frequency converter. It provides insights into how effectively the converter utilizes electrical power from the source, contributing to a more efficient energy conversion process.

- Energy Conservation: The input power factor is an indicator of how efficiently the converter draws power from the electrical grid. By optimizing the power factor, engineers can reduce unnecessary reactive power consumption, minimizing energy losses and conserving electrical energy.

- Operational Cost Reduction: Efficient power factor management can lead to reduced operational costs. A higher power factor often results in more efficient use of electrical power, reducing the amount of apparent power required from the grid and, consequently, lowering electricity bills.

- Avoidance of Penalties: Some utility providers impose penalties or charges based on the power factor. Calculating and improving the input power factor helps avoid these penalties and ensures compliance with utility regulations and cost-saving measures.

- Transformer and Equipment Sizing: The power factor affects the sizing and capacity requirements of transformers and other equipment in the power distribution system. Calculating the input power factor assists in selecting appropriately sized components, optimizing system design, and avoiding overdimensioned equipment.

- Voltage Drop Mitigation: A poor power factor can lead to increased voltage drops in the electrical distribution system. By calculating and improving the power factor, engineers can mitigate voltage drop issues, ensuring that connected devices receive stable and efficient voltage levels.

- Compliance with Standards: Many industries and regions have established standards for power factor levels. Calculating and maintaining an acceptable input power factor ensures compliance with these standards, contributing to the reliability and stability of the power distribution network.

- Reducing Line Losses: A higher input power factor is associated with lower line losses in the electrical distribution system. Calculating and optimizing the power factor helps reduce resistive losses in the lines, minimizing energy waste and improving overall system efficiency.

- Enhancing Power Quality: Improving the power factor contributes to better power quality. It reduces harmonic distortions and minimizes reactive power flow, leading to a more stable and reliable electrical supply for connected devices.

- Efficiency in Power Generation: A high input power factor is desirable for power generation facilities. It ensures that the generated power is utilized efficiently and reduces the strain on the power generation infrastructure.

In summary, the calculation of the input power factor of a frequency converter is performed for system efficiency assessment, energy conservation, operational cost reduction, avoidance of penalties, transformer and equipment sizing, voltage drop mitigation, compliance with standards, reducing line losses, enhancing power quality, and improving efficiency in power generation in electrical engineering and power systems.

Calculation of the input power factor of the frequency converter in nominal mode

2.2.1 Calculation of the switching angle of FC valves

The calculation of the switching angle of FC valves is performed for control of power flow, voltage and current regulation, minimization of harmonics, efficiency improvement, mitigation of overvoltage and overcurrent, optimization of converter operation, reduction of electromagnetic interference, heat dissipation management, system stability, and compliance with standards in power electronics and electrical engineering.

$$y^0 = arccos\left(cosa_n \frac{m\, \omega_1 L_f I_{dn}}{\pi E_{d0}}\right) \tag{2.5}$$

$$y^0 = arccos\left(cos25^0 - \frac{6 \cdot 314 \cdot 1.195 \cdot 10^{-3} \cdot 86.025}{3.14 \cdot 513}\right) - 25^0 = 11{,}8°$$

where $\alpha_н$ — the value of the control angle of the frequency converter in nominal mode (according to the task: α_n = 25 el. deg.).

2.2.2 Calculation of the distortion coefficient of the input current of the FC

The calculation of the distortion coefficient of the input current of the frequency converter is performed for power quality assessment, compliance with standards, prevention of equipment damage, efficiency improvement, mitigation of electromagnetic interference, voltage and current waveform analysis, equipment sizing and selection, avoidance of resonance conditions, prevention of nuisance tripping, and as a diagnostic tool in power electronics and electrical engineering.

This coefficient is the ratio of the current value I1(д) of the main (first) harmonic component of the input phase current of the converter to the current value Iд of the total input phase current TP:

$$\nu = I_{1(d)}\ I_l$$

The distortion coefficient of the input phase current of the frequency converter is determined approximately from the relations:

$$\upsilon \approx \frac{3}{\pi}\left(1 + \frac{\gamma}{4\pi} + \frac{\gamma}{24}\right) \tag{2.6}$$

where γ — valve switching angle, expressed in radians:

$$\gamma = \frac{\pi\gamma^{\circ}}{180^{\circ}} \qquad (2.7)$$

$$\gamma = \frac{3{,}14 \cdot 11{,}8^{\circ}}{180} = 0.359\ (rad)$$

$$v \approx \frac{3}{3{,}14}\left(1 + \frac{0.359}{4 \cdot 3{,}14} + \frac{0.359^2}{24}\right) = 0.955$$

2.2.3 Calculation of the input power factor of the FC

The calculation of the input power factor of the frequency converter is performed for efficiency assessment, energy conservation, operational cost reduction, avoidance of penalties, transformer and equipment sizing, voltage drop mitigation, compliance with standards, reducing line losses, enhancing power quality, and improving efficiency in power generation in electrical engineering and power systems.

$$K_M = 0{,}5 \cdot v\left[cos\left(\frac{\gamma^0}{2}\right) + cos\left(\alpha_{n+}\frac{\gamma^0}{2}\right)\right] \qquad (2.8)$$

$$K_M = 0{,}5 \cdot 0.955\left[cos\left(\frac{0.359^0}{2}\right) + cos\left(25^0{}_{+}\frac{0.359^0}{2}\right)\right] = 0.91$$

3 CALCULATION OF PROTECTIVE RC-CHAINS

3.1 Calculation of RC-circuits providing protection of TP from switching overvoltages

The calculation of RC (resistor-capacitor) circuits providing protection for transformers (TP) from switching overvoltages is conducted for several important reasons in the field of electrical engineering and power systems:

- Overvoltage Protection: RC circuits are designed to protect transformers from switching overvoltages, which can occur during switching operations, load changes, or fault conditions. Calculating the parameters of the RC circuit ensures effective protection against these overvoltages.

- Transformer Insulation Protection: Overvoltages can pose a threat to the insulation system of transformers. By calculating the RC circuit parameters, engineers can design protective measures that limit the amplitude and duration of overvoltages, preserving the integrity of transformer insulation.

- Prevention of Core Saturation: Switching overvoltages can lead to magnetic saturation of the transformer core. The RC circuit helps control and mitigate these overvoltages, preventing core saturation and maintaining the transformer's magnetic performance within safe limits.

- Avoidance of Dielectric Breakdown: Overvoltages can cause dielectric breakdown in the insulation materials of transformers. Calculating the RC circuit parameters ensures that the protective elements are appropriately sized to prevent dielectric breakdown, enhancing the overall reliability of the transformer.

- Controlled Damping of Transient Oscillations: RC circuits can provide controlled damping of transient oscillations caused by switching overvoltages. By tuning the parameters of the RC circuit, engineers can optimize the damping effect, reducing the amplitude and duration of oscillations that could affect transformer performance.

- Reduction of Voltage Stress on Windings: Switching overvoltages can induce high voltage stresses on transformer windings. The RC circuit helps attenuate these stresses, ensuring that the voltage across the windings remains within safe operating limits and preventing insulation damage.

- Mitigation of Harmonic Distortion: RC circuits can contribute to mitigating harmonic distortions associated with switching operations. Harmonics can lead to additional stress on transformer insulation and affect the overall power quality. Calculating the RC circuit parameters aids in minimizing these effects.

- Compliance with Standards: Many standards and regulations set guidelines for overvoltage protection in power systems. Calculating the parameters of RC circuits ensures compliance with these standards, promoting the safety and reliability of the transformer and the power distribution system.

- Prevention of Ferroresonance: In some cases, switching overvoltages can lead to ferroresonance phenomena, which can be damaging to transformers. RC circuits help prevent or mitigate ferroresonance, ensuring stable and safe transformer operation.

- Enhanced Transformer Lifespan: Effective protection against switching overvoltages contributes to the overall longevity of transformers. By preventing stress and damage caused by overvoltages, the RC circuit helps extend the operational life of the transformer.

In summary, the calculation of RC circuits providing protection for transformers from switching overvoltages is conducted to ensure overvoltage protection, safeguard transformer insulation, prevent core saturation, avoid dielectric breakdown, control transient oscillations, reduce voltage stress on windings, mitigate harmonic distortion, comply with standards, prevent ferroresonance, and enhance the overall lifespan and reliability of transformers in electrical power systems.

Switching overvoltages arise at switching (disconnection) by the automatic switch of voltage of a secondary winding of the power transformer, and also at inclusion and disconnection of the power transformer. Schemes of protective RC-circuits against switching overvoltages are shown in fig. 3.

