Форма № 25

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

Інститут, факультет__Фізико-технічний інститут, Електротехнічний факультет___
Кафедра____Електричні та електронні апарати_______________________________
Ступінь вищої освіти Бакалавр____
Спеціальність ____141__Електроенергетика, електротехніка та електромеханіка_
(код і найменування)
Освітня програма (спеціалізація)______Електричні та електронні апарати_________
(назва освітньої програми (спеціалізації)

ЗАТВЕРДЖУЮ
Завідувач кафедри
____

____
«_______»
_________________20___року

З А В Д А Н Н Я
НА ДИПЛОМНИЙ ПРОЄКТ (РОБОТУ) СТУДЕНТА(КИ)

___________________Мікулін Дмитро Антонович_______________________________
(прізвище, ім’я, по батькові)
1. Тема проєкту (роботи)____Комплектний розподільний пристрій 10 кВ, 2000 А
____
____
Керівник проєкту (роботи)__Жорняк Людмила Борисівна к.т.н., доцент___________
(прізвище, ім’я, по батькові, науковий ступінь, вчене звання)
затверджені наказом закладу вищої освіти від «11» березня 2021 року №72
2. Строк подання студентом проєкту (роботи)____19.04.2021____________________
3. Вихідні дані до проєкту (роботи)___U_{nom}=10 кВ, I_{nom}=2000 А, f=50-60 Гц._____
____
____
____
____

4. Зміст розрахунково-пояснювальної записки (перелік питань, які потрібно розробити) 1 Техніко-економічне обґрунтування необхідності розробки; 1.1 Огляд існуючих конструкцій КРУ на 10 кВ; 1.2 Огляд енергетичного обладнання; 1.3 Обґрунтування необхідності інновацій; 2. Розрахунок струмоведучих елементів; 2.1 Вибір перерізу шин; 2.2 Перевірка шин на тривалий режим експлуатації; 2.3 Перевірка шин на термостійкість; 2.4 Перевірка шин на електродинамічну стійкість; 2.5 Вибір контактів вимикача з приводом; 3 Розрахунок ізоляції КРУ; 3.1 Вибір ізоляційних проміжків; 3.2 Визначення значень розряду напруг; 3.3 Розрахунок ізоляційних проміжків; 4 Дослідження та розрахунок надійності розподільних пристроїв при напрузі 10 кВ; 5 Охорона праці; 5.1 Заходи з охорони праці; 5.2 Заходи пожежної

безпеки; 6 Економічні підстави для розвитку КРУ; 6.1 Вартість і ціна КРУ; 6.2 Оцінка витрат.

5. Перелік графічного матеріалу (з точним зазначенням обов'язкових креслень)
1. Circuit breaker with a drive. Assembly drawing ГКІЮ 671214.015 AD – A1, 1 лист;
2. Switchgear panel 10 kV 2000 A. Assembly drawing ГКИЮ 671214.015 AD – A1, 1 лист;
3. Reliability graphs GKIU.671214.0015 – A1,1 лист
4. Set up of grounding. Assembly drawing GKIU.687425.0015 AD – A1, 1 лист

6. Консультанти розділів проєкту (роботи)

Розділ	Прізвище, ініціали та посада консультанта	Підпис, дата	
		завдання видав	прийняв виконане завдання
Економіка	Пожуева Т.О. проф.		
Охорона праці	Скуйбіда О.Л. доцент		
Англійська мова	Сивачук О.М. стар. викл.		

7. Дата видачі завдання «______» ________________20___року.

КАЛЕНДАРНИЙ ПЛАН

№ з/п	Назва етапів дипломного проєкту (роботи)	Строк виконання етапів проєкту (роботи)	Примітка
1	Огляд існуючих конструкцій КРУ	15.10.2020	
2	Розрахунок струмоведучих елементів	20.01.2021	
3	Розрахунок ізоляції КРУ	10.02.2021	
4	Дослідження та розрахунок надійності розподільних пристроїв	25.02.2021	
5	Охорона праці	12.03.2021	
6	Економічні підстави для розвитку КРУ	26.03.2021	
7	Оформлення дипломного проєкту	10.04.2021	

Студент(ка) ______________ _____Мікулін Д.А_____
(підпис) (прізвище та ініціали)

Керівник проєкту (роботи) ______________ ______Жорняк Л. Б.___
(підпис) (прізвище та ініціали)

Форма № 24

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
Національний університет «Запорізька політехніка»

Фізико-технічний інститут, Електротехнічний факультет
(повне найменування інституту, факультету)

Електричні та електронні апарати___________________
(повне найменування кафедри)

Пояснювальна записка

до дипломного проєкту (роботи)
__________________Бакалавр ______________________
(ступінь вищої освіти)

на тему_Комплектний розподільний пристрій 10 кВ, 2000 А_
____

Виконав: студент(ка) _4_курсу, групи Е-417а

Спеціальності 141 Електроенергетика, електротехніка та електромеханіка
(код і найменування спеціальності)

Освітня програма (спеціалізація)
____Електричні та електронні апарати_____

____Мікулін Дмитро Антонович___________
(прізвище та ініціали)

Керівник _Жорняк Л.Б.______________________
(прізвище та ініціали)

Рецензент__Сергієнко В.С.____________________
(прізвище та ініціали)

2021

ABSTRACT

EN: 89 pages, 18 figures, 17 tables, 51 sources.

SWITCHGEAR PANEL, VACUUM BREAKER, BUS, CURRENT TRANSFORMER, SWITCHING CONTACTS, CURRENT CARRYING ELEMENTS, INSULATION, RELIABILITY PARAMETERS.

The object of research is 10 kV, 2000 A distribution switchgear panel (DSP).

The working out method is an analytical method of calculation of empirical formulas.

It is necessary to choose the basic device among different types, to specify advantages and disadvantages of the system, also to look into power equipment of necessary parameters, current transformer insulation, block of relay protection, to state techno-economic reasons for new research and to make an innovation proposition that would significantly increase efficiency of DSP exploitation, and in this way would bring about economic effect, that would make our device highly competitive and desirable for potential owners.

Our city is a developed industrial region with a plethora of organizations producing electrical equipment for various purposes. That is why the goal to produce DSP is quite reasonable due to the rich material base, but, on the other hand, this factor points out the necessity of conducting additional research of possibilities to make DSP production and exploitation cheaper and more effective.

For this purpose the developer can either decrease the price of the device, using cheaper equipment, or equipment of national production, which is produced nearby, or install some additional equipment, which increases total price of the product, but provides sufficient increase of protection of the system, decreases time for maintenance and non-operating time, excludes big damage to equipment, and thus covers all additional costs on equipment and brings profit to the organization that own it.

CONTENT

INTRODUCTION

The object of research is 10 kV, 2000 A distribution switchgear panel (DSP). The given DSP is the major element of systems of electrical supply and influences reliability of power supply to consumers.

DSPs are the switching centers consisting of closed metal cases in which switching devices, protection and automatics devices, high voltage equipment, devices of measurement are mounted.

In a chain of electricity transmission from a power station to the consumer, DSP carries out the function of energy reception from high-voltage networks and its distribution between consumers. Thus, it is important that DSP could ensure reliability of electrical supply, decrease operating expenses and equipment maintenance service expenses, and also provide control over the electric power consumption. Successful solution of all these problems greatly depends on perfection of design and quality of DSP. These tasks can be solved by installation of microprocessor elements into devices of automation and protection.

DSPs are produced on vast scales, so the task is to perfect the construction and decrease its material capacity. Also one of the major tasks is frequent detection of short circuits inside the construction.

In techno-economic analysis and justification of the need of the project there are defined the potential of the basic construction of the device, possibility of modernization with the aim to increase effectiveness of its exploitation, to decrease maintenance lost and to increase of its protection properties not only for internal equipment, but also for the staff that provides its maintenance.

For this purpose it is necessary to perform a review of different types of DSP constructions of national and foreign production, provide their short description, specify main advantages and disadvantages, some peculiarities that single them out from among all other constructions. As a result one the most prospective types should be chosen as the basic one and the possibility of introducing all possible advantages into our basic device should be stated.

The same should be fulfilled for all power equipment, devices of microcontroller and relay protection, insulation, and detectors of short circuit.

Also parameters of current-carrying parts and insulation gaps should be stated in order to be sure that our device is capable of withstanding all permissible loads.

1 PROJECT FEASIBILITY STUDY OF DEVELOPMENT OF 10 kV DSP

Technical progress in the electrical industry states the task of development of new constructions of DSP that would satisfy world's standards.

Analysis of construction peculiarities of national and foreign DSP shows that there are some new progressive trends in performing these tasks, and their review is for the benefit of DSP developers.

By case performance DSPs are divided into devices in isolated and metallic constructions.

DSP in isolated cases are characterized by compact dimensions and small weight that can be achieved by using total insulation of current-carrying parts or multilayer insulation cores (for example, DSP of "Magnetix" type (Holland).

DSP in metallic cases, as a rule, are divided into compartments by metallic or dielectric partition.

DSP constructions of various manufacturers have certain peculiarities:

- usage of epoxy insulators;
- installation of commutation apparatuses on carts for their easier maintenance;
- usage of built-in voltage indicators for staff safety improvement (DSP of «ColorEmac» manufacturer (Germany));
- making full isolation of current-carrying parts by epoxy compound («Toshiba» (Japan))

Over the past years DSP with vacuum breakers has become more popular in developed countries. The prospect of their application is the possibility to construct DSP with 2 and 3 layers of breakers that decreases the space, occupied by DSP.

1.1 Review of existing designs of DSP on 10 kV

1.1.1 DSP of КЭ-10 type

Now a great number of factories and private concerns are engaged in manufacturing DSP. Here will be considered the basic ones.

“ELECTROSHIT” public company, a Samara factory, makes DSP of КЭ-10 series [1].

The considered DSP, Figure 1.1, is intended for work in common industrial installations, especially with frequent switching operations, and its nominal voltage is 10 kV.

By execution, DSP of КЭ-10 series are subdivided into:

- cases with sliding elements;
- cases without sliding elements;
- cases with some equipment mounted on sliding elements, and some equipment permanently mounted.

Sliding elements can be incorporated: breakers, voltage transformers, movable contacts on currents from 630 to 3150 A (instead of the breaker), current and voltage transformers, power fuses, dischargers of PBO (Valve Lightweight Discharger) type, transformers of voltage with cast isolation together with PBO dischargers.

The DSP case with the switch, Figure 1.1, consists of three blocks: the case of panel is modular (not welded), and is divided by metal partitions into compartments:

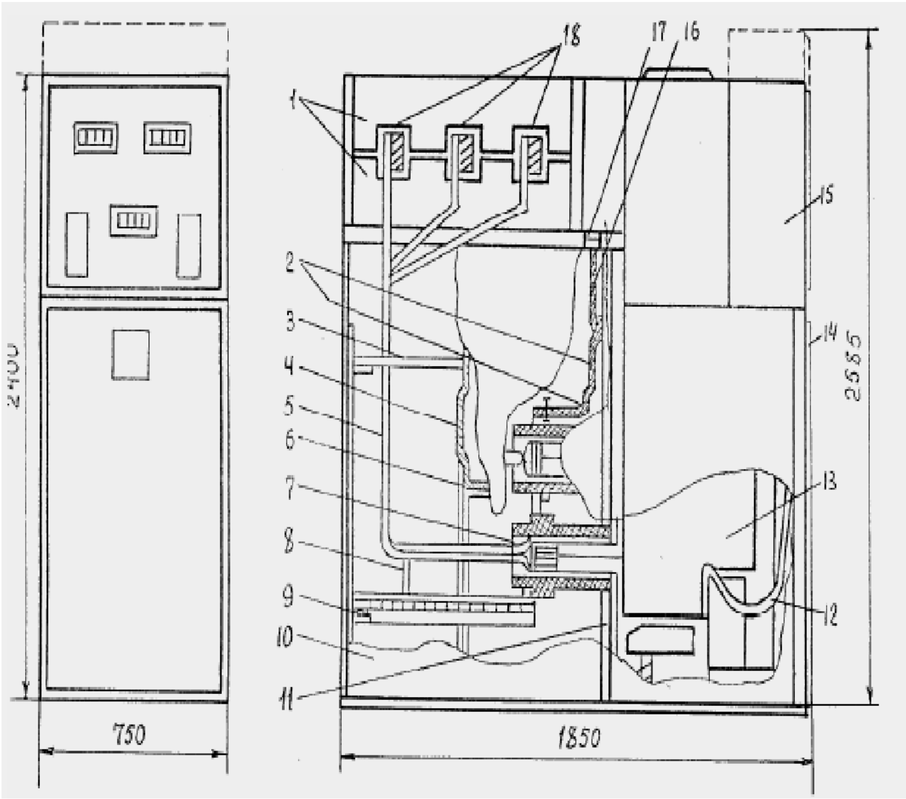
- collecting buses compartment;
- breaker with a drive compartment;
- transformers and grounding compartment;
- relay compartment.