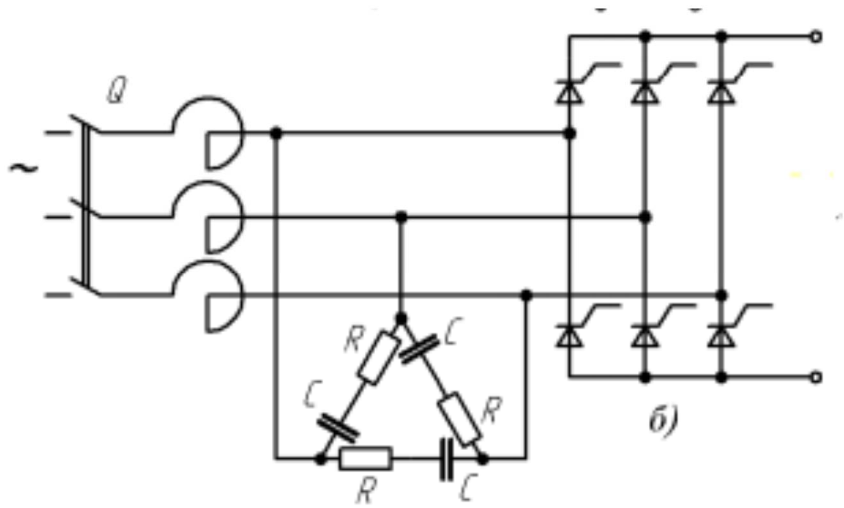

Figure 3. RC-circuit providing protection of TP from switching overvoltages

3.1.1 Calculation of the nominal value of the current of the primary winding of the power transformer

The calculation of the nominal value of the current of the primary winding of a power transformer is crucial for transformer sizing, equipment selection, prevention of overloading, voltage regulation, efficiency considerations, adherence to standards, coordination with protective devices, system stability, load flow analysis, and operational safety in electrical engineering and power systems.

$$I_{1nf} = {S_N}/{\sqrt{3}U_{1l}} \tag{3.1}$$

where U_{1f} and U_{1l} — respectively phase and linear rated voltages of the primary winding of the power transformer.

$$I_{1nf} = \frac{63000}{\sqrt{3 \cdot 380}} = 95{,}719 \text{ (A)}$$

3.1.2 Calculation of no-load current of a power transformer

The calculation of the no-load current of a power transformer is essential for transformer design, efficiency assessment, evaluation of core losses, voltage regulation, consideration of residual flux, diagnostics, adherence to standards, transformer testing, prevention of overexcitation, and operational cost considerations in electrical engineering and power systems.

$$I_0 = I_{xx} \cdot I_{1nf} \tag{3.2}$$

where I_{xx} — the relative value of the no-load current, which leads in the passport data for the power transformer

$$I_0 = 0{,}06 \cdot 95{,}719 \approx 5{,}743\ (A)$$

3.1.3 Calculation of capacitor capacitance of protective RC-circuit

The calculation of capacitor capacitance in a protective RC circuit is essential for limiting voltages, suppressing transients, protecting against switching surges, filtering harmonics, maintaining system stability, avoiding resonance, coordinating protection, extending equipment lifespan, ensuring compliance with standards, and preserving power quality in electrical systems.

$$C \geq \frac{S_H I_H 10^4}{3\omega_1 (U_{tr\,n}^2 - U_{tr\,max}^2)} \tag{3.3}$$

where U_{trmax} and U_{trn} — parameters previously calculated in paragraph 5.1, b and paragraph 5.1, respectively.

$$\mathrm{C} = \frac{63000 \cdot 5{,}714 \cdot 10^4}{3 \cdot 314(1000^2 - 622.254^2)} = 6.268\ (mkF)$$

3.1.4 Choice of capacitor for protective RC-circuit against switching overvoltages

The choice of capacitor for a protective RC circuit against switching overvoltages is essential for ensuring proper voltage rating, energy absorption, capacitance value, time constant, resonance avoidance, impulse withstand capability, temperature stability, service life, cost-effectiveness, and compliance with standards. This careful selection contributes to the overall effectiveness and reliability of the transient voltage protection system.

Let's choose the capacitor K 01 400 472 SH MOJ105

$$U_{c\,rab} \geq K_{c\,max} U_{2ln} \tag{3.4}$$

$$C^* \geq C \tag{3.5}$$

$$U_{tr\,n} \geq \left[\frac{S_H I_0 10^{-2}}{3\omega_1 c^*} + U_{tr\,max}^2\right]^{1/2} \tag{3.6}$$

$$U_{c\,rab} = 1000(V) \geq 1{,}1 \cdot 440 = 484\ (V)$$

$$C^* = 1 \cdot 8 = 8\ (mkF) \geq C = 4.768\ (mkF)$$

$$U_{tr\,n} \geq \left[\frac{63000 \cdot 5{,}743 \cdot 10^{-2}}{3 \cdot 314 \cdot 8 \cdot 10^{-6}} + 622.254^2\right]^{\frac{1}{2}} = 622.254\ (V)$$

3.1.5 Calculation of the resistance of the resistor of the protective RC-circuit from switching overvoltages

The calculation of the resistance of the resistor in the protective RC circuit against switching overvoltages is essential for damping transient surges, preventing resonance, controlled energy dissipation, voltage limitation, influencing the time constant, coordinated protection, managing temperature rise, maintaining system stability, avoiding nuisance tripping, and complying with standards in electrical engineering and power systems.

The specified resistor provides an aperiodic process of charging the capacitor of the RC circuit (which eliminates overvoltages on thyristors or diodes), the value of this resistor follows from the ratio:

$$R^* \geq 2\sqrt{\frac{L_f}{C^*}} \tag{3.7}$$

$$R^{*} \geq 2\sqrt{\frac{1.195 \cdot 10^{-3}}{8 \cdot 10^{-6}}} = 16{,}401\ (Ohm)$$

3.1.6 Calculation of the power of the resistor RC-circuit

The calculation of the power dissipated in the resistor of an RC circuit is essential for managing energy dissipation, preventing overheating, selecting an appropriate resistor rating, maintaining system stability, coordinating with protective devices, avoiding component damage, ensuring efficient transient voltage suppression, enabling predictive maintenance, designing cost-effective solutions, and complying with industry standards in electrical engineering and power systems.

$$P_R \geq 0{,}001\frac{P_H}{9} \quad (3.8)$$

$$P_R \geq 0{,}001\frac{35000}{9} = 3.889(Wt)$$

3.1.7 Choice of resistor of protective RC-circuit

The choice of the resistor for a protective RC circuit is essential for managing energy dissipation, preventing overheating, controlling transient voltages, tailoring the time constant, avoiding resonance, coordinating with protective devices, ensuring temperature stability, achieving cost-effective design, preventing component damage, complying with standards, and enabling predictive maintenance in electrical engineering and power systems.

Carried out in accordance with conditions (3.7) and (3.8) of the standard range of existing resistors and capacitors of resistors such as: C5-35B and other.

3.2 Calculation of RC-circuits that provide protection of TP from operating overvoltages

The calculation of RC (resistor-capacitor) circuits for the protection of TP (transformer protection) from operating overvoltages is performed for several important reasons in electrical engineering and power systems:

- Voltage Limitation: RC circuits are designed to limit the amplitude of overvoltages that may occur during normal operation of the power system. Calculating the values of resistors and capacitors helps determine the circuit parameters needed to effectively suppress and control overvoltage levels.

- Transient Voltage Suppression: The RC circuit provides transient voltage suppression by dissipating excess energy during transient events. Proper calculation ensures that the circuit can efficiently absorb and dissipate energy, preventing overvoltage conditions that could damage transformers or other connected equipment.

- Protection of Transformer Windings: Transformers are susceptible to overvoltages that can lead to insulation breakdown and damage to winding insulation. RC circuits help protect transformer windings by limiting the voltage stress during transient conditions, enhancing the overall reliability and lifespan of the transformer.

- Prevention of Core Saturation: Overvoltages can lead to core saturation in transformers, affecting their performance. RC circuits aid in preventing core saturation by controlling the rate of voltage rise and limiting the amplitude of transient voltages that could lead to magnetic core saturation.

- Coordination with Protective Devices: The RC circuit is coordinated with protective devices, such as surge arresters or circuit breakers, to ensure a comprehensive and coordinated protection strategy. Calculating RC circuit parameters helps achieve proper coordination and integration within the overall protection scheme.

- Harmonic Filtering: In addition to limiting overvoltages, RC circuits may contribute to filtering out high-frequency harmonics present in the system. Proper calculation ensures that the circuit is optimized for harmonic suppression, contributing to a cleaner and more stable power supply.

- System Stability: Limiting overvoltages through RC circuits contributes to the stability of the power system. The calculated parameters of the RC circuit help maintain system stability by preventing voltage excursions beyond acceptable limits.

- Protection against Switching Transients: Operating conditions such as switching operations can generate transient overvoltages. RC circuits are designed to protect transformers from such switching transients by controlling voltage levels and preventing damage to transformer insulation.

- Avoidance of Resonance: Calculating the parameters of the RC circuit helps avoid resonance conditions with other elements in the system. Resonance can amplify voltages and lead to detrimental effects. Proper calculation ensures that the circuit operates within safe and non-resonant conditions.

- Compliance with Standards: RC circuits for transformer protection must comply with industry standards and regulations. Calculating and designing the circuits in accordance with standards ensures that the protection measures meet safety, reliability, and performance criteria.

In summary, the calculation of RC circuits for the protection of transformers from operating overvoltages is essential for limiting voltage stress, suppressing transients, protecting transformer windings, preventing core saturation, coordinating with protective devices, filtering harmonics, maintaining system stability, guarding against switching transients, avoiding resonance, and ensuring compliance with industry standards in electrical engineering and power systems.

The scheme of protective RC-circuits that prevents operating overvoltages on the transistors of the converter (caused by turning on and off adjacent transistors), is shown in Fig.4.

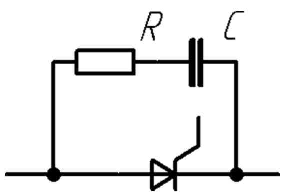

Figure 4. Scheme of the protective circuit against overvoltages in the FC

3.2.1 Calculation of capacitor capacitance of protective RC-circuit

The calculation of capacitor capacitance in a protective RC circuit is crucial for voltage limitation, transient voltage suppression, energy dissipation, time constant control, prevention of core saturation, harmonic filtering, coordination with protective devices, avoidance of resonance, system stability, and compliance with industry standards in electrical engineering and power systems.

$$C \geq \frac{n\, U_K E_{d0}^2\, \tau_{vst}^2 sin^2(\alpha_H + \gamma)}{9\omega_1 L_f I_{tr\,n} U_{tr\,n}}\, 10^6 \tag{3.9}$$

$$C \geq \frac{1 \cdot 0.055 \cdot 540^2 \cdot 35^2 \cdot sin^2(25^0 + 0.359°)}{9 \cdot 314 \cdot (1.195 \cdot 10^{-3})^2 \cdot 63 \cdot 1000} = 0.016\ (mkF)$$

3.2.2 Choice of capacitor of protective RC-circuit

The choice of the capacitor for a protective RC circuit is essential for energy storage, voltage rating, transient voltage suppression, time constant control, prevention of core saturation, harmonic filtering, coordination with protective devices, avoidance of resonance, system stability, temperature stability, and compliance with industry standards in electrical engineering and power systems.

When choosing a capacitor of the protective RC-circuit from overvoltages should be guided by the following:

- use the same types of capacitors installed in the protective RC-circuits against switching overvoltages (discussed in paragraph 8.1, d);
- the choice of the operating voltage of the capacitor to make the conditions

$$U_{c\,rb} \geq \frac{U_{tr\,max}}{\sqrt{2}} \tag{3.10}$$

where U_{trmax} — the maximum voltage applied in the operating modes of the thyristor converter to the closed thyristor (calculated from paragraph 5.1, b);
- select the capacitor with the closest value of capacity that exceeds the calculated value of (53):

Choose a capacitor PMB 0,47 mkF, 1200 V DC

$$C^* \geq C \tag{3.11}$$

$$U_{c\,rab} \geq \frac{622.254}{\sqrt{2}} = 440(V)$$

$$C^* = 0{,}25mkF \geq C = 0.016 \ (mkF)$$

3.2.3 Calculation of the resistance of the resistor of the protective RC-circuit

The calculation of the resistance of the resistor in a protective RC circuit is essential for controlling energy dissipation, limiting transient voltages, controlling the time constant, preventing resonance, coordinating with protective devices, avoiding nuisance tripping, ensuring temperature stability, maintaining system stability, preventing component damage, and complying with industry standards in electrical engineering and power systems.

$$R \geq \frac{U_{tr\,n} L_f}{E_{d0} \tau_{vst} \sin(a_H + \gamma)} \tag{3.12}$$

$$R \geq \frac{1000 \cdot 1.195 \cdot 10^{-3}}{540 \cdot 35 \cdot \sin(25^0 + 0{,}115^0)} = 148.447 \ Ohm$$

3.2.4 Calculation of power of the resistor of a protective RC-circuit (from operating overvoltages)

The calculation of the power dissipated in the resistor of a protective RC circuit in response to operating overvoltages is essential for controlling energy dissipation, preventing equipment damage, limiting voltage amplitudes, optimizing resistor rating, ensuring temperature stability, coordinating with protective devices, avoiding nuisance tripping, maintaining system stability, complying with standards, and enabling predictive maintenance in electrical engineering and power systems.

$$P_R \geq \frac{\Delta P_{RC}}{N} \tag{3.13}$$

where ΔP_{RC} — power losses in the RC-circuits of the converter, previously calculated in paragraph 7.1, a;

N — the total number of protective RC-circuits in the converter, which is in the form:

$$N=9$$

$$P_R \geq \frac{35}{9} = 3.889(Wt)$$

3.2.5 Choice of resistor of protective RC-circuit (from operating overvoltages on the transistor)

The choice of the resistor for a protective RC circuit, specifically in the context of protecting a transistor from operating overvoltages, is essential for energy dissipation, voltage limitation, current limiting, time constant control, prevention of resonance, temperature stability, compatibility with transistor characteristics, coordination with protective devices, avoidance of nuisance tripping, and compliance with industry standards in electrical engineering and electronic systems.

Carried out similarly to previously described in paragraph 3.1, g.

Choose a resistor C5-35B-25-10 кОм ±10 % (resistance of 35 Ohms, power of 10 W), Resistor type C5-35B-25-10 кОм ±10 %

4 CHECKING THE COMPLETENESS OF THE FREQUENCY CONVERTER

Checking the completeness of the frequency converter is a crucial step in the installation and commissioning process of an electrical system. Here are several reasons why this verification is important:

- Quality Assurance: Ensuring that all components and parts of the frequency converter are present verifies the quality of the equipment. It helps confirm that the converter is manufactured and delivered with all the necessary elements.

- System Integrity: Checking completeness ensures that no critical components are missing, which could compromise the integrity of the entire frequency conversion system. Each part plays a specific role, and the absence of any component may lead to malfunctions or inefficiencies.

- Correct Functionality: Verifying the presence of all components is essential for confirming that the frequency converter will function correctly. Missing elements could result in improper operation or failure to achieve the desired conversion tasks.

- Safety Compliance: Complete frequency converters are designed with safety features and components. Confirming the presence of all safety-related parts ensures that the system adheres to safety standards and regulations.

- Avoidance of Downtime: Detecting missing components before installation or commissioning prevents unnecessary downtime. Addressing any completeness issues early in the process helps avoid delays in the operation of the frequency converter.

- Warranty Validation: Checking completeness is often a prerequisite for validating equipment warranties. Manufacturers may require that the system is fully intact as a condition for providing warranty coverage.

- Documentation Verification: Completeness checks involve verifying accompanying documentation such as manuals, schematics, and installation guides. This ensures that the end user has access to all necessary information for proper setup and maintenance.

- Installation Planning: Knowing that all components are present allows for proper planning of the installation process. It helps installers organize their work efficiently and reduces the risk of overlooking crucial steps.

- Performance Assurance: Each component in a frequency converter contributes to its overall performance. Confirming completeness ensures that the converter will meet specified performance criteria and deliver the expected results.

- Commissioning Efficiency: A complete frequency converter simplifies the commissioning process. Commissioning engineers can proceed with confidence, knowing that all necessary components are available for testing and calibration.

- Customer Satisfaction: Delivering a complete and functional frequency converter contributes to customer satisfaction. It helps avoid post-installation issues and ensures that the customer receives a reliable and fully operational system.

In summary, checking the completeness of the frequency converter is essential for quality assurance, system integrity, correct functionality, safety compliance, avoidance of downtime, warranty validation, documentation verification, installation planning, performance assurance, commissioning efficiency, and customer satisfaction in electrical engineering and power systems.

4.1 General requirements for test conditions, facilities and conduct

Establishing general requirements for test conditions, facilities, and conduct is a critical aspect of any testing process, especially in technical and engineering domains. Here are several reasons why these requirements are essential:

- Standardization: Defining general requirements ensures standardization in testing procedures. This allows for consistent and uniform testing across different projects, ensuring reliability and comparability of results.

- Reproducibility: By specifying test conditions and facilities, the goal is to create an environment where tests can be reproduced reliably. This is crucial for quality control, as it allows for the replication of experiments and verification of results.

- Consistency: Standardized test conditions and facilities contribute to the consistency of testing practices. This is particularly important in industries where repeatability and accuracy are paramount, such as manufacturing and product development.

- Interoperability: In cases where testing involves interoperability between different systems or components, having standardized conditions ensures that the tested elements can work seamlessly together.

- Quality Assurance: Establishing requirements for test conduct helps ensure the quality of the testing process. It sets expectations for the methodology, documentation, and reporting, which are crucial for maintaining high standards.

- Safety: Test conditions and facilities should adhere to safety standards and protocols. This is essential to protect individuals involved in testing, prevent accidents, and safeguard equipment and the surrounding environment.

- Risk Mitigation: Clearly defined test requirements help identify potential risks associated with the testing process. This allows for the implementation of risk mitigation strategies, ensuring that testing is conducted safely and without adverse consequences.

- Compliance: Many industries have regulatory standards and compliance requirements. Establishing general requirements helps ensure that testing practices align with these regulations, avoiding legal or regulatory issues.

- Efficiency: Clearly defined test conditions and conduct contribute to the efficiency of the testing process. This includes optimizing resources, reducing testing time, and streamlining workflows.

- Cost Control: Standardizing test conditions and conduct helps control costs by avoiding unnecessary variations or repetitions in the testing process. It enables efficient resource allocation and prevents the waste of time and materials.

- Accurate Data Collection: Having well-defined test conditions ensures accurate and relevant data collection. This is crucial for making informed decisions based on the results of the tests.

- Benchmarking: Establishing general requirements allows for benchmarking against industry standards or best practices. This helps organizations assess their testing processes against recognized norms, identify areas for improvement, and stay competitive.

In summary, setting general requirements for test conditions, facilities, and conduct is essential for standardization, reproducibility, consistency, interoperability, quality assurance, safety, risk mitigation, compliance, efficiency, cost control, accurate data collection, and benchmarking in various technical and engineering testing scenarios.

All tests should be carried out in normal climatic conditions according to GOST 15150-69. If necessary, test under the extreme climatic conditions specified in the standard.

All tests must be carried out at supply voltage (380±38) V.

Measuring instruments used during measurements and tests should be verified in due time and provide control of parameters with specified accuracy. A list of equipment and instruments is given in Appendix A. Use only tested and calibrated measuring instruments. Make sure that the instruments can monitor the parameters with the specified accuracy.

Employ personnel with electrical safety qualifications of at least group 3 for electrical installations with voltages up to 1000 V. Ensure that personnel are trained and competent in testing and servicing the inverter.

Preparation for tests, tests and works on the transducer on completion of tests should be carried out by personnel with qualification group on electrical safety not lower than three for electrical installations with voltage up to 1000 V.

Develop detailed procedures for preparing, conducting, and completing tests that comply with GOST 15150-69. Ensure compliance with all safety standards throughout the testing process. Maintain strict documentation of all phases, including test preparation, conduct, and completion. Conduct adequate results processing to meet the requirements of standards and specifications.

4.2 Safety Requirements

Establishing safety requirements is a fundamental aspect of various processes, industries, and environments. The reasons for implementing safety requirements are paramount for ensuring the well-being of individuals, protecting assets, and maintaining the integrity of operations. Here are key reasons why safety requirements are essential:

- Human Protection: The primary purpose of safety requirements is to protect the health and well-being of individuals. Implementing safety measures reduces the risk of accidents, injuries, and illnesses in the workplace or any environment where human activities take place.