Among its advantages there are the following:

- possibility of installation of all necessary equipment on sliding elements which decreases time of servicing;
- possibility of frequent switching operations;
- the modular case allows decreasing time of installation and assembly, increasing anticorrosive characteristics of the case.

Disadvantage of the construction:

- low level of protection from short circuits.



1,3,9 – insulated supports; 2,4,6,8,11,16,17 – metal partitions; 5 – taps; 7 – an insulator of a special design; 10 – the panel case; 12 – metal sleeve; 13 – breaker with a drive; 14 – a front door; 15 – a relay case;
18 – assembly of buses

Figure 1.1 – Case of – КЭ-10 DSP with the breaker on 2000 A

1.1.2 DSP of К-02-3МК type

DSP of К-02-3МК type is intended for reception and distribution of electric energy of a three-phase alternating current of 50 and 60 Hz frequencies and 6 (10) кV voltage in networks with the isolated or rounded neutral. The basic parameters of DSP К-02-3МК are given in Table 1.1.

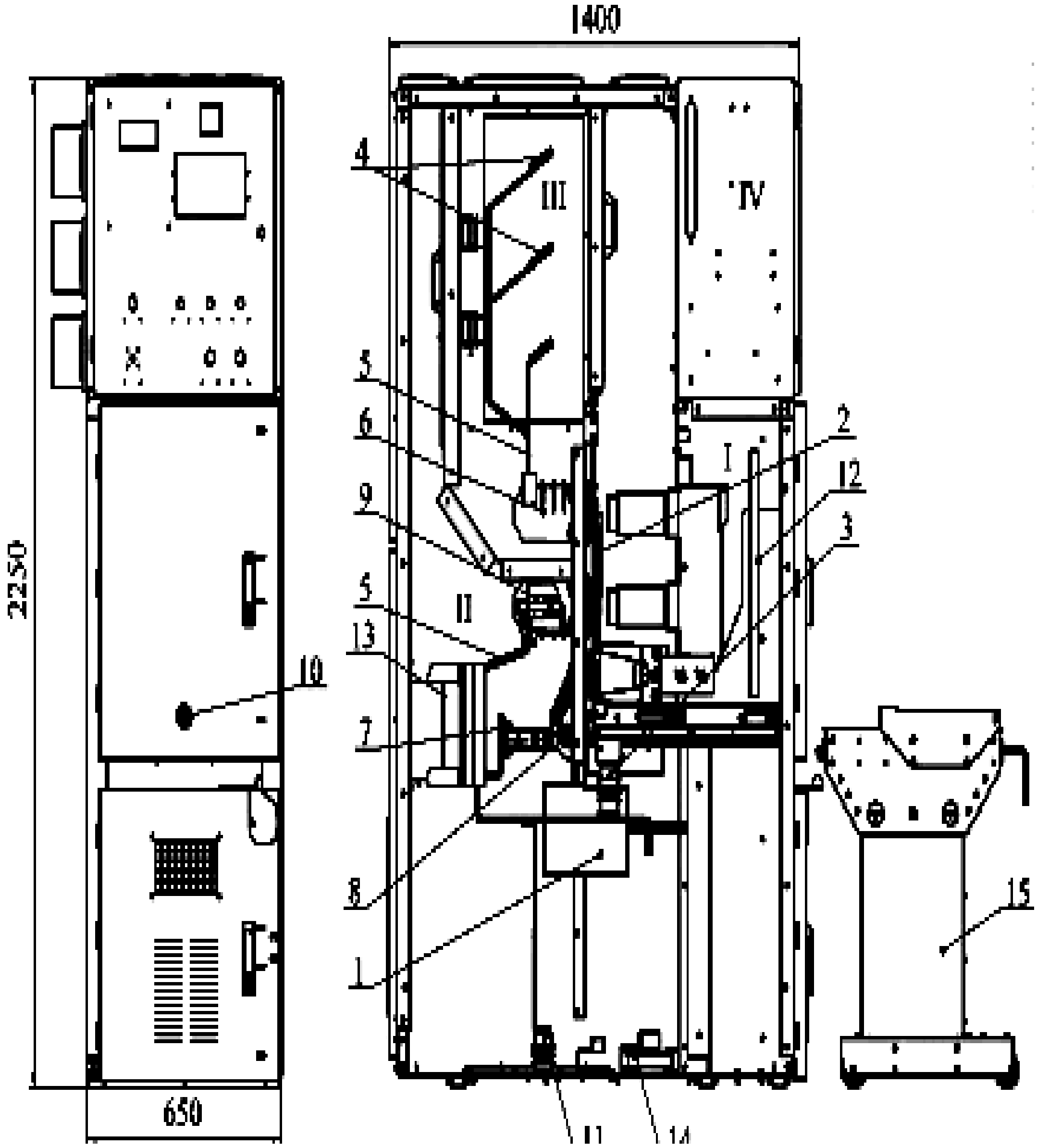
Table 1.1 – Basic parameters of DSP К-02-3МК

Parameter	Value
Nominal voltage (linear) at frequency of 50 Hz, kV	10
The maximum working voltage (linear), kV	12
Nominal current of the main buses at frequency of 50 Hz, A	2000
Nominal current of assembling buses at frequency of 50 Hz, A	3150
Current of thermal stability at time of current flow 3-s, kA	40
Nominal current of electrodynamics stability, kA	51
Nominal current of switching-off of the switch, 50 Hz, kA	31.5

The panel of К-02-3 МК type, which is shown in Figure 1.2, is unified and does not depend on schemes of electric connections of the main chains. They have similar design of the basic nodes both the identical dimensional and adjusting sizes.

The case of penal represents a metal modular design made of zinc coated steel. It is divided into four compartments:

- compartment of a breaker with a drive (position I);
- compartment of control and measure equipment (position II);
- compartment of collecting buses (position III);
- relay compartment (position IV).



I – a compartment of a breaker with a drive; II – a compartment of current transformer and linear buses; III – a compartment of collecting buses; IV – a relay compartment. 1 – insulation partitions; 2 – insulation blinds; 3 – pedestal insulator; 4 – assembling buses; 5 – linear buses; 6 – bushing insulator; 7 – grounding knifes; 8 – a grounding conductor; 9 – contacts; 10 – a nest for operating a breaker with a drive; 11 – voltage limiters; 12 – a breaker with a drive; 13 – measuring current transformers ; 14 – transformers of a current of zero sequence; 15 – the service cart

Figure 1.2 – DSP of K-02-3MK type

In a control and measure equipment compartment of a case there are current transformers, bottom fixed contacts, the grounding breaker, voltage limiters.

In a compartment of collecting buses there are top fixed contacts and the aluminum or copper buses fixed on transient insulators.

In a compartment of a breaker with a drive there is a cassette breaker on which the high-voltage equipment defined by the scheme of electric connections of the main chains of a case, and separating contacts are established.

The discharging valves combined with photo-thyristors or fiber-optical detectors are established for protection of compartments of collecting buses, of control and measure equipment and of a breaker with a drive from arising at short circuiting arcs.

Among its advantages there are the following:

- high level of protection from short circuits;
- unified electrical scheme for all design;
- wide variety of switches that can be installed (ABB, TAVRIDA ELECTRIC, AMPER) [2,3,4];
- possibility of sliding off and sliding on of a sliding element when door is closed;
- usage of zinc metal constructions sufficiently increases anticorrosive ability of the case;
- medium disposition of the breaker, which allows for service equipment based at the bottom of the penal without pulling out the cart.

Disadvantages of the construction are:

- high price;
- big material consumption.

1.1.3 DSP of КМ-1ФМ type

DSP of КМ-1Ф type is intended for reception and distribution of electric energy of three-phase alternating current of 50 or 60 Hz frequency, of voltage class 6 or 10 kV in networks with isolated neutral, or grounded through arcing reactor by a neutral, and also in networks with frequent switching operations.

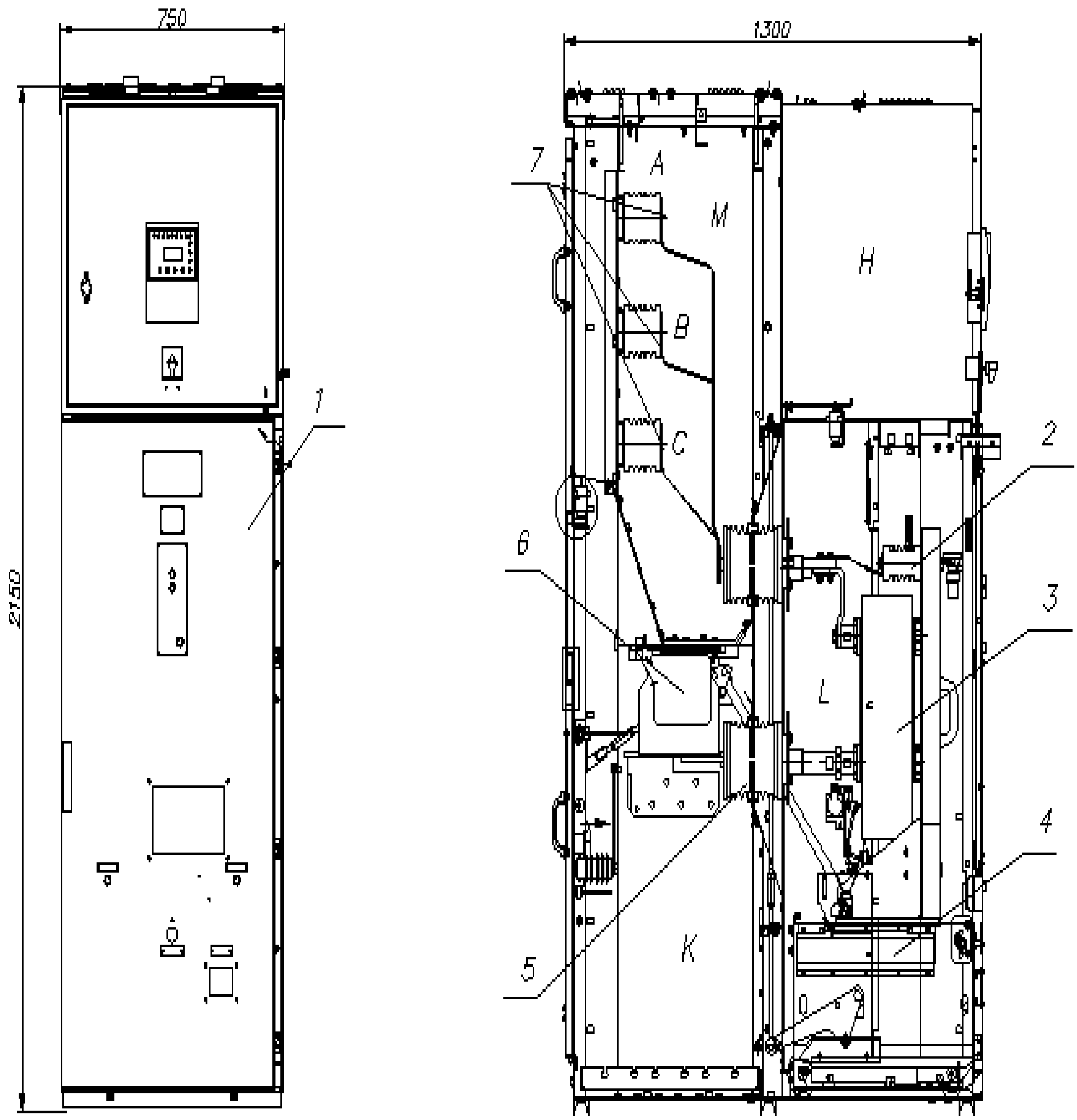
The basic component of DSP is its case.