- Risk Mitigation: Safety requirements are designed to identify, assess, and mitigate potential risks and hazards. This proactive approach helps prevent accidents and minimizes the severity of consequences if unforeseen events occur.

- Legal Compliance: Many jurisdictions have laws and regulations governing safety standards. Implementing safety requirements ensures compliance with legal obligations, reducing the risk of legal actions, fines, or other penalties.

- Asset Protection: Safety measures are not only about protecting people but also about safeguarding assets, equipment, and infrastructure. Preventing accidents helps avoid damage to property, machinery, and valuable resources.

- Environmental Preservation: Safety requirements often include measures to protect the environment. This can involve the proper handling and disposal of hazardous materials, reducing emissions, and preventing environmental pollution.

- Workplace Morale: A safe working environment contributes to positive workplace morale. Employees feel more secure, valued, and motivated when they know that their safety is a priority.

- Reduced Insurance Costs: Implementing effective safety measures can lead to lower insurance premiums. Insurers often provide favorable rates to organizations that demonstrate a commitment to safety, as this reduces the likelihood of claims.

- Operational Continuity: Safety requirements contribute to the continuity of operations. By preventing accidents and disruptions, organizations can maintain a smooth workflow and avoid downtime.

- Brand Reputation: Safety-conscious organizations build a positive brand reputation. Customers, clients, and the public are more likely to trust and support businesses that prioritize the safety of their employees and stakeholders.

- Employee Retention: A safe working environment enhances employee satisfaction and can contribute to higher retention rates. Employees are more likely to stay with an organization that prioritizes their safety and well-being.

- Emergency Preparedness: Safety requirements often include protocols for emergency situations. This ensures that individuals know how to respond in case of accidents, natural disasters, or other unforeseen events.

- Ethical Responsibility: Prioritizing safety is an ethical responsibility for organizations. It reflects a commitment to doing business responsibly, ethically, and with a concern for the welfare of all stakeholders.

In summary, implementing safety requirements is crucial for protecting individuals, mitigating risks, ensuring legal compliance, safeguarding assets, preserving the environment, boosting workplace morale, reducing insurance costs, maintaining operational continuity, building brand reputation, enhancing employee retention, preparing for emergencies, and fulfilling ethical responsibilities across various sectors and industries.

When testing it is necessary to carry out organizational and technical measures to ensure safe execution of works in electrical installations with voltage up to 1000 V, guided by the requirements of current "Rules of technical operation of electrical installations of consumers" and "Rules of safe operation of electrical installations of consumers", as well as fire safety rules, rules of operation of lifting devices and safety instructions in force at the workplace .

Observe the fire safety regulations, the regulations for the operation of lifting equipment and the safety instructions applicable to the workplace.

When testing the electrical strength of the insulation it is necessary to be guided by the documents according to clause 3.1 for electrical installations over 1000 V.

All repair works on the transducer and on the load connected to it should be carried out at full removal of power supply voltage of the transducer.

The frequency converter contains electrolytic capacitors with high capacity.

After the supply voltage has been removed from the inverter's input, it is possible to make changes to the circuit, connections on its input and output not earlier than after 5 minutes.

Inspection of appearance, quality of protective and decorative coatings, completeness of the product and its marking is carried out by inspection and comparison with the corresponding requirements of the design documentation. At the same time check the availability of marks on the acceptance tests on all boards and other components of the product, for which such tests are provided. Check the completeness of the spare parts and accessories according to the specifications of the sets of spare parts and accessories. Check the completeness of the operational documentation according to the inventory or list of operational documents.

Checking of installation for compliance with electrical circuit diagrams and wiring diagrams is performed by means of testing.

Checking of power contact connections is carried out randomly on at least 16 demountable busbar connections with a stylus. The connection is considered to pass the test if the probe 0,03 mm does not enter the groove of the mating of current-carrying parts beyond the zone, limited by the perimeter of the washer.

Checking of the contact connections of power modules to the cooler surface is performed on each module with a stylus. The connection is considered to pass the test if the stylus 0.03 mm does not enter the slot between the module base and the cooler beyond the zone limited by the perimeter of the module base.

Dimensions, mounting and connection dimensions shall be checked with a measuring tape.

5 RESEARCHING ELECTRICAL RESISTANCE AND TESTING THE INSULATION

Researching electrical resistance and testing insulation are vital activities in the field of electrical engineering and maintenance. Here are several reasons why these activities are crucial:

- Equipment Safety: Testing electrical resistance helps ensure the safety of electrical equipment and systems. It allows for the identification of any abnormal resistance that could lead to overheating, electrical fires, or other safety hazards.

- Preventing Electrical Accidents: Researching and testing electrical resistance help prevent electrical accidents, such as shocks and electrocutions. By identifying and rectifying high resistance or faulty insulation, the risk of accidents is significantly reduced.

- Equipment Reliability: Electrical resistance testing is essential for maintaining the reliability of electrical components. It helps detect degradation, corrosion, or other issues that could compromise the functionality of conductive elements.

- Compliance with Standards: Many industries and regulatory bodies set standards for electrical resistance and insulation testing. Adhering to these standards is necessary for ensuring compliance with safety regulations and industry best practices.

- Preventing Downtime: Regular testing helps identify potential problems before they escalate. This proactive approach helps prevent unexpected equipment failures, reducing downtime and minimizing the impact on operations.

- Extending Equipment Lifespan: By identifying and addressing issues early on, electrical resistance and insulation testing contribute to extending the lifespan of electrical equipment. This is essential for maximizing the return on investment in expensive machinery and systems.

- Energy Efficiency: Poor electrical connections or insulation issues can result in energy losses. By maintaining proper electrical resistance and insulation levels, energy efficiency is improved, reducing power consumption and associated costs.

- Fire Prevention: Faulty insulation or high resistance can lead to overheating, posing a fire risk. Regular testing helps identify potential fire hazards and allows for corrective measures to be taken before a fire can occur.

- Quality Assurance: Electrical resistance and insulation testing are critical components of quality assurance programs. Ensuring that electrical components meet specified resistance and insulation standards guarantees the reliability and safety of the entire system.

- Predictive Maintenance: Regular testing provides data that can be used for predictive maintenance. Predicting when equipment may fail allows for scheduled maintenance, reducing the likelihood of unplanned downtime.

- Environmental Protection: Proper insulation testing contributes to environmental protection by preventing leaks of electrical current that could harm the environment. It ensures that electrical systems are well-contained and do not pose environmental risks.

- Occupational Safety: Testing insulation helps create a safe working environment for personnel working with or around electrical systems. It minimizes the risk of electric shock and creates a safer workplace.

In summary, researching electrical resistance and testing insulation are essential for ensuring equipment safety, preventing electrical accidents, maintaining reliability, complying with standards, preventing downtime, extending equipment lifespan, improving energy efficiency, preventing fires, ensuring quality, enabling predictive maintenance, protecting the environment, and promoting occupational safety in the field of electrical engineering and maintenance.

Measurement of electrical resistance and the test of electrical strength of the converter insulation is carried out in normal climatic conditions according to method 101 and 102 of GOST. 26567-85.

Before testing it is necessary to carry out preparatory works:

- turn on the circuit breaker SF1 in the inverter cabinet and make sure that its poles are closed;

- disconnect all plug-in connections from the boards;

- remove SKYPER 32 boards from AK1...AK4;

- disconnect the ribbon cables, including those from the control panel terminal;

- Disconnect fans M1 to M6;

- ground the cabinet enclosure;

- form groups of electrically unconnected circuits according to Table 4.1.

Table 5.1 Circuit groups for insulation test

Name of chains (group), preparatory operations	Voltage of the megohmmeter, V	Test voltage (effective value), V
Group 1 Power Circuits Short-circuit breaker Q1 input and output, reactors L1 and L2 input and output, closing contacts KV1, XTN1 in the cabinet, circuits U, V, W, 25, 26, R - contacts of sockets X100, X200 of boards AK1...AK4 in the power unit AA1.	1000	2000

Group 2 Lighting and socket Short-circuit XTO terminal strip, SQ1 limit switch (21, 22)	1000	2000
Group 3 Isolated source circuits 2P24, 2M Short contacts: XG2:4,6, XG3, XG6:1,3 XAS3 in cabinet, XP3:4-6, XP6,7 in block AA1	500	1500
Group 4 Power supply circuits and control system information signals Short-circuit contacts XG1:3,5, XG2:1,3, XG4:4,5, XG5:1,6 in the cabinet, XP2, XP3:1,3, XP4, XP5, XP11, XAS1, XA61, in block AA1	100	500
Group 5 CAN circuits Short-circuit XP8 contacts in block AA1.	100	500
Group 6 Fan Power Circuits Short-circuit fan contacts M1-M6.	500	-

Measurement of electrical insulation resistance should be performed for each group relative to the enclosure. All circuits, except for the tested one, must be connected to the housing. The value of insulation resistance for each group must be at least 5 Mohm.

The tests of electric strength shall be carried out for each group relative to the case, all circuits except for the tested one shall be connected to the case. Magnitude of the test voltage shall correspond to the value indicated in Table 4.1. The test of insulation electric strength shall be carried out on a test facility with alternating voltage and frequency of 50 Hz.

Test voltage should be increased to the set value for time not more than 10 s, smoothly or in steps of maximum 5% Uin, starting from the value not less than 0,5 Uin.

The transducer should be kept under full test voltage for 1 minute, after which the voltage should be reduced to 0.3 Ucal and disconnected.

The product is considered to have passed the test, if there was no breakdown or overlapping of insulation on the surface, sharp decrease of readings of the voltmeter included into the tested circuit and sharp increase of leakage current.

After completing the tests according to par. 4.2.2, 4.2.3 it is necessary to remove all installed jumpers, turn off the circuit breaker SF1.

DO NOT CONNECT connectors to the boards!!!

6 RESEARCHING OF THE OUTPUT VOLTAGE, FREQUENCY RANGES OF CHANGE

Researching the output voltage and frequency ranges of change is essential in the field of electrical engineering for several reasons:

- Equipment Performance: Understanding the output voltage and frequency ranges is crucial for assessing the performance of electrical equipment. It ensures that the equipment operates within specified parameters and delivers the expected output.

- System Compatibility: Researching the output voltage and frequency ranges helps ensure compatibility between different electrical components and systems. It is vital for avoiding mismatches that could lead to malfunctions or damage to equipment.

- Equipment Selection: For designers and engineers, researching voltage and frequency ranges is necessary during the selection of electrical components. This ensures that the chosen components align with the requirements of the overall system.

- Regulatory Compliance: Many regions and industries have standards and regulations governing the acceptable voltage and frequency levels. Researching and adhering to these standards is essential for compliance and legal conformity.

- Safety Considerations: Understanding the output voltage and frequency is crucial for ensuring the safety of electrical systems. It helps prevent overloading, overheating, and other issues that could pose safety hazards to both equipment and personnel.

- Optimizing Power Consumption: Researching voltage and frequency ranges allows for the optimization of power consumption. It helps engineers design systems that operate efficiently within specified voltage and frequency parameters, minimizing energy wastage.

- Equipment Longevity: Operating electrical equipment within its specified voltage and frequency ranges contributes to its longevity. Continuous operation outside these ranges may lead to premature wear and tear, reducing the lifespan of the equipment.

- Predictive Maintenance: Monitoring changes in output voltage and frequency ranges over time enables predictive maintenance. Deviations from normal ranges may indicate potential issues, allowing for proactive maintenance to prevent equipment failures.

- Grid Compatibility: Researching output voltage and frequency is critical for ensuring compatibility with the electrical grid. Different regions may have variations in grid specifications, and understanding these variations is necessary for seamless integration.

- Quality Assurance: For manufacturers, researching and testing output voltage and frequency ranges is a part of quality assurance. It ensures that products meet specified standards and perform reliably under normal operating conditions.

- Performance Optimization: Knowing the optimal voltage and frequency ranges allows for the fine-tuning of electrical systems to achieve optimal performance. This is particularly important in applications where precision and stability are critical.

- Customer Satisfaction: Delivering electrical equipment that operates within the expected voltage and frequency ranges enhances customer satisfaction. It ensures that the equipment performs as promised and meets the customer's requirements.

In summary, researching the output voltage and frequency ranges is crucial for assessing equipment performance, ensuring system compatibility, selecting appropriate components, complying with regulations, ensuring safety, optimizing power consumption, promoting equipment longevity, enabling predictive maintenance, ensuring grid compatibility, maintaining quality standards, optimizing performance, and enhancing customer satisfaction in the field of electrical engineering.

Make sure that the jumpers and switches on the boards are set according to diagrams E3 and Table 6.1.

Table 6.1

Plate	Connector on the plate	Position
AP1	PIN1J1	open
	Switch S203:1	open
	Switch S203:2	open
	Switch S203:3	open
	Switch S203:4	open

Checking control system supply voltages

To check the presence and parameters of unstabilized voltage on all sockets and wires before connecting them to the boards, connect all connectors except XG5 to the power board AG1.

Check for short circuits between circuits:

- phases of auxiliary circuits A1, B1, C1 (with SF1 switch off)

- 1 and 1M;

- 2 and 2M;

- 3 and 3M.

Apply supply voltage of 380 V to the inverter input. The "Power supply" lamp (HL1) on the cabinet door should turn on.

Turn on circuit breaker SF1.

Measure output voltages of AG1 rectifier board without load. Compare the measured voltages with Table 6.2. Control the voltages with a DC voltmeter.

Table 6.2

Monitored voltage	Voltage, V
Mains sensor voltage UC	2.93+0.1-0.1
1P24	24+6-2
2P24	24+6-2
3P24	24+6-2

Check the presence and magnitude of stabilized voltages.

Check the output voltage on the AG2 board on the test points KT2, KT4. The voltage must correspond to the range specified in Table 4.4, in case of nonconformity set the necessary output voltage with the help of resistor R3 on AG2 board.

Before testing, make sure there are no short circuits between the circuits on sockets XAS1, XAS2, XAS3, XG21, XZ1, XBK1, XP17...XP19 not yet connected to the boards.

Connect to the AP1 control board - connector XP11.

Switch on SF1. Make sure that the corresponding LEDs of stabilizers AP1, AG2, AS1, AS2 in the AA1 block are lit.

Parameters of stabilized voltages must comply with Table 6.3.

Table 6.3 Parameters of stabilized voltages

Monitored voltage	Voltage, V
P5 to XTR1	5 ± 0,1
P12 to XTR1	12 ± 0,4
N12 to XTR1	minus 12 ± 0,4

P15 to AS1:X1	15 ± 0,5
N15 to AS1:X1	minus 15 ± 0,5
3P15 to AG2:X1	15 ± 0,5

Connect all connectors to converter boards, install SKYPER 32 boards on AK1...AK3.

Check ADC channel zeros

Check and, if necessary, set zero voltages "U=0±0.01V" for ADC channels, "n4 - Us", "n5 - Ud", "n6 - ia", "n7 - ib". Setting the zero voltage in each channel is made by changing the values of offset settings (using the keys "□" and "□") in the main menu item "ADC test", when the parameter "Access" is set to 1.25=3. After adjusting make a record of the changed shifts with the recording program.

If zero "n4 - Us" is set, short-circuit pins XG5:1 and XG5:6.

Setting the mains voltage sensor

Connect XG5 to AG1 power board.

Select on the display of the control panel terminal (hereinafter the display) in the main menu item "Display" parameters Ud, Ugrid and by adjusting the scaling factor 9.31 KUs set the display reading Ugrid in accordance with the AC line voltage voltmeter reading UAB at the converter input.

Checking of transistor inverter pulse shapers

Set jumpers between XT4:3 and XT4:4 in the power block AA1.

Set the main menu item "Basic.(P1)" on the display, select the parameter "Access" and set its value 1.25=3. Return to the main menu and set the menu item "ADC test", enter the command for execution by pressing the Enter key, select the number of analog channel "n14 - Ud", press the Enter key and holding the ▼ key (less) on the terminal, set the value U=3V on the display

Set the main menu item "Basic.(P1)" on the display, select the parameter "Setting (A)" and set its value to 1.7=5.

Press the button Start. Using oscilloscope check the pulses of control on transistors between the contact pad 42 of AK1, AK2, AK3 boards and output phases U, V, W respectively, also between the contact pad 44 of AK1, AK2, AK3 boards and the -Ui bus (circuit 26) in the power block AA1. Compare the shape of pulses with Fig. 4...6. The PWM frequency must be 1 kHz. Small high-frequency oscillations are allowed at the beginning of the control pulse front and fall.