The case of DSP is the metal welded design of basic-penal type made of high-quality sheet steel on the high-precision equipment, painted by powder dusting (color RAL 7032) with high voltage equipment which is integrated in it, and also devices of measurement, the alarm system, the system of protection and management.

The case of DSP consists, Figure 1.3, of the panel case, the breaker with a drive and a relay case.

The case is divided by partitions into compartments:

- compartment of linear buses (cable) – K;
- compartment of a breaker with a drive – L;
- compartment of modular tires – M;
- a relay compartment – H.



1 – steel door; 2 – pedestal insulation; 3 – breaker; 4 – cart; 5 – bushing insulation of the breaker terminal; 6 – current transformer; 7 – taps

Figure 1.3 – KM-1 ФМ DSP of Public company "ЗЗВА"

The arrangement of phases of modular tires is the following:

- phase "A" (yellow) – top;
- phase "B" (green) – middle;
- phase "C" (red) – bottom.

Table 1.2 – Main parameters of DSP of KM-1ФМ type

Nominal voltage, kV	10
Nominal frequency, Hz	50
Nominal current of main buses, A	2000
Nominal current of collecting buses, A	2000
Nominal current of turning off, kA	22
Current of thermal stability, kA	24
Current of electro-dynamic stability, kA	54

Advantages of the construction are as follows:

- possibility to move sliding element from operating position into control one and vice versa while the door is closed, which increases safety level;
- low material consumption and as a result low price;
- presence of metallic partitions between sections, which allows localizing fault inside one section;
- presence of the blocking system that prevents staff from wrong actions while execution of switching operations;
- presence of systems of combined arcing protection that provides operation speed from 12 to 20 ms.

There is a disadvantage:

- absence of distant system for monitoring and quick change of parameters of protection.

The construction of DSP of KM-1ФМ series of Public company "ЗЗВА" [5] is chosen as the basic one for the course project, due to its high techno-economic parameters. Its upgrading includes installation of fiber-optical short circuit detectors to increase its safety, decrease time and costs for repairing, maintenance, and non-operating regimes during exploitation.

1.2 Power equipment review

When developing and manufacturing DSP, different apparatuses are used.

The reliable work of DSP can be provided only if each apparatus is chosen correctly under conditions of normal working regimes and of short circuit and overload regimes.

Also it is necessary to take into consideration working conditions of DSP that depend on its purpose [7].

1.2.1 Choosing a breaker for power part of DSP

When choosing apparatuses for main circuits of DSP, it is necessary to use the following parameters: nominal voltage of 10kV, nominal current of 2000 A and switch-off current of the breaker of 20 kA.

Today there exist only two types of breakers that satisfy the set parameters. They are vacuum and SF6 gas.

SF6 gas breaker uses SF6 gas as a working field.

SF6 gas breaker uses the rotation of arc and gas expansion during heating to extinguish it. It provides reliable arc extinction even during capacitive and inductive currents.

Figure 1.4 – External view of the SF6 gas breaker

Advantages of SF6 gas breakers are the following:

- full explosion and conflagration proof;
- high switching-off ability;
- long service life.

Disadvantages are:

- high price of SF6 gas;
- necessity of additional equipment for cleaning, filling in and transmission of SF6 gas.

Vacuum breaker has vacuum inside its construction for arc extinguishing.

Advantages of vacuum breaker are as follows:

- the most ecologically friendly breaker;
- low maintenance costs;

- small dimensions.

The disadvantage is:

- small resource of switching off of short circuit currents.

A vacuum breaker with electro-magnet drive of BB/TEL-10-31.5/2000 Shell type produced by TAVRIDA ELECTRIC is chosen as the main commutative apparatus for DSP. It is intended for commutation of electrical circuits at normal and emergency regimes at three-phase circuits of alternating current of 50 Hz frequency with nominal voltage of 10 kV.

In the basic principle of operation of the BB/TEL-10-31.5/2000 breaker, Figure 1.5 is used of electromagnet drives with magnet click by each phase, mechanically connected by the common shaft.

Technical characteristics of the breaker are given in Table 1.3.

Table 1.3 – Parameters of vacuum breaker

Parameter of DSP	Value
Nominal voltage	10 kV
Nominal current	2000 A
Nominal breaking current	31.5 kA
Current of electro-dynamic stability	80 kA
Full time of turn off	55 ms

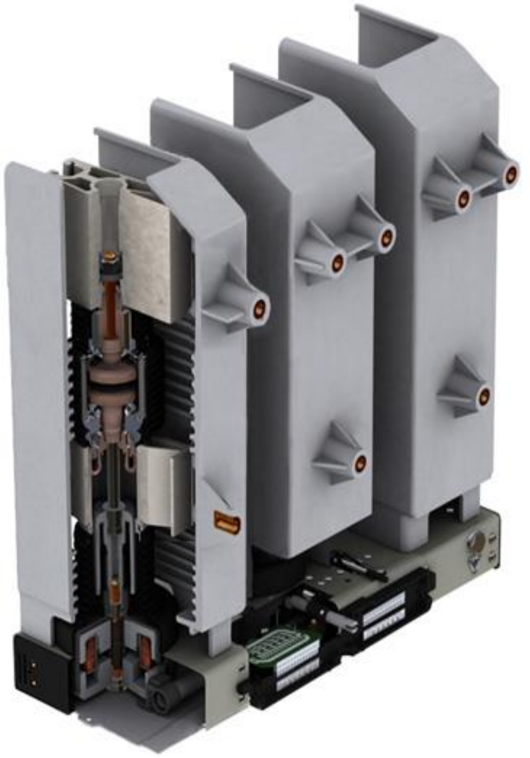


Figure 1.5 – BB/TEL-10-31.5/2000 vacuum breaker, external view

1.2.2 Choosing a current transformer

The type of the current transformer is defined by nominal voltage of DSP, calculated operating current, and requirements to accuracy of measurements.

ТОЛ–10 transformer (Figure 1.6) by “ENERGOMASH” [11] is intended for installation in DSP for transition of signal to measuring equipment and devices of protection and control, and also for insulation of secondary circuits from high voltage.

Figure 1.6 – External view of ТОЛ–10 current transformer

It should have its parameters greater or equal to parameters of DSP. The review is provided in Table 1.4.

Table 1.4 – Comparison of parameters

Parameters of DSP	Parameters of transformer
Nominal voltage $U_{ном}$=10 kV	Nominal voltage $U_{ном}$=10 kV
Nominal current $I_{ном}$=2000 A	Nominal primary current $I_{ном}$=2000 A
Current of electrodynamics stability $i_{уд}$=54 kA	Current of electrodynamics stability $i_{уд}$=102 kA
Current of thermal stability $I_т$=24 kA	Current of thermal stability $I_т$=40 kA

The current transformer is chosen correctly.

1.2.3 Insulator choosing

Pedestal insulator is chosen respectively to its mechanical strength, i.e. load in thinness cross-section of insulator must be less than permissible load for the given type of insulator.

In DSP there are used pedestal insulators of ИОР-10-3.75УХЛ2 type, they have permissible load of 3750 N. They are intended for insulation and fixing of current leading parts in electrical apparatuses and DSP of nominal voltage of a network till 10 kV and frequency till 60 Hz.

So, ИОР-10-3.75УХЛ2 insulator (Figure 1.7) by “ENERGOMASH” is used as a pedestal insulator.

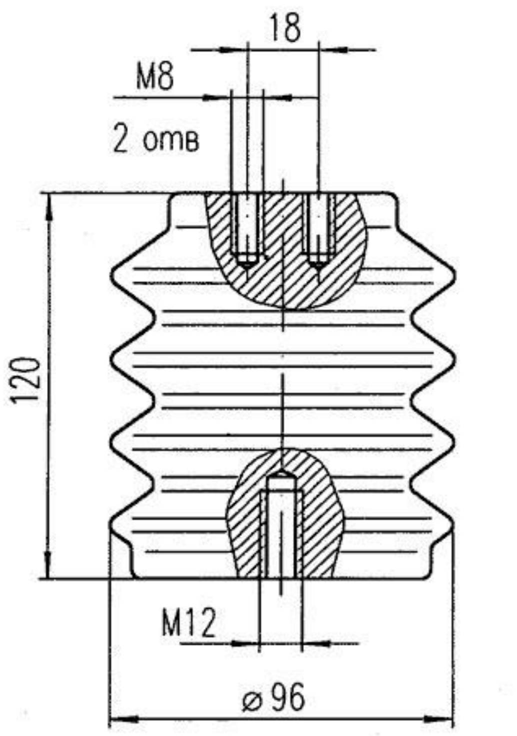


Figure 1.7 – ИОР-10-3.75УХЛ2 pedestal insulator

Bushing of ИП-10/630-7.5УХЛ2 type (Figure 1.8) by "ENERGOMASH" is used as bushing insulator.

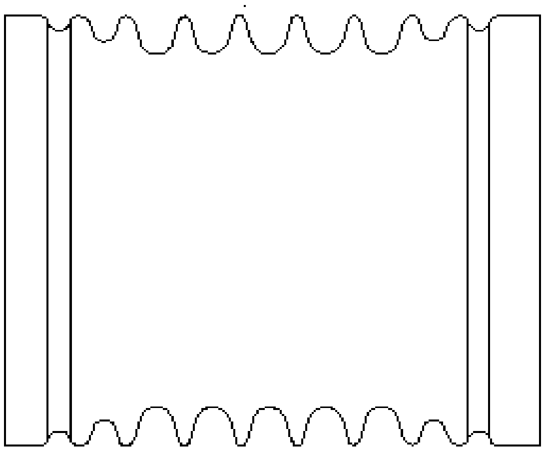


Figure 1.8 – Bushing insulator of ИП-10/630-7.5УХЛ2 type

1.2.4 Review of systems of microprocessor defense

Relay protection is a basic kind of electrical automatics that provides normal and reliable operation of energetic systems.

Growth of power of electrical supply systems leads to an increasing role of relay protection, as it provides continuous control over the operation state and regime of all the elements of the energetic system and reacts to damages and abnormal regimes [13].

For the DSP protection, automatics, control and signalization it was chosen to use МРЗС-05М microprocessor protection system, Figure 1.9, that combines all these functions.

It is intended for:

- two stage protection of minimal voltage of the basic channel (U_{min});
- two stage protection of maximal voltage of the basic channel (U_{max});
- grounding protection (ЗЗ);
- protection of maximal voltage of an auxiliary channel (Umax–В);
- summary protection of minimal voltage (ЗМН);
- control of failures of voltage circuits of basic and auxiliary channels (КИЦН).

The structure of the microprocessor protection device is presented in Table 1.5.