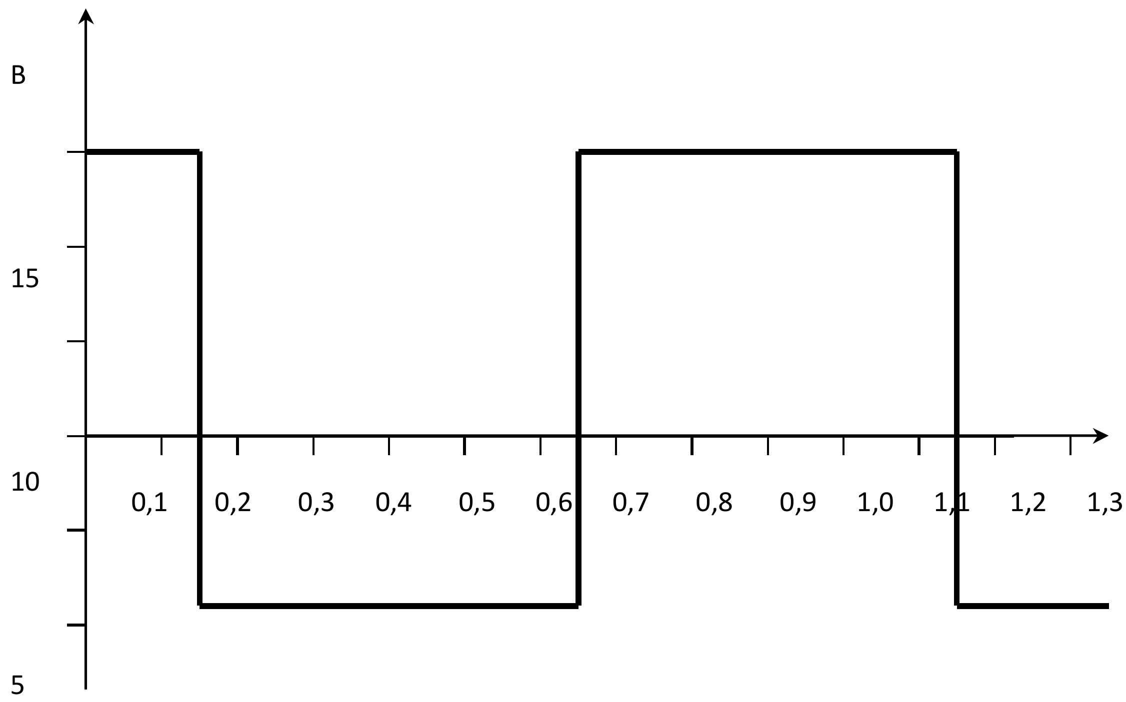

Figure 5. Transistor control pulse

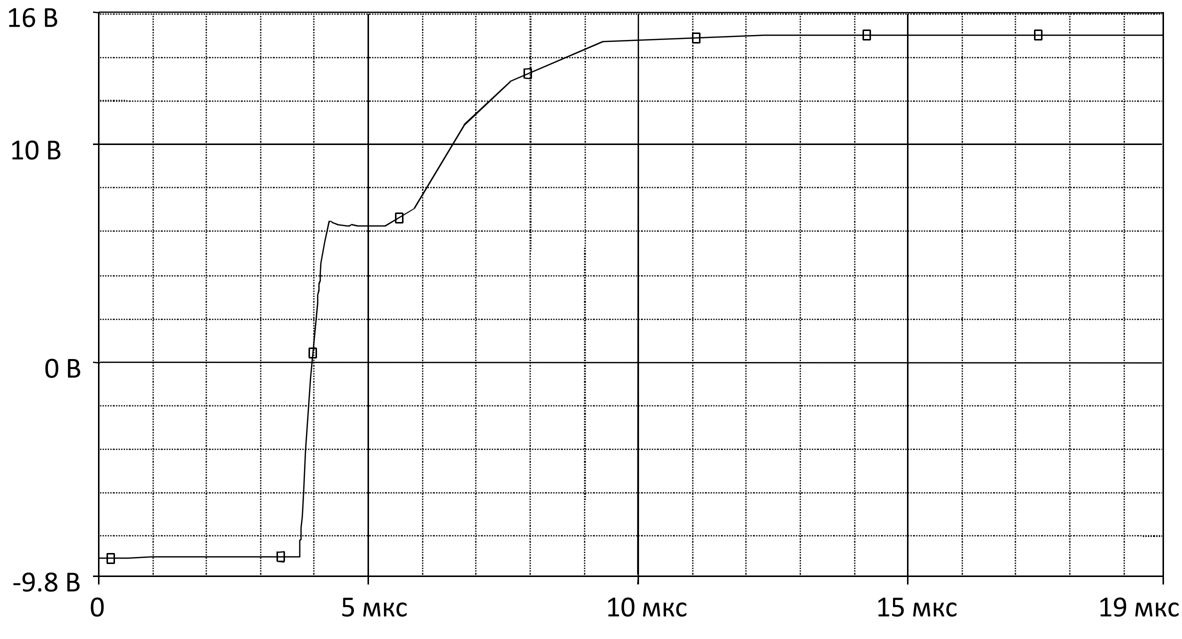

Figure 6. - Pulse front

Figure 7. Impulse decay

Note - All measurements with an electronic oscilloscope should be made with a calibrated measuring halyard not more than 1.5 m long and with an input capacitance not more than 120 pF.

Use oscilloscope to monitor voltage between pads 42 and 44 of boards AK1, AK2, AK3. Compare the voltage waveform with Figures 8 and 9.

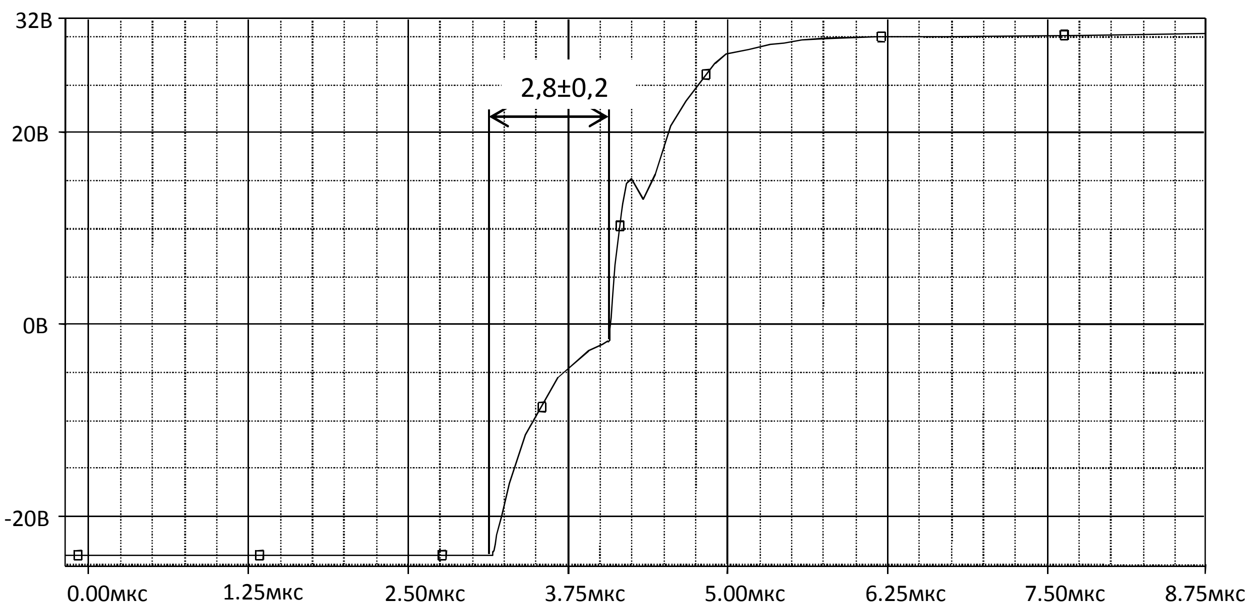

Figure 8. - Pulse delay when switching on

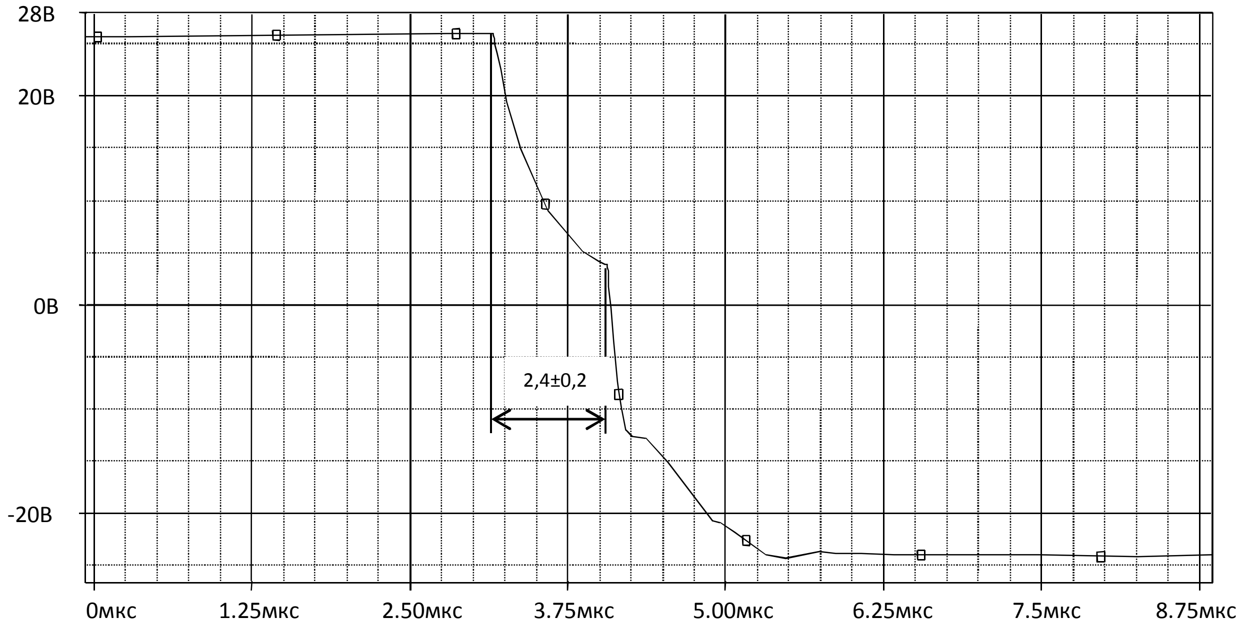

Figure 9. - Pulse delay when turning off

Turn off the circuit breaker SF1 in the transducer cabinet, remove the jumper between XT4:3 and XT4:4 in the power block AA1, turn off the supply voltage from the transducer input and the "Power supply" lamp (HL1) on the cabinet door.

Checking the pulse shapers of the dynamic brake transistor

Set the main menu item "Basic.(P1)" on the display, select the parameter "Access" and set its value 1.25=3. Return to the main menu and set the menu item "ADC test", enter the command for execution by pressing the Enter key, select the number of analog channel "n14 - Ud", press the Enter key and holding the ▼ key on the terminal (less), set the display to U=3.3 V.

Use an oscilloscope to monitor the control pulses on the transistor module VT4. the pulse parameters are similar to those of the inverter transistors.

Turn off the SF1 circuit breaker in the cabinet, remove the jumper between XT4:1 and XT4:4 in the power block AA1, turn off the power supply from the cabinet input and the "Power supply" lamp (HL1) on the cabinet door should go off.

Note. If the new value of channel offset "n14 - Ud" was recorded when checking the pulse shapers, the output voltage of the channel U=0V must be set and recorded.

Rectified voltage sensor setup

Connect the "+" and "-" DC voltmeter with limits up to 750 V between pins XT1:1 and XT1:3 on the AZ1 sensor board respectively.

Disconnect circuit 2-6 from +XT5:1 on board A3.

Apply supply voltage to the input of the inverter, turn on circuit breakers SF1 and Q1, the "AC Off" lamp "On" (HL2) must turn on.

To select in the main menu item "Display" parameters Ud, Ugrid and adjusting potentiometer R2 on the sensor board AZ1 set on the display reading of Ud in correspondence with the DC voltmeter reading.

Turn off the circuit breaker Q1 and discharge the capacitors of the power filter C1...C6 through the portable resistor.

Connect circuit 2-6 to +XT5:1 on A3.

Checking the diode and thyristor rectifier

With the Q1 circuit breaker switched on check the voltage on diode-thyristor modules V1...V3 with an oscilloscope in the AA1 power unit. The measuring halyard must have a 1:100 divider. Check the voltage on board A3 between XT4:2 and XT1:2, XT2:2, XT3:2 respectively.

Compare the voltage waveform with the oscillogram shown in Figure 10.

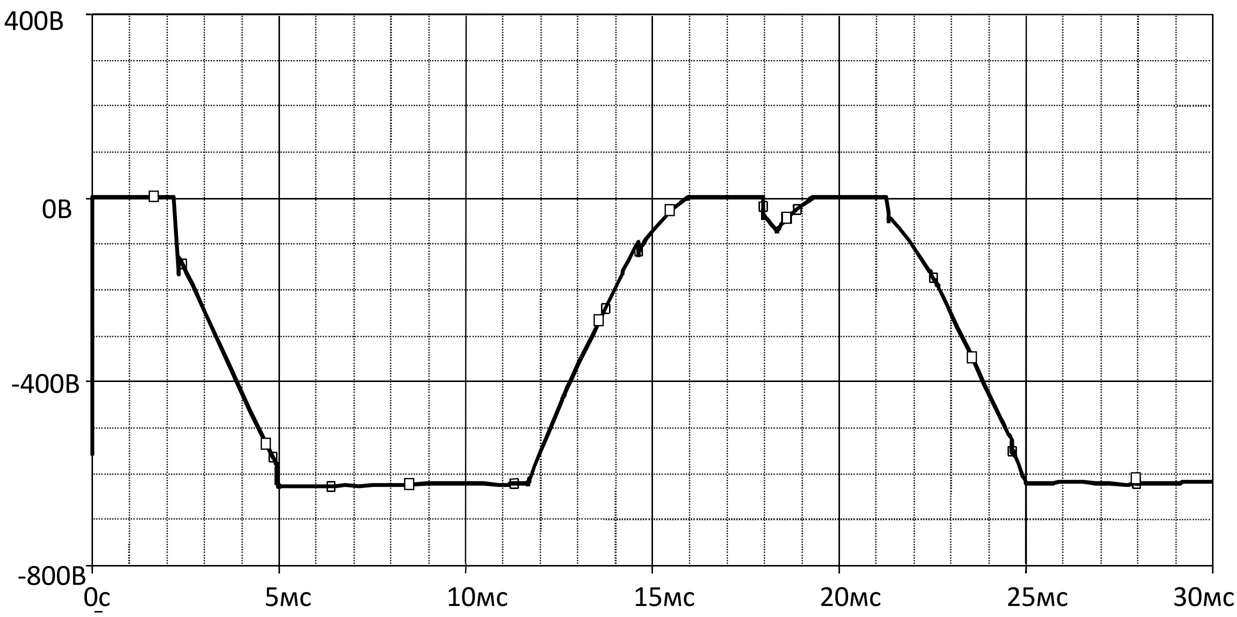

Figure 10 - Thyristor voltage

Checking the operation of the transistor inverter

With the Q1 circuit breaker switched on set the main menu item "Basic.(P1)" on the display, select parameter P1.8-"Setting (A)" and set its value P1.7=5. Return to the main menu and set the menu item "Control", select the control mode F* and set the value F*=50.0 Hz by pressing the key ▲ on the terminal.

Press the Start key.

Monitor in steady-state mode output voltage of the transducer and its frequency. Actual value of line voltage must be U=(380+22) V, and its frequency Fad=(50,0±0,5) Hz

Control the shape of output voltage of inverter by oscilloscope on U, V, W busbars and compare with figure 4.7. Frequency of PWM must be 1 kHz.

Set on the display frequency setting F*=0,0 Hz. Control the smooth decreasing of inverter's output voltage and frequency up to U=(0+10) V and up to Fad=0,0 Hz.

Press key Stop on the terminal, turn off circuit breakers Q1 and SF1, remove supply voltage 380 V from the inverter input.

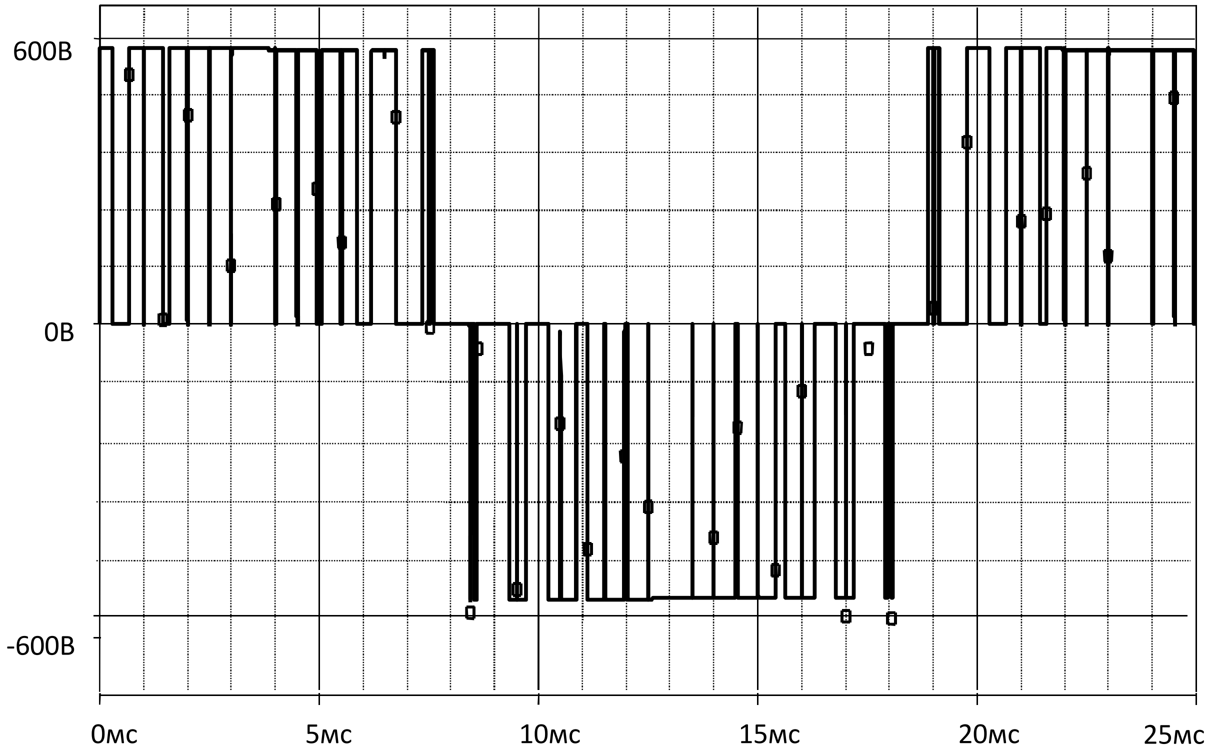

Figure 11. - Voltage at the converter output

Check on the display in the menu item "Display" the cooler temperature Tnh, which must be equal to the ambient air temperature with an accuracy of ±2oC. Check the ambient air temperature with a spirit thermometer.

Scaling of current sensors

Connect the transducer to the network through the power step-down transformer 380/48. At that, voltage of 380 V must be supplied to the input of circuit breaker SF1.

Connect a three-phase serial RL-load to the inverter output with 180 A current. Resistance in phase R=0.041 Ohm, inductance in phase L=23+140 mcg. Connect the load in star configuration.

Turn on circuit breaker SF1.

Set the main menu item "Main.(P1)" on the terminal display, set "Access" 1.25=3. Enter the main menu set the following parameters:

"Ipch-nom" 9.13=120,

"I failure" 9.9= 2,2*In=264A,

"Fmax" 1.1=50

"Inch-max" 1.11=1.5*In=180A,

"Iad-nom" 1.12=10A,

"Uad-nom" 1.13 = 260 V,

"Fad-nom" 1.14 = 50 Hz.

Enter main menu, select record mode and record.

Press the Reset button (SW1) on the AP1 control board.

Switch on the circuit breaker Q1.

Set the main menu item "Basic.(P1)" on the display, set the parameter "Setup (A)" 1.7=5.

Return to the main menu and set the menu item "ADC test", select the number of analog channel "n5 - Ud". set on the display the value U=2,5-3V. Check in the menu item "Indication" Ud must be equal to 520V±20.

Press the button Start.

Go back to the main menu and set the item "Control", select the control mode F* and hold the button ▲ on the terminal and set the inverter output current to 100A (F*~20Hz). Check the current with a clamp meter.

Use R4 and R14 on A6 to set the indication current to 100 A. Voltages on the A6 output on XT1.1 and XT1.3 must be equal, amplitude value~2V ±5%.

Set the output current frequency of the transducer to 180A. Compare the clamp readings with the indication on the display Iad. The difference of readings must not exceed 5 % of a nominal current of the converter if the asymmetry of phase currents does not exceed 2 %.

Press the button "Stop".

Checking of protection against current overload of the transducer

With connection of the converter through the step-down transformer and connected RL-load (R=0.041 Ohm, L=23+140 mcg) switch on the circuit breakers SF1 and Q1. HL3 "Ready" should light up with a time delay.

Parameters of the converter must be set according to 4.3.9.4.

Press the button Start on the control panel, HL5 "Operation" must light up.

Set the menu item "Control", select the control mode F* and holding the key ▲ or ▼ on the terminal set the inverter output current 120 A (F*~25Hz).

Wait (1±0.2) min and set transducer output current to 180 A (F*~50Hz).

After (60±6) s the terminal should enter the alarm mode "A>", the inverter current should decrease to zero. On the cabinet door HL4 "Alarm" will light up. Selecting the menu item "Messages" to display the message "Inverter overload".

Note. - To control the current on the converter output using the measuring clamp.

Reset the overcurrent protection by pressing simultaneously the keys Fn and Stop on the remote terminal.

Turn off the circuit breaker Q1.