Table1.5 – Structure of МРЗС-05М microprocessor protection device

Name	Designation
Analog block	БА2-ТН-МРЗС-М РСГИ.468171.025
Computer block	БВ2-МРЗС-М РСГИ.467444.031
Interface block	БИ2-МРЗС-М РСГИ.467119.018
Block of discrete inputs-outputs	БДВВ3-МРЗС-М РСГИ.467119.028

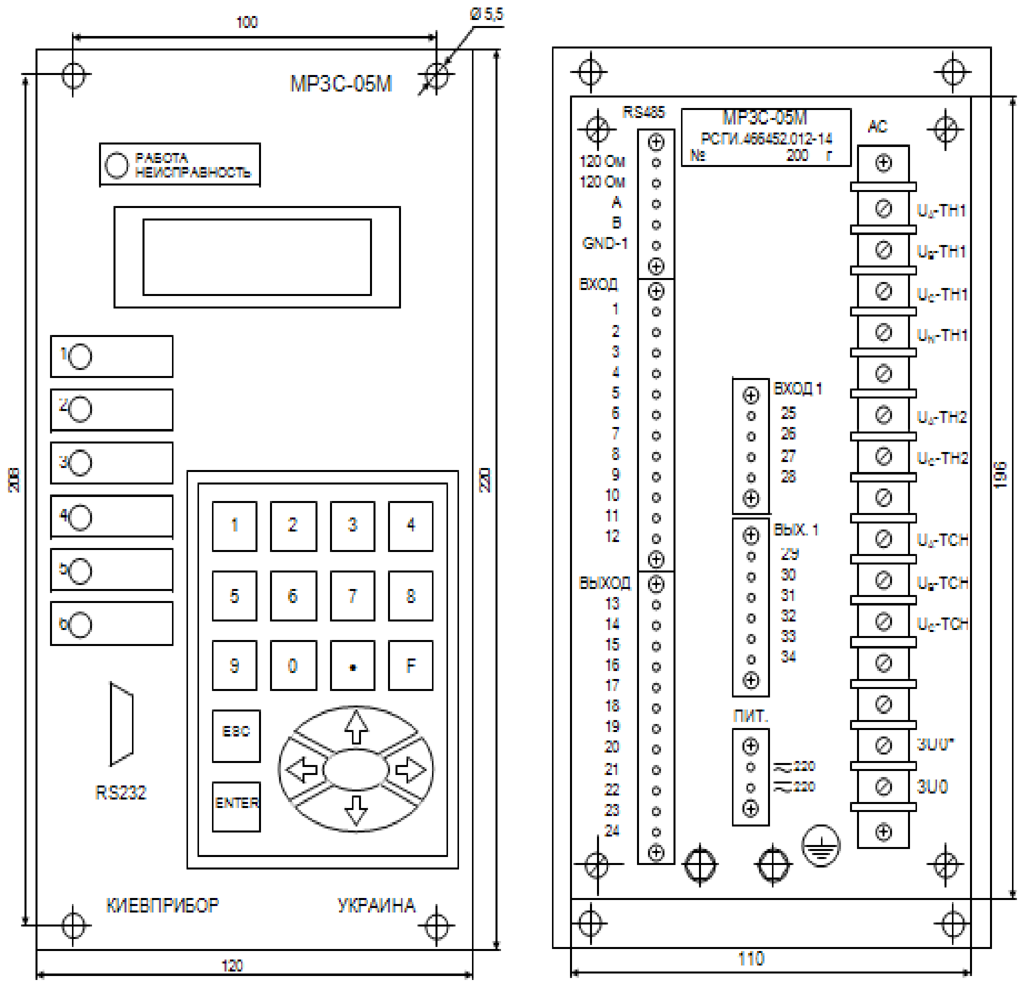


Figure 1.9 – Front and opposite view of МРЗС-05М microprocessor protection device

1.3 Grounds for innovation

The designed DSP is almost identical to its basic analog DSP of КМ-1ФМ series. They have the same basic parameters, construction of panels, breakers with drives, and systems of microprocessor security. But as it has been mentioned above it is planned to increase its arc safety level of equipment and safety level of staff.

A short review of existing devices is provided below.

1.3.1 Device for protection of DSP from short circuits (SC)

Arc of SC reaches a temperature of 26000 °C in several seconds. The harm of arcing depends on its time:

- 35 ms does not damage the equipment. After checking up of insulation, the equipment can be used;
- 100 ms produces small harm, cleaning of contacts of switch is necessary;
- 500 ms is a big harm for equipment and maintenance. Equipment should be partially changed;
- 1000 ms means that consequences of arcing are unpredictable.

Statistics of failures shows that depending on production and place of installation it varies from 5 to 120 SC on 1000 DSP. In its turn, costs of repairing equipment after SC varies and can reach 1,000,000 UAH.

That is why additional short circuit protection is very important today, as it allows reducing costs of repairing, maintenance and non-operating time.

There are three basic types of SC detection:

- detection of light radiation of SC;
- changing of electrical circuit parameters;
- increase of temperature and pressure inside DSP.

In our case ОВОД–Л fiber optic detector (Figure 1.10) was chosen due to its high speed of operation (7 ms), compared to others, the possibility to change parameters without additional help of specialists, commutation to a personal computer via USB port that allows controlling the state of DSP from the working place, and possibility to provide safety on 35 panels by one device that reduces its costs.

Figure 1.10 – ОВОД–Л fiber optic detector of short circuit

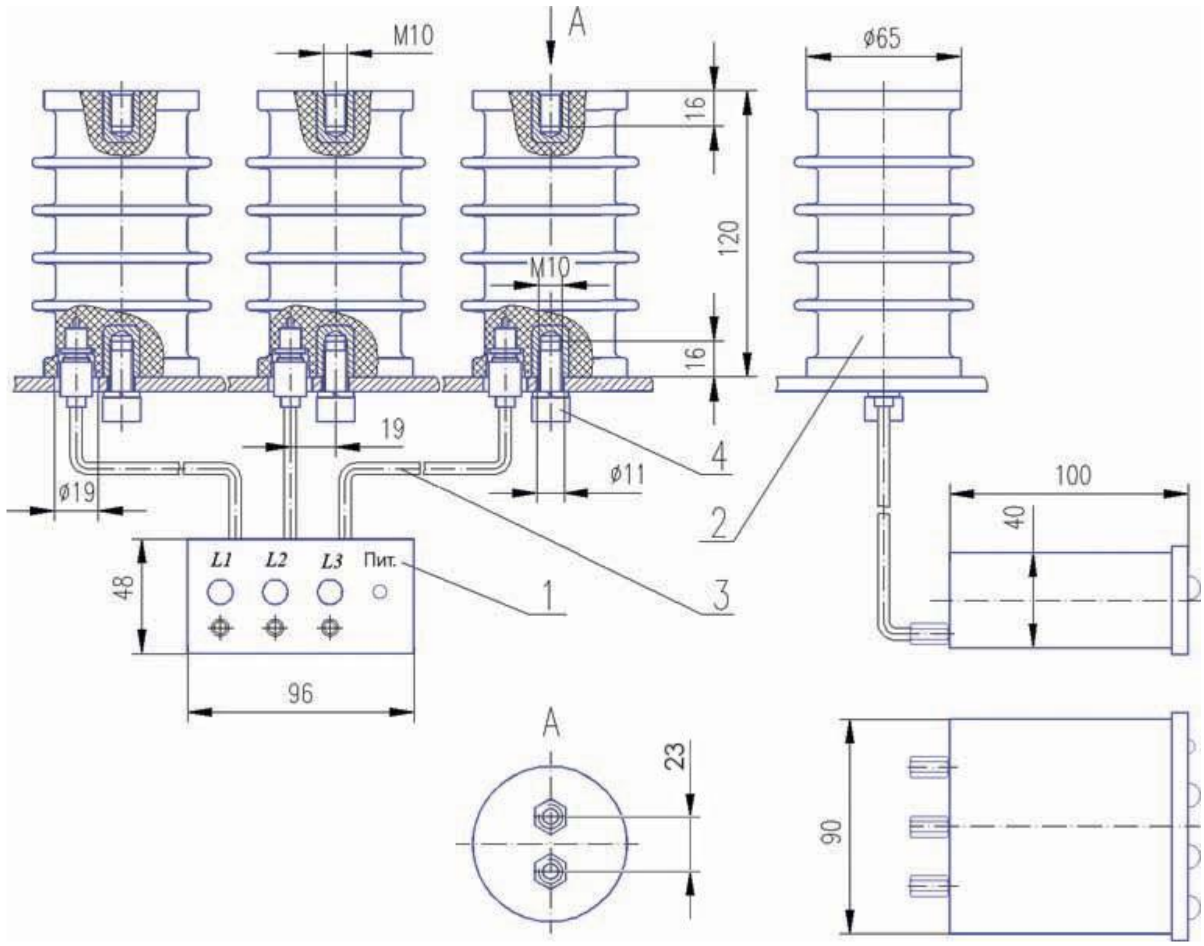
1.3.2 Device for voltage indication

Device for voltage indication with built-in ИНЗ-10Р-00 У3 relay is intended for usage in circuits of blocking and signalization (it reacts to the absence of current in, at least, one of phases, to a non-voltage state and a normal state) in electrical stations with nominal voltage up to 10 kV.

It consists of 3 resistive detectors and a block of indication – Figure 1.11, Figure 1.12. In the front panel of the block of indication there are 4 light diodes and three control inputs.

Little yellow diode indicates the presence of auxiliary voltage. Three red indicate the presence of operation voltage. Control inputs are used for checking the block intactness and can be used for phase control.

Figure 1.11 – ИН 3-103-00 У3 device for voltage indication



1– indication block; 2 – detector; 3 – connecting cables; 4 – bolt for fixing of cable with detector.

Figure 1.12 – Dimensions and scheme of connection of the voltage indicator device

2 CALCULATIONS OF CURRENT-CARRYING ELEMENTS

Connection of the transformer with the switchgear panel of 10 kV is carried out by a flexible current carrier, by the bus bridge or a closed complete current carrier. All connections inside 10 kV DSP, including collective buses, are carried out by rigid naked copper buses of rectangular or box-shaped cross-section.

For the given device, one striped aluminum bus is chosen.

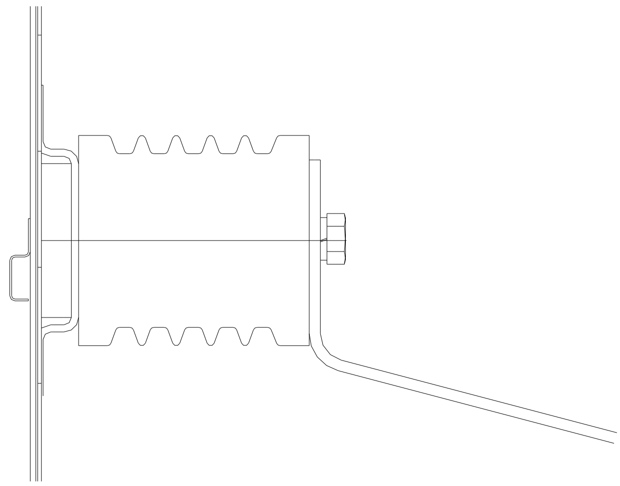


Figure 2.1 – Scheme of bus joining to insulator

2.1 Choice of cross–section of buses

For the projected DSP on 10 kV and 2000 A the one-strip copper bus of rectangular cross-section is chosen, as such form provides the best cooling conditions and smaller losses from the effect of closeness and superficial effect, and copper has the greatest specific resistance and big mechanical durability.

The choice of section of tires is made by the formula that starts with the equation of thermal balance:

$$b = \sqrt[3]{\frac{I^2 \cdot \rho_\theta \cdot k_\text{п}}{2 \cdot n \cdot (n+1) \cdot k_\text{т.о} \cdot \tau_y}} \qquad (2.1)$$

where I is nominal current, A;

ρ_θ is specific resistance of copper at established temperature θ, Ω*m;

$k_\text{п}$ is factor of superficial effect;

$k_\text{т.о}$ is factor of thermal conductivity, $\frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$, $k_\text{т.о}$ is equal to 10 $\frac{\text{W}}{\text{m}^2 \cdot ^\circ\text{C}}$ [14];

τ_y is difference between temperature established and environmental in DSP and is equal to 15 ℃;

n is the relation of length of the section of the bus to width equal to 12 [15].

For class C isolation, the admissible temperature of heating $\theta_\text{доп}$ equals 120 ℃.

$\Theta_\text{o.c}$ is ambient temperature in the case, $\Theta_\text{o.c}$ 55 °C.

Specific resistance of copper at the established temperature 120 ℃ is calculated by the next formula:

$$\rho_\theta = \rho \cdot (1 + \alpha \cdot \theta), \qquad (2.2)$$

where ρ is specific resistance of copper, ρ is equal to $1.62 \cdot 10^{-8}$Ω*m;

α is a temperature factor of resistance, $\frac{1}{^\circ\text{C}}$, for copper α is equal to 0.0043 $\frac{1}{^\circ\text{C}}$.

$$\rho_\theta = 1.62 \cdot 10^{-8} \cdot (1 + 0.0043 \cdot 120 = 2.46 \cdot 10^{-8} \ \Omega\text{*m}.$$

The factor of superficial effect is defined by graphical dependencies on criterion of similarity.

The criterion of similarity represents expression, according to the following formula:

$$\sqrt{\frac{f}{R_{100}}} = \sqrt{\frac{f \cdot b \cdot a}{\rho_{\theta} \cdot 100}}, \qquad (2.3)$$

where f is frequency of the main, f equals 50 Hz;

R is active resistance of the bus of 100 m long at DC;

a, b are dimensions of rectangular bus cross-section, m.

In first approximation let's choose b equal to 8 mm, a equal to 100 mm.

$$\sqrt{\frac{f}{R_{100}}} = \sqrt{\frac{50 \cdot 8 \cdot 100 \cdot 10^{-6}}{2.46 \cdot 10^{-8} \cdot 100}} = 127.5$$

The factor of superficial effect, equal to 1.1, by graphical dependencies corresponds to the criterion of similarity 127.5 [14].

Then the cross-section is calculated by formula (2.1):

$$b = \sqrt[3]{\frac{2000^2 \cdot 2.351 \cdot 10^{-8} \cdot 1.1}{2 \cdot 12 \cdot (12+1) \cdot 10 \cdot (105-55)}} = 11 \text{ mm},$$

$$a = 11 \cdot 12 = 132 \text{ mm}.$$

By [14] standard dimensions of bus of the same cross-section, (12.5 x 120) mm^2 are defined.

2.2 Checking buses on long-term operating regime

Calculation begins with determination of the factor of thermal conductivity of the copper bus.

Thermal emission from a bus surface into environment takes place by means of convection and radiation, therefore the total factor, according to the next has two components:

$$k_{т.о} = k_{т.к} + k_{т.и} \ , \quad (2.4)$$

where $k_{т.к}$ is convective factor of thermal emission, $\frac{W}{m^2 \cdot K}$;

$k_{т.и}$ is radiation factor, $\frac{W}{m^2 \cdot K}$.

Convective factor of thermal emission is defined by the following formula [14]:

$$k_{т.к} = \frac{\mathrm{Nu} \cdot \lambda}{\mathrm{L}} \ , \quad (2.5)$$

where Nu is Nusselt criterion;

λ is thermal conductivity factor, $\frac{\mathrm{W}}{\mathrm{m \cdot K}}$.

It is defined for air at medium temperature θ_m which is calculated by the following formula:

$$\theta_m = \frac{(\theta_{доп} + \theta_{о.с})}{2} \ , \quad (2.6)$$

$$\theta_m = \frac{120+55}{2} = 88 \ ^\circ\mathrm{C}.$$

So at temperature 88 °C, λ equals $3.5 * 10^{-2} \ \frac{\mathrm{W}}{\mathrm{m \cdot K}}$ [14];

L is characteristic geometrical dimension, m;

Here it is equal to the bus width, i.e;

L equals a, i.e. 120 mm or 0.12 m.

The criterion of Nusselt from criterion equations for a free convection in unlimited space is defined by the following formula [14]:

$$Nu = C \cdot (Gr \cdot \mathrm{Pr})_m^n \ , \tag{2.7}$$

where C and n are coefficients, defined by [14];

Gr is Grasgof factor;

Pr is Prandtl factor, Pr equals 0.696 [14];

m states that all data is taken for medium temperature θ_m.

From criterion equation the Grashof factor is calculated as follows:

$$Gr = \frac{\beta \cdot g \cdot L^3 \cdot (\theta_{\text{доп}} - \theta_{\text{о.с}})}{\nu^2} \ , \tag{2.8}$$

where β is coefficient of volume expansion, K^{-1}; β is equal to $\frac{1}{273}$ K^{-1};

g is free fall acceleration, g is equal to 9.81 $\frac{m}{s^2}$;

ν is kinematic viscosity, $\frac{m^2}{s}$, ν is equal to $21.09 \cdot 10^{-6} \frac{m^2}{s}$.

$$Gr = \frac{\frac{1}{273} \cdot 9.81 \cdot 0.03^3 \cdot (120 - 55)}{(21.09 \cdot 10^{-6})^2} = 10^5,$$

$$[Gr \cdot Pr] = 10^5 \cdot 0.696 = 7 \cdot 10^4.$$

When $[Gr \cdot Pr]$ is known, by [14] factor C equal to 0.54 is obtained, and factor n equals 0.25.

By formulas (2.5) and (2.6):

$$Nu = 0.54 \cdot (7 \cdot 10^4)^{0.25} = 8.78,$$

$$k_{\text{т.к}} = \frac{8.78 \cdot 3.05 \cdot 10^{-2}}{0.12} = 2.23\ \frac{W}{m^2 \cdot K}.$$

Thermal emission factor is obtained as follows:

$$k_{\text{т.и}} = 5.67 \cdot \varepsilon \cdot [(\frac{T_1}{100})^4 - (\frac{T_2}{100})^4] \div (T_1 - T_2), \tag{2.9}$$

where T_1 is permissible bus temperature, given in K;

T_2 is ambient temperature, given in K;

ε is degree of blackness, ε equals 0.6.

$$T_1 = 273 + 120 = 393\ \text{K},$$

$$T_2 = 273 + 55 = 328\ \text{K},$$

$$k_{\text{т.и}} = 5.67 \cdot 0.6 \cdot [(\frac{393}{100})^4 - \left(\frac{328}{100}\right)^4\Big] \div (393 - 328) = 6.43\ \frac{W}{m^2 \cdot K}.$$

By formula (2.4) the coefficient of thermal emission is obtained.

$$k_{\text{т.о}} = 6.43 + 2.23 = 8.66\ \frac{W}{m^2 \cdot K}\ .$$

The steady state temperature of a bus is calculated by the following formula:

$$\theta = \frac{I^2 \cdot \rho_\theta}{k_{\text{т.о}} \cdot \rho \cdot S_{bus}} + \theta_{\text{о.с}}\ , \tag{2.10}$$

where ρ_θ is specific resistance of copper, at the steady state temperature, ρ_θ equals $2.351 \cdot 10^{-8}\Omega$*m;

$\theta_{\text{o.c}}$ is ambient temperature in panel, $\theta_{\text{o.c}}$ equals °C.

The perimeter of a bus is defined by the formula:

$$p = 2 \cdot (a + b), \tag{2.11}$$

$$p = 2 \cdot (120 + 12.5) = 265\ mm = 0.265\ m.$$

So the square of the bus cross-section is defined as follows:

$$S_{bus} = a \cdot b, \tag{2.12}$$

$$S_{bus} = 120 \cdot 12.5 = 1500\ mm^2 = 0.0015\ m^2.$$

Then steady state temperature, by formula (2.10), equals:

$$\theta = \frac{2000^2 \cdot 2.351 \cdot 10^{-8}}{8.66 \cdot 0.265 \cdot 0.0015} + 55 = 82\ ℃,$$

$$\theta_{доп} < \theta,$$

$$82\ ℃ < 120\ ℃\ ,$$

So the steady state temperature at the surface of buses during the long-term nominal operating regime does not exceed the permissible temperature of heating for the class C insulation, which equals 120 °C.

2.3 Check of buses on thermal stability

Thermal stability of buses is a property of buses to maintain short-term thermal actions of a current of short circuit. This property is characterized by rated current of thermal stability a certain nominal time of thermal stability and thus temperature of tires in the end of short circuit is above admissible [15].

The maximum admissible temperature during short circuit for copper $\theta_{доп}$ is 300 °C. For this temperature on a curve of adiabatic heating the value is defined by $[j^2 \cdot t]_{кон}$ – $4.25 \cdot 10^{16}\ \frac{A^2 \cdot s}{m^4}$. For $\theta_{нач}$ – 82 °C $[j^2 \cdot t]_{нач}$ – $1.5 \cdot 10^{16}\ \frac{A^2 \cdot s}{m^4}$ [14].

The cross-section of the bus at which it maintains a short circuit current, in a short period of time is defined by the following formula:

$$S_{calc} = \sqrt{\frac{I^2 \cdot t}{[j^2 \cdot t]_{кон} - [j^2 \cdot t]_{нач}}}\,, \tag{2.13}$$

where t is time of flowing of a current of short circuit, for calculation it is chosen 10 s;

I is current of thermal stability, equal to 24 kA, as per Table 1.3.

$$S_{calc} = \sqrt{\frac{24000^2 \cdot 10}{4.25 \cdot 10^{16} - 1.5 \cdot 10^{16}}} = 4.68 \cdot 10^{-4}\ m^2,$$

$$S_{calc} < S_{bus},$$

$$0.000468 < 0.0015.$$

As the calculated value of the cross-section of the bus is less than the cross-section calculated by the equation of thermal balance, the bus is thermally stable.

2.4 Check of buses on electro-dynamic stability

The rigid buses installed on insulators represent a dynamic oscillatory system that is influenced by electro-dynamic forces. If the frequencies of the oscillatory system of the bus and insulator coincide with frequencies of change of electro-dynamic forces, loads on tires and insulators would increase.

If the frequency is less than 30 and more than 200 Hz, the mechanical resonance does not arise. In the majority of applied designs of buses these conditions are met, therefore [21] the check of electro-dynamical stability taking into account mechanical fluctuations of bus designis not necessary. In peculiar cases, for example, in new research, the definition of frequency of fluctuations is made for copper buses [17].

Frequencies of their fluctuations of copper buses are defined by the formula:

$$f_0 = \frac{173.2}{l^2} \cdot \sqrt{\frac{J}{S}}, \qquad (2.14)$$

where l is the distance between buses, m;

J is the moment of inertia of the cross-section of the bus relative to the axes, perpendicular to the direction of bending force, cm;

S is cross-section of a bus, cm.

Here it is accepted to have perpendicular position to insulator (Figure 2.1), so it is calculated by the following formula:

$$J = \frac{b \cdot h^3}{12}, \qquad (2.15)$$

where b is width of rectangle, cm;

h is height, cm.

$$J = \frac{12 \cdot 1.25^3}{12} = 1.95\ cm^4,$$

$$f_0 = \frac{173.2}{0.2^2} \cdot \sqrt{\frac{1.95}{12 \cdot 1.25}} = 1561.2 \text{ Hz}.$$

At f_0 is greater than 200 Hz, mechanical resonance is absent [17].

It is necessary to calculate mechanical stress of bus material on bending and compare it with the admissible one. Accordingly, the following formula is:

$$\sigma_{\text{р}} \leq \sigma_{\text{доп}}, \qquad (2.16)$$

where σ_p is a calculated value of stress of the bus material on bending, $\frac{N}{m^2}$;

$\sigma_{доп}$ is the admissible value of stress of bus material on bending, $\frac{N}{m^2}$.

For copper, $\sigma_{доп}$ equals 13.73·10^7 $\frac{N}{m^2}$ [17].

As the bus consists of one strip, then σ_p equals $\sigma_ф$.

Stress on bending is calculated by the following formula:

$$\sigma_{\text{р}} = \frac{M_{\text{ф}}}{W}, \qquad (2.17)$$

where $M_ф$ is maximal bending moment $N \cdot m$;

W is the resisting moment of bus, m^3, defined by the following formula:

$$W = \frac{b \cdot h^2}{6}, \qquad (2.18)$$

where b is width of bus, m;

h is length (rectangular cross-section) of the bus, m.

$$W = \frac{12.5 \cdot 120^2}{6} = 30000\ mm^2 = 0.03\ m^2.$$

Bending moment that is calculated as follows depends on force, acting on bus:

$$M_{\text{ф}} = \frac{F_{\text{расч}} \cdot l}{10}, \qquad (2.19)$$

where $F_{расч}$ is an electro-dynamic force of interaction between neighboring phases, N;

l is length of the bus, m.