Checking the overheating protection of the inverter

Select "Main.(P1)"/"Access" in the main menu, set 1.25=3. Return to the main menu and set the menu item "ADC test", enter the command for execution by pressing the Enter key, select the number of analog channel "n3 - Rt", press the Enter key and set the channel voltage U≈3,26 V by holding the ▼ key (less) until the fans M1, M2, M3 in the converter cabinet start. Control the direction of rotation of the fan blades by the arrows on their housings.

In the main menu item "Indication" on the display monitor the cooler temperature Tnh=50°C.

Continue decreasing the offset of the channel "n3-Rt" until the FC enters the mode of alarm message - "FC overheating" (U≈3,56 V).

In the main menu item "Indication" on the display monitor the cooler temperature Tpc=80°C.

Turn off the circuit breaker SF1 and Q1, disconnect supply voltage from the converter input.

Disconnect the step-down transformer from the input and RL-load from the output. Restore the power supply circuit of circuit breaker SF1.

Testing of operation of the transducer from the panel terminal

Connect a 30 kW asynchronous motor to the converter output and supply 380 V to its input.

Turn on circuit breakers SF1 and Q1.

Select in the main menu "Basic (P1)"/"Setpoint (A)", set 1.7=5,

"Fmax", set 1.1=50, "Uad-nom" set 1.13 = 380 V, "Fad-nom" set 1.14 = 50 Hz.

Enter the main menu, select the record mode and record.

Go back to the main menu and set the item "Control"\F*, press Enter and Start on the terminal, holding the key ▲ set the frequency F*=50.0 Hz, control the change of motor rotation, output voltage of the transducer to the steady state Uad=380 V and its frequency to Fad=(50.0±0.5)Hz.

Select "Operation"/"Reverse" in the main menu item, press Enter and set "Reverse"=1 by pressing ▲. The engine speed should decrease to zero in (5.0±0.5) seconds and then change the direction of rotation to its initial values in (3.0±0.5) seconds.

Press the Stop key on the terminal. In this case the engine should decrease its revolutions to zero in (5,0±0,5) s.

Note - When checking according to p. 4.4.3 and further the reference frequency F*, the output voltage Uad and its frequency Fad can be checked on the terminal display in the main menu item "Display".

Turn off the circuit breakers Q1 and SF1.

Check the operation of the inverter from the remote control.

Connect the remote control (hereinafter the remote control) to the converter according to the diagram shown in Fig. 4.8. Connect the braking resistor.

Turn on the circuit breakers SF1 and Q1 and the Ready LED (V1) on the remote control.

Select in the main menu "Basic (P1)"/"Setpoint (A)", set 1.7=1.

Switch the rocker switch S6 on the keyboard to the position "Voltage Channel Setting". Set the reference voltage Uin = (10±0,3) V using the frequency setting potentiometer (RP1). By regulating the variable resistor 2R9 on the control board AP1 set the set frequency F*=(50,0±0,1) Hz.

Switch the tumbler Start (S3) in position "Forward". After that LED Start (V2) turns on and indication of operating mode "R>" appears on the display.

Control the change of motor turns, output voltage of converter up to steady state Uad=380 V and its frequency up to Fad=(50,0±0,5)Hz.

Control the setpoint voltage Uin with the voltmeter PV1, and F*, Fad and Uad on the display of the control panel terminal in the menu "Display".

Set the Start toggle switch to "Back" position. In this case the motor should change the direction of rotation smoothly, and Uad and its frequency Fad should decrease to zero in (5.0±0.5) seconds and then increase to the initial values in (3.0±0.5) seconds.

Set the deceleration ramp to 1 sec. Repeat the start and check if the dynamic brake is activated by the characteristic sound of the resistor and the rapid deceleration ramp of the motor

Set the Start toggle switch into the neutral position with the engine speed reducing to zero.

Check the fixed frequency reference via binary inputs.

Set the frequency reference potentiometer (RP1) to zero position and the Start switch to "Forward" position.

Turn on the tumbler Frequency 1 (S4), the output voltage of the converter must increase to Uad=76 V, its frequency to Fad=(10,0±0,5) Hz, and the engine speed must correspond to the frequency of 10 Hz.

Turn off the tumbler Frequency 1 and turn on the tumbler Frequency 2 (S5), the transducer output voltage must increase to Uad=152V, its frequency to Fad=(20,0±0,5) Hz, and motor speed must correspond to frequency of 20 Hz.

Turn toggle switches Frequency 1 and Frequency 2, thus the output voltage of the transducer must increase to Uad=380V, its frequency to Fad=(50.0±0.5)Hz, and motor rotational speed must correspond to frequency of 50 Hz. Set tumbler Start in neutral position, after the engine speed decreases to zero, LED Start will turn off on the control panel, and indication of readiness mode "G>" will appear on the display.

Switch off the toggle switches Frequency 1 Frequency 2.

Select in the main menu "Basic (P1)"/"Task (A)", set 1.7=2.

Switch the rocker switch S6 on the keyboard to the position "Setting the current channel" and set the setting current Iin = (20±0,2) mA with the potentiometer Frequency setting. Adjusting variable resistor 1R9 on control board AP1 set setting frequency F*=(50,0±0,1) Hz, controlling it on display in "Display"/"F*" mode.

Control the setting current Iinh on the panel with milliammeter PA1.

Switch the Start toggle switch to "Forward" position. Monitor the change of engine speed, output voltage of the transducer up to the steady-state value of Uad=380V and its frequency up to Fad=(50.0±0.5)Hz.

Press the button External fault (S2), an emergency shutdown of the transducer should take place, when the output voltage of the transducer Uad and its frequency Fad take zero value at once and the motor will stop on "coasting". On the display of the terminal the indication of the emergency mode "External fault" appears.

Press the Reset button (S1) on the terminal, the alarm mode must be reset and it must go to the standby mode with indication "G>" on the display of this mode. After resetting the emergency mode the stopped motor must not start until the Start switch is turned off and then on again.

After the stop of the engine switch off the circuit breakers Q1 and SF1, remove the supply voltage from the input of the transducer.

Check the operation of the CANopen interface

Connect the PC with the CANopen adapter to XT2:(1-3).

Switch on the circuit breaker SF1. Check the data exchange between inverter and PC via the CANopen communication interface.

Turn off circuit breaker SF1

Check phase failure protection

Set a circuit breaker to phase B of the input voltage with a current of at least 25 A and switch it on.

Supply voltage 380 V to the input of the converter, turn on circuit breakers SF1 and Q1.

Accelerate the motor to nominal speed as in section 4.4.3.

Turn off the circuit breaker in phase B of the input voltage. In this case the motor will rotate at "coasting", the display will show the message of failure "U grid-min".

Restore the input voltage phase B by turning on the circuit breaker, the motor should not restart.

Measuring the output voltage, its frequency and the range of its variation

Run the motor at its rated speed.

Measure the output voltage of the inverter with an electromagnetic voltmeter. Linear effective voltage must be U=(380±20) V, and its frequency Fad=(50,0±0,5) Hz.

Press the button Stop on the remote control the motor must stop. At that the output voltage and frequency of the transducer will smoothly decrease. After the stop of the motor measure output voltage of the transducer and its frequency. The voltage must be U=(0+10) V and its frequency Fad=0,0 Hz.

Turn off circuit breakers Q1 and SF1, disconnect supply voltage from inverter input.

Restoring of factory settings

Set on the display main menu item "Basic.(P1)"\"Access" and set its value 1.25=2.

Select "Programs.(P8)" item in the main menu and set the "Basic" program.

Set the nominal parameters:

"Ipc-nom" 9.13=100,

"I failure" 9.9= 2,2*In=220A,

"Fmax" 1.1=50

"Inch-max" 1.11=1.5*In=150A,

"Iad-nom" 1.12 = 100A,

"Uad-nom" 1.13 = 380 V,

"Fad-nom" 1.14 = 50 Hz.

Select item "Record" in the main menu and record.

Disconnect circuit breaker SF1 and supply voltage from inverter input.

CONCLUSIONS

In conclusion, the meticulous analysis conducted in this project culminated in the selection of a frequency converter scheme featuring transistor modules, chosen for its superior efficiency and performance characteristics. This scheme, compared to alternative designs, emerged as the optimal choice for several compelling reasons.

The transistor module-based scheme excels in enhancing control precision due to the swift switching capabilities of transistors. This feature enables finer adjustments to the output frequency, contributing to precise motor speed control critical for various industrial applications. Additionally, the modular nature of transistors allows for scalability and flexibility, accommodating a range of power ratings while maintaining efficiency.

Energy efficiency is a paramount consideration in modern power electronics, and the chosen scheme stands out in this aspect. The inherent characteristics of transistor modules result in relatively low switching losses and minimal power dissipation, leading to an overall efficiency of 93%. This impressive efficiency not only reduces energy consumption but also minimizes heat generation, contributing to the longevity and reliability of the system.

The reduction in maintenance requirements further underscores the superiority of the transistor module-based scheme. With fewer mechanical components susceptible to wear and tear, the converter exhibits enhanced reliability and longevity, ultimately translating into diminished operational costs throughout its service life.

The results of the investigation revealed [specific findings], underscoring the effectiveness of the chosen frequency converter scheme with its emphasis on minimal losses and high efficiency. These findings contribute valuable insights into the converter's behavior, showcasing its potential for various industrial applications requiring precise motor speed control and energy efficiency.

In summary, the project's emphasis on the frequency converter scheme with transistor modules is justified by its superior control precision, energy efficiency, and reduced maintenance needs compared to alternative designs. These attributes position the selected scheme as an advanced and effective solution for applications demanding precise motor control, energy conservation, and reliability. The outcomes of this project not only contribute to the specific field of power electronics but also hold broader implications for enhancing the sustainability and efficiency of electrical systems across various industrial sectors.

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