Electro-dynamic force has small value at action in the middle of the phase and at three-phase short circuiting is defined by the following formula [17]:

$$F_{расч} = \frac{i_{уд}^2 \cdot L}{a \cdot 10^{-7}}\ , \tag{2.20}$$

where $i_{уд}$ equals 54 kA, according to Table 1.3;

L is length of the bus.

So, for the calculated earlier copper bus of 1000 mm long and with the distance from bus to the axes of the nearby phase equal to 300 mm.

$$F_{расч} = (54 \cdot 10^3)^2 \cdot \frac{1000}{300} \cdot 10^{-7} = \ 972 \text{ N}.$$

Then the bending moment, by formula (2.19), is equal to:

$$\text{M}_{ф} = \frac{972 \cdot 1}{10} = 97.2\ \ \frac{N}{m}\ .$$

Stress on bending is defined by formula (2.17) and compares with the admissible one for the copper

$$\sigma_{р} = \frac{97.2}{0.03} = 3240\ \ \frac{N}{m^2}\ ,$$

$$3.24 \cdot 10^3 < 13.73 \cdot 10^7\ ,\ \frac{N}{m^2}\ .$$

As $3.24 \cdot 10^3$ is less than $13.73 \cdot 10^7$, then the bus is electro-dynamically stable.

2.5 Choosing contacts of breaker with a drive

The cart, where the switch is mounted, is a mobile element of DSP. It allows carrying out replacement or repair of switches. It connects to DSP by means of contact, Figure 2.2. Movable manual contact is connected with a switch output, and fixed contact in the form of the bus is mounted on a basic insulator. At sliding in of the cart fingers of movable contacts cover fixed contacts and create a reliable contact.

The main requirement that is need from contacts is a reliable work in the closed condition. Plug-in contacts, Figure 2.2, are chosen. At identical force of pressing, transitive resistance of plug-in contacts is much less than that of flat contacts. The narrow platform of contact creates good conditions for disposal of oxides, dust and products of destruction of metal during sliding of one contact on another. Also these contacts have high electro-–dynamic stability, through them the currents of one direction are passed, elements attract each other, and therefore forces of contact pressing increase.

Requirements, to properties of a material of switching contacts are the following:

- low contact and specific transitive electro-dynamic resistance;
- high heat conductivity;
- thermal capacity and fusion temperature;
- high resistance to corrosion, etc.

Plug-in fixed contacts of "TULPAN" type by “TERMA-ENERGO” public company are intended for application in automatic breakers with drive of DSP.

A plug-in contact consists of lamellas joined by springs. Lamellas are produced by a method of powder metallurgy under high pressure. Springs are made from 65Г spring steel. Plug-in contact is covered by silver film of 24 mcm thick and has high electrical properties.

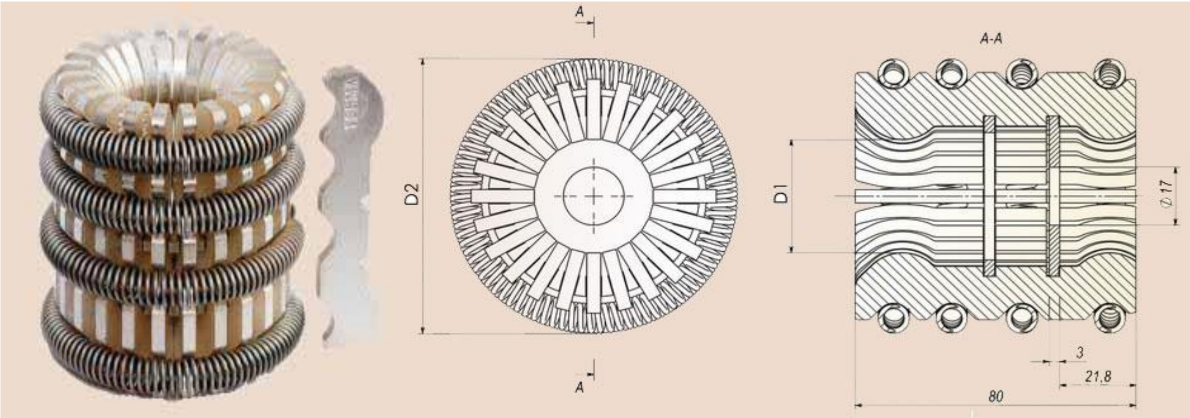


Figure 2.2 – Plug-in fixed contacts of "TULPAN" type

Table 2.1 – General parameters of plug-in contacts

Parameters	Value
Nominal current, A	2000
Diameter of a rod, mm	55
Internal diameter (Figure 2.2, D1), mm	52
External diameter (Figure 2.2, D2), mm	102
Mass, kg	4.1

3 CALCULATION OF INSULATION OF DSP

Insulation is one of the most important structural elements of switchgear and largely determines the size and reliability during operation. The electrical circuits of the designed device shall be provided an appropriate level of isolation between the parts that are under stress and the earthed parts and between live parts of adjacent poles are energized.

The required level of insulation is provided by selecting the length of the relevant period. Insulation distances are taken as such so that the device withstands test voltage of industrial frequency and lightning impulse fully. At the same time it should be able to operate. Dielectric strength is characterized by the breakdown voltage in the air, in an appropriate insulating medium and the surface of a solid dielectric. The electrical insulation is designed for a predetermined voltage class, taking into account the specific conditions of use.

3.1 Choosing insulation gaps

There are major insulation gaps of DSP that should be calculated – the air, on surfaces of insulators, and through the thickness of the hard dielectric. Here are the following periods of isolation, which are represented in Figure 3.1:

S1 is an air gap between grounded parts of the steel case and current leading parts (the collective buses);

S2 is an air gap between the collective buses of different phases;

S3 is the height of the supporting insulator;

S4 is an air gap between the taps;

S5 is an air gap between contacts of the disconnector plug at the control position of the breaker with a drive;

d is thickness of insulating barriers which are bushing insulators.

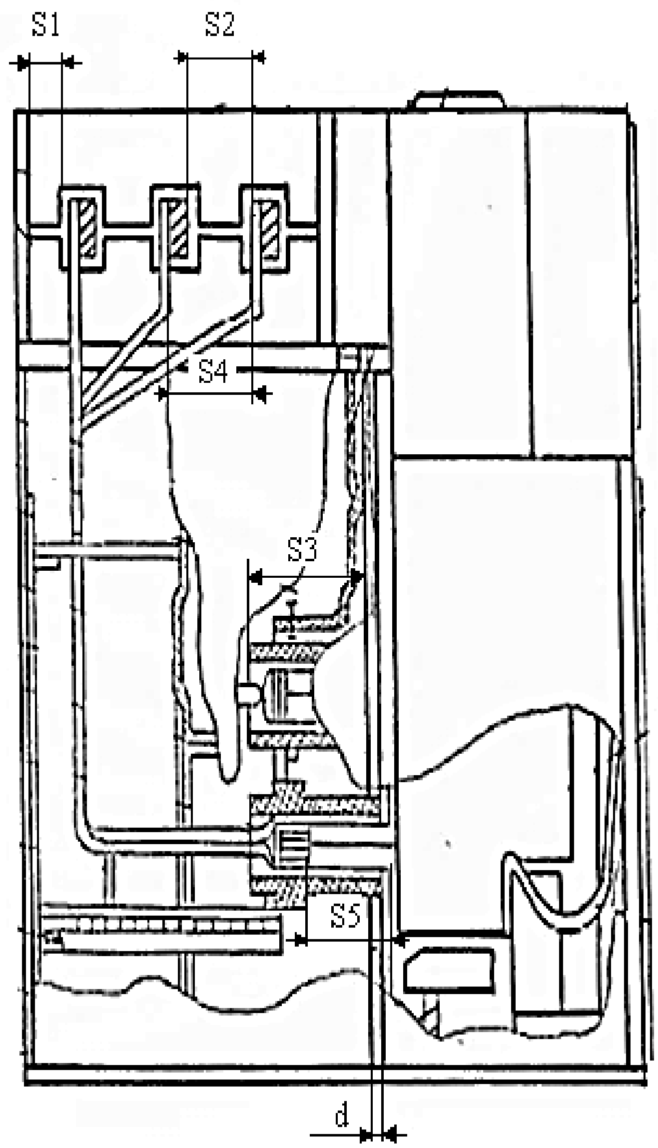


Figure 3.1 – General insulation gaps in the DSP construction

3.2 Definition of discharge values of voltages

Determination of the discharge voltage values goes according to the state standard GOST 1516.1-76 for DSP with 10 kV voltage class:

a) testing one-minute power-frequency voltage is 42 kV, including insulators, tested separately;

b) withstand voltage U_p is frequency between the contacts of the same poles in the open position of 53 kV.

The calculated discharge voltages are determined by the following formula:

$$U_{\text{рн}} = K_{\text{р}} \cdot U_{\text{р}} \;, \tag{3.21}$$

where $K_{\text{р}}$ is a safety factor, depending on the safety factor, which depends on the height of the unit installation above sea level. Projected DSP is designed for installation at an altitude of 1000 m above sea level, for a given height KR–1;

$U_{\text{рн}}$ is accepted value of the test voltage.

Accordingly, from formula (3.1), take the estimated discharge voltage for installation gaps:

a) dry-discharging voltage to the installation gap S1:

$$U_{\text{р3}} = 1 \cdot 42 = 42 \text{ kV}.$$

b) dry-discharging voltage to the installation gap S2:

$$U_{\text{р4}} = 1 \cdot 42 = 42 \text{ kV}.$$

c) dry-discharging voltage to the installation gap S5:

$$U_{\text{р5}} = 1 \cdot 53 = 53 \text{ kV}.$$

3.3 Calculation of insulation gaps

3.3.1 Definition of value of specified air gaps

The smallest distance from the current-carrying circuit to various parts of the switchgear is normalized by the rules of the device electrical installations p.4.2.86 [16].

In accordance with these requirements, as a first version, the following values of air gaps are taken: S1 is equal to 120 mm, S2 is equal to 130 mm. More specifically, the amount of air insulation gaps can be determined based on design features and operating conditions.

The length of the insulating gap, providing reliable work of switchgear elements under the given conditions, determines the estimated discharge voltage. When installing the equipment at an altitude of 1000 m in a closed switchgear (ISG), the calculated stresses can be determined with the following equation:

$$U_{\text{расч}} = 1.1 \cdot U_{\text{исп.сух}} \, , \qquad (3.22)$$

where $U_{исп.сух}$ is normed test voltage of external insulation in the dry state [19];

$U_{расч}$, determined for the two types of test intensity, is frequency voltage of 50 Hz ($U_{расч}$) and the full lightning impulse ($U_{расч.гр}$). Settlement of the insulating gap length whichever is greater when using the above test impacts.

Determine the value of test voltages in accordance with [19]:

S_1: $U_{\text{исп}} = 42$ kV, $U_{\text{исп.гр}} = 75$ kV,

S_2: $U_{\text{исп}} = 53$ kV, $U_{\text{исп.гр}} = 90$ kV.

Determine the value $U_{расч}$:

S_1: $U_{\text{расч}} = 1.1 \cdot 42 = 46.2$ kV,

$U_{\text{расч.гр}} = 1.1 \cdot 75 = 82.5$ kV,

S_2: $U_{\text{расч}} = 1.1 \cdot 53 = 58.3$ kV,

$U_{\text{расч.гр}} = 1.1 \cdot 90 = 99$ kV.

The insulating gap length at a voltage of 50 Hz frequency is determined based on the shape of its forming electrodes [19]. For periods with the shape of the needle electrodes – ground plane (S1) and needle – needle (S2) while $U_{расч} > 40$ kV:

$$S1 = 0.285 \cdot U_{расч} - 2.85, \tag{3.23}$$

$$S1 = 0.285 \cdot 46.2 - 2.85 = 10.3 \text{ cm},$$

$$S2 = S3 = 0.27 \cdot U_{расч} - 2.7, \tag{3.24}$$

$$S2 = S3 = 0.27 \cdot 58.3 - 2.7 = 13 \text{ cm}.$$

The length of the gaps S1 and S2 with full lightning impulses is determined based on a graph shown in [19]:

$$S1_{гр} = 13 \text{ cm},$$

$$S2_{гр} = 9 \text{ cm}.$$

Over long periods of settlement accepted:

$$S1 = S2 = 14 \text{ cm}.$$

The shortest distance from live circuits to different parts of the switchgear devices is standardized according to rules of electrical installations [16]. In accordance therewith, take into account design features selected for further calculations $S1 = S2 = 0.15$ m.

3.3.2 Calculation of the insulating gap on the surface of pedestal insulators

In the general case, as first version, dry-discharging voltage insulators are determined by the following formula [20]:

$$U_0 = 3.95 \cdot S_3^{0.93}, \tag{3.25}$$

For calculation U_0 is accepted equal to U_{p3} and is equal to 42 kV.

By formula (3.25) the value of insulation gap S3 is found out as:

$$S_3 = \frac{ln\frac{42}{3.95}}{0.93} = 12.2 \cdot 10^{-2} \text{ m.}$$

More specifically, taking into account the design features and operating conditions, electric payment support and other types of insulators in case of breakdown on the surface (S3, see on Figure 3.1) is performed to determine the creepage distance along the surface of the insulator, the magnitude of which selects the desired type of insulator, or the size of the insulating structure.

Active height of the support insulator indoors is determined by a normalized test voltage of industrial frequency of 50 Hz and the full lightning impulse. On the basis of [19] it is to be determined at 50 Hz:

$$U_{\text{расч}} = 1.1 \cdot 42 = 46.2 \text{ kV},$$

$$h_{\text{акт}} = 115 - \sqrt{13225 - 50 \cdot U_{\text{расч}}}, \tag{3.26}$$

$$h_{\text{акт}} = 115 - \sqrt{13225 - 50 \cdot 46.2} = 11 \text{ cm.}$$

To test voltage of full lightning impulse need to determine:

$$U_{\text{расч.гр}} = 1.1 \cdot 75 = 82.5 \text{ kV},$$

$$h_{акт} = 26.1 - \sqrt{718 - 5 \cdot U_{расч.гр}}, \tag{3.27}$$

$$h_{акт} = 26.1 - \sqrt{718 - 5 \cdot 82.5} = 8.6 \text{ cm}.$$

For active insulator height, take more of the values obtained from the formulas (3.26) and (3.27), namely:

$$h_{акт} = 11 \text{ cm}.$$

Determine creepage distance along the surface of a solid dielectric. For category *A* and isolation of a predetermined voltage class, its value should not be less than 0.2 m [19].

Select the standard form of the rib according to [19] and the analogue data.

Determine the number of edges on the insulator, providing a predetermined leakage path, based on the following equation [19]:

$$n = \frac{l_{n.y} - h_{акт}}{l_{ут} - l_2}, \tag{3.28}$$

where l_{ny} is creepage distance, 0,2 m;

l_{ym} is the leakage path length of the ribs and is chosen according to [19];

l_2 is a parameter of insulator ribs, and is selected based on [19].

$$n = \frac{0.2 - 0.11}{0.034 - 0.026} = 1.2 .$$

Determine the number of ribs on the surface of the insulator that is not less than 2. According to [19] the number of ribs for tropics should be increased to 5. The reference insulator switchgear is designed for the type of insulator chosen ИОР-10-3.75 УХЛ2. General view of the insulator is shown in Figure 1.7.

Similarly, the calculation is performed on the surface of the insulating gaps epoxy resin instrument transformers and bushings.

3.3.3 Definition of distance between taps of collective buses

As a calculated model the system of electrodes “needle-grounded needle” is taken. Dry-discharging voltage in air gap is defined by the following formula [20]:

$$U_0 = 10 + 3.51 \cdot S4, \tag{3.29}$$

where U_0 is accepted equal to U_{p4} and is equal to 42 kV.

By formula (3.29) the value of air gap is found *S4*:

$$S4 = \frac{(U_0 - 10)}{3.51}, \tag{3.30}$$

$$S4 = \frac{(42 - 10)}{3.51} = 9.12 \text{ cm.}$$

3.3.4 Calculation of air insulation gap between contacts of plug-in contacts

At calculation of the movable and motionless plug-in contacts the yard is assumed as a system of electrodes “needle-grounded needle”. Dry-discharging voltage is defined by formula:

$$U_0 = 10 + 3.51 \cdot S5, \tag{3.31}$$

where U_0 is accepted equal to U_{p4} and is equal to 58.3 kV.

By formula (3.31) the value of insulation gap S5 is found as follows:

$$S5 = \frac{(U_0 - 10)}{3.51}, \tag{3.32}$$

$$S5 = \frac{(58.3 - 10)}{3.51} = 13.76 \text{ cm.}$$

3.3.5 Calculation of width of insulation barriers

Collective bus compartment shall be separated from other compartments by partitions. The thickness of the insulating barrier is determined by the formula:

$$d \geq \frac{U_{\text{пр}}}{E_{\text{пр}}}, \quad (3.33)$$

where U_{np} is accepted equal to U_{p4} and is equal to 58.3 kV;

$E_{\text{пр}}$ is electrical reliability of dielectric, to get of mark I equal to $12{\cdot}10^6\ \frac{V}{m}$.

$$d \geq \frac{42{\cdot}10^3}{12{\cdot}10^6},$$

$$d \geq 3.5 \cdot 10^{-3}\ m.$$

In construction insulation barriers of width $6{\cdot}10^{-3}$ m are applied.

4 STUDY AND CALCULATION OF SWITCHGEAR RELIABILITY AT VOLTAGE 10 kV

Reliability is a quality characteristic. Depending on the appliance’s sphere of application, construction and exploitation conditions it can be determined by the following parameters:

- durability;
- safety;
- storageability;
- repair capability.

The first three reliability characteristics testify about the ability to withstand physical-mechanical and chemical destructions. The last requires favorable conditions to prevent faultiness and to find their reasons.

Non-reliable work of switchgear eventuates in considerable economic expenses, such as expensive spares, considerable wages for highly qualified service management etc. And also unpredictable consequences connected with complete stop of technological lines. That is why it is quite important to provide a high level of reliability.

The projected switchgear is a complex system that involves a large number of fitting elements working at different regimes. In this situation it is almost impossible to provide long-term stable work, that is why consequences of hardware fault are eliminated by substitution of new elements instead of fault ones. In our case reliability is convenient under consideration of basic parameter – parameter of fault flux – $\omega(t)$ [21, 22].

According to technical conditions of exploitation the setting and technical service of switchgear elements is performed periodically, no less than once a year. During this exploitation period switchgear can be presented as a non-repairable system and the corresponding mathematics of computation can be used.

For reliability calculation a logical distributional model can be built. It involves logical computation scheme and mathematical calculation model with application of the law of distribution. The appearance of the scheme is determined on the basis of analysis of faults that were revealed during exploitation period. The fault criterion for the projected switchgear is the necessity of involuntary repair due to breakdown of any electro supplying users. The possible faults can be classified by the following reasons [22, 23]:

- constructive reasons that appear because of violation of set up rules of exploitation and norms of device construction;
- manufacturing reasons that are caused by the reasons of violation of the set up production process;
- exploitation ones that are induced by violation of exploitation norms and rules.

On the basis of statistical data [22] and industrial exploitation data the next typical elements and correspondent faults are chosen:

- collecting bars – they are de-energized due to electrical damages of jumper insulation that leads to short circuit or damage of contact connection;
- contact connections – welding, electrical and mechanical erosion, weakening of jumper contacts tightening;
- disconnectors – damage of isolation causing short circuit, mechanical damages and short circuit caused by service inadvertence;
- breaker – failure to carry out its protecting functions (failure to switch off short circuit on divergent lines, failure to automatic switch of load current, drive and mechanical faults etc.);
- devices for measurement and signalization – faults of fitting elements causing incorrect functioning or fault operation;
- automation and relay protection devices – failure to execute protective functions and direction purposes;
- current and voltage measurement transformers – breakdown of basic insulation, overlap of inputs, demotion of accuracy class;
- power transformers and throttle governors – rupture or fusion of cable lines, demotion of electric insulation strength, unreliable mounting of body and moisture protection.

The above mentioned analysis has shown that reliability of the projected system greatly depends on climatic conditions of exploitation that are in the particular case of aluminum production not beneficial enough. Influence of exploitation conditions is determined by the following factors.

Temperature increase makes worsens insulation properties of fitting elements and brings to an increase of leakage current, causing the insulation breakdown. Low temperatures embarrass electromechanical work of the system (switch, relay etc.) due to solidification of lubricant and increasing of friction forces. Sharp change of temperature (in winter) creates additional mechanical load or impermissible wide gap due to different coefficients of contact material linear growth.

Dust presence. Sand and dust complicates work of electrical devices. Moreover dust parts are abrasive in case of aluminum production that negatively influences the working ability of most fitting details.

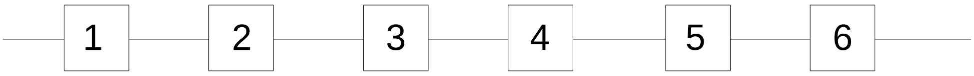
Moisture and dust medium creates semi conducting films. Due to that leakage current appears on the surface and inside of the elements like transformer, windings, and cables.

Vibration loads. These loads wear out contact connections quality and eventuate slackening of bonding.

The projected switchgear involves a large number of elements that differ by its parameters, functional capabilities and reliability. In this case for description of reliability the exponential method can be used. The next condition is valid through [22]:

$$\omega = const$$

The scheme of the switchgear panel is performed without reservation, so then the logical computing scheme has the form of connected elements series. In this case calculation of reliability is best made by means of the following computing scheme that is shown in Figure 4.1 [24].



1 – collecting buses; 2 – vacuum breakers;
3 – current transformers; 4 – device of protection and automatics;
5 – disconnector; 6 – cable line.

Figure 4.1 – Calculating model of switchgear panel at voltage 10 kV

The structure of DSP is a combination of different elements that are different by their characteristics, principle of operation, processes of wearing and as a result by their reliability. In this case it is convenient to use exponential law as the theoretical law of distribution [21, 24].

To calculate parameters of fault flux of DSP [24] there are considered groups of elements that operate at the same conditions and have neighbouring values of fault flux. Their parameters are shown in Table 4.1. The values of parameters of the fault flux for normal conditions of operation and for medium temperature 20 ^0C are defined for each group [22, 19]. Initial data for calculation is presented in Table 4.1. Calculation is fulfilled on using MATHCAD [24] software. Results of calculation of the basic parameters of reliability of DSP are shown in Figure 4.1 and Figure 4.2.

Table 4.1 – Initial data for calculation of reliability of DSP of function output line

DSP elements	.	$\omega_0 \times 10^{-6}$,1/hour	$K_н$	θ, ^0C	a_i	K_1	K_2	K_3
Collecting buses	0	0,05	0,3	20	0,32	1,1	1	1
Breaker		0,08	0,63	20	0,38	1,1	1	1
Current transformers;		0,1	0,45	20	0,62	1,1	1	1
Voltage transformers;	3	0,01	0,85		0,75			
Relay protection		0,05	0,5	20	0,5	1,1	1	1
Disconnector		0,06	0,2	20	0,35	1,1	1	1

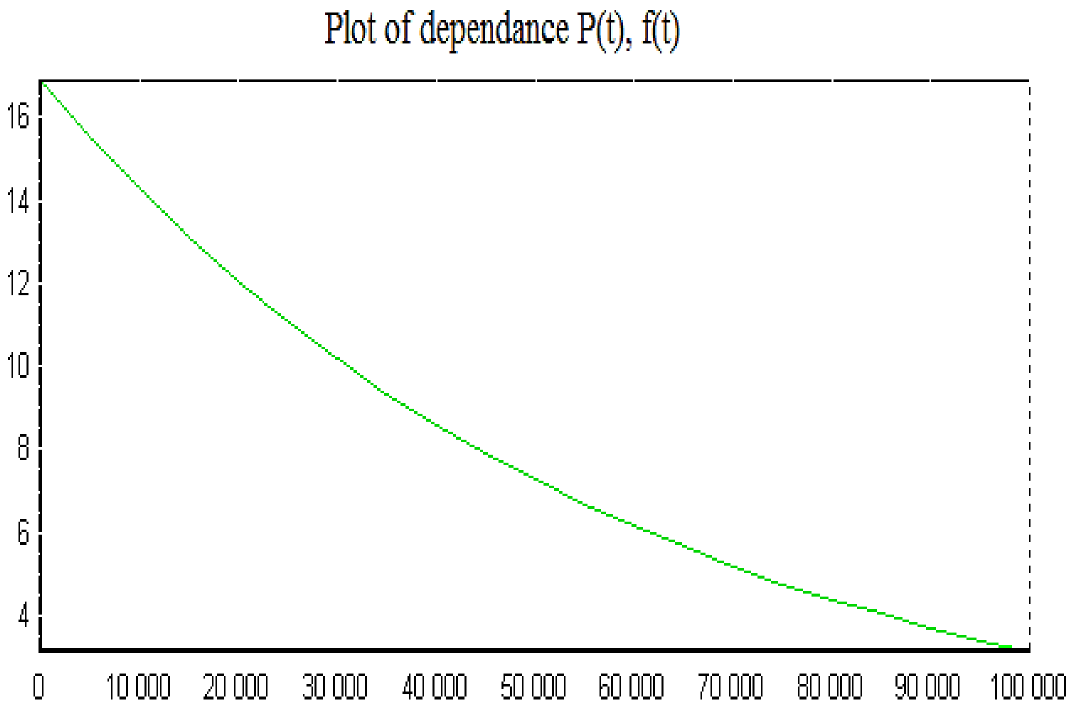


Figure 4.1 – Plot of density of operation till failure of the projected DSP at ambient temperature of 20 ^{0}C

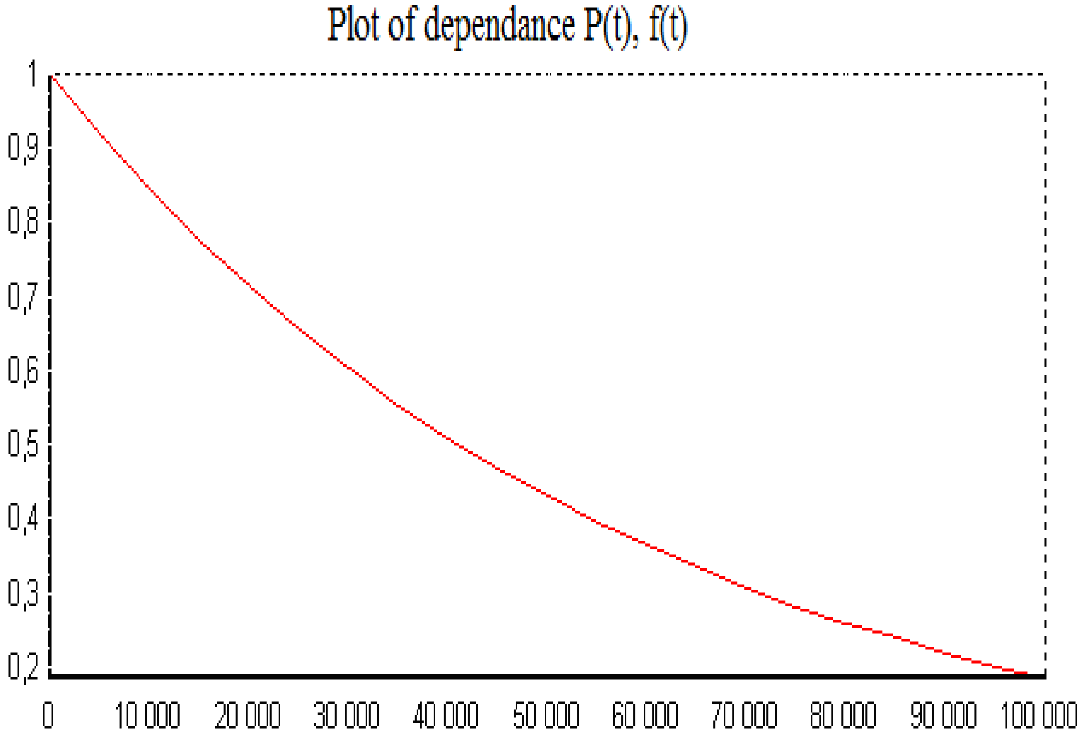


Figure 4.2 – Plot of distribution of operation till failure of the projected DSP at ambient temperature of 20 ^{0}C

5 OCCUPATIONAL SAFETY

Since the theme of the thesis "A distribution switchgear panel with voltage of 10 kV and a current of 2000 A" provides for calculations (work, research) in a room (laboratory) equipped with personal computers with visual display terminals, therefore, below we will consider measures to ensure safety, industrial sanitation, occupational health and fire safety for the premises (laboratory) equipped with visual display terminals, in accordance with the guidelines.

It has been established that the state of the organism of PC users in terms of objective and subjective indicators depends on the type of work and the conditions for its performance. All PC users can be conditionally divided into users who constantly work at a PC in accordance with their professional duties and those who work with a PC from time to time, for example, pupils or students.

The work of a user of a personal computer is performed in a monotonous posture under conditions of limited general muscle activity with mobility of the hands, high tension of visual functions and neuro-emotional stress under the influence of various physical factors, such as electromagnetic radiation in the above low-frequency, low-frequency and medium-frequency ranges (5 Hz – 400 kHz); electrostatic field; X-ray, infrared and ultraviolet radiation, as well as radiation of the visible range, acoustic noise; unsatisfactory level of illumination, unsatisfactory meteorological conditions, and so on [31].

Constant computer work can lead to many diseases. The causes of diseases are improper organization of the workplace, poor ergonomic characteristics of the monitor, as well as poor sanitary and hygienic working conditions, all of which can lead to many diseases. For example, visual impairment, skin diseases, body poisoning, musculoskeletal disorders and disorders associated with stressful situations and neuro-emotional overload [31].

Do not forget that any PC is an electrical installation with a supply voltage of up to 1000 V, therefore, electrical safety rules apply to it and everything related to its operation.

Therefore, to ensure the safety of PC users and maintenance personnel, electrical safety requirements are applied in accordance with the Arrangement of Electrical Installations (PUE) [16], as well as the normative legal act "On Labor Protection" NPAOP 40.1-1.01-97 «Rules of safe operation of electrical installations» [32].

Based on the analysis of the technological process, as well as on the analysis of the available equipment in the room equipped with a PC, according to GOST 12.0.003-74 "Occupational safety standards system. Dangerous and harmful production effects. Classification" [31], the following hazardous and harmful production factors were identified that can lead to injury or damage to the health of workers:

1) Electric shock

Risk of electric shock due to electrical malfunction or safety violations that could cause an electrical injury or even death.

2) Fire

Risk of fire due to non-compliance with safety precautions or short circuits near flammable substances, which could result in burns or death.

3) Bad lighting

Poor lighting due to irrational positioning of lamps or an insufficient number of lamps can lead to impaired vision.

4) Noise and vibrarion

Prolonged exposure to noise and vibration from the printer or computer parts can result in decreased productivity, hearing impairment, deafness, and increased visual fatigue.

5) Electromagnetic field

Since the monitor emits an electromagnetic field with a frequency of 50 Hz, the effect of this field on the human body can lead to brain tumors and ischemia.

6) Microclimate

Unsatisfactory microclimate parameters due to improper operation of the air conditioning or heating system can lead to general diseases.

7) Psycho-physiological

Psycho-physiological factors include overstrain of the organs of vision. During an eight-hour working day behind the display, the user looks at the screen up to 30,000 times. An overloaded eye cannot adequately adapt to this situation, and fuzzy images and screen flickering increase health risks. Constant gaze at matted glass reduces the frequency of blinking and there is a threat of Sikk's syndrome, that is, drying and curvature of the cornea of the eyes.

8) Unsatisfactory ergonomic characteristics

Irrational use of the workplace or the use of outdated office equipment can lead to fatigue, mechanical traumas, as well as diseases of the musculoskeletal system.

9) Poisoning

Fire extinguishing means are included in the monitor case and printed circuit boards; during a fire, these means emit dioxin and furan gases. Also, laser printers emit ozone. It is highly irritating to the lining of the nose, throat and eyes and can cause cancer. And dioxin and furan are poisons that are poisoning the human body.

10) Monitor

The image on the screen should not flicker, there should also be no glare and reflections, and the level of radiation emitted by the monitor should be minimal, since a bad image can lead to impaired vision, and radiation can cause cancer.

5.1 Occupational safety measures

The room (laboratory), in which all work is carried out, is located on the second floor and has an area of no more than 15 square meters. The room also has five windows.

The equipment and organization of workplaces for PC users is provided in accordance with the state sanitary regulations DSANPIN 3.3.2.007-98 "State sanitary rules and regulations for work with visual display terminals of electronic computers" [33].

In accordance with the rules laid down in this document, the floor surface must be smooth, non-slip and antistatic, and the floor covering must be matt with a reflectivity of 0.3 – 0.5. For the interior decoration of the laboratory, diffuse-reflective materials were used with a reflectance for the ceiling of 0.7 – 0.8; for walls 0.5 – 0.6.

It is forbidden to use polymer materials for interior decoration of rooms with PC classes (chipboards, washable wallpaper, rolled synthetic materials, laminated paper plastic, etc.) that emit harmful chemicals into the air that exceed the maximum permissible standards.

The laboratory is equipped with the following equipment:

1) 20 monitor displays with a total electrical power of up to 1.2 kW / h;

2) 20 pcs with a total electric power of 4.5 kW / h;

3) one inkjet printers with a total electrical power of 0.05 kW / h;

4) one 3-D printer.

The laboratory uses a varying number of computers and monitors, and also uses a projector. Printers are used to print university documents.

In the laboratory, all equipment operates from an electrical network with a voltage of 220 V. According to the PUE, the reference grounding resistance at any time of the year does not exceed 8 ohms.

According to EU Directive 90/270 EEC - display screen equipment in the section of minimum requirements for health and safety [34] strictly regulates safe working conditions and health requirements for people working with computers, putting forward the following five requirements for working with the monitor:

a) the image does not flicker;

b) characters on the screen are clear and well distinguishable;

c) brightness and / or contrast are easily adjustable;

d) the radiation level is reduced to an extremely low level;

e) there are no glare and reflections on the screens.

1) In order to avoid electric shock, technical and organizational measures are provided.

Technical measures include ensuring inaccessibility to current carrying parts of the equipment, the use of insulation, as well as the installation of grounding of electrical equipment in accordance with the “Arrangement of Electrical Installations” (PUE). It is also necessary to periodically check the grounding resistance and check the damage to the insulation of the wires.

Organizational measures include carrying out of briefings and certifications for knowledge of electrical safety.

2) In order to avoid fire, technical and organizational measures are provided too.

Technical measures include the installation of fire alarms, automatic fire extinguishing systems, and the existence of fire corners containing fire extinguishing equipment such as a fire extinguisher, water bucket, sand, and so on.

Some words about organizational measures. These include carrying out fire safety briefings and subsequent certification to test the knowledge gained.

3) The laboratory with computers has natural and artificial lighting.

Artificial light sources are fluorescent lamps.

In case of unsatisfactory lighting, the productivity of computer users decreases, myopia and fatigue may appear.

Improvement of lighting in the laboratory is carried out according to the requirements DBN V.2.5-28:2018 "Engineering equipment of buildings and constructions. Natural and artificial lighting" [38].

Artificial lighting in laboratories equipped with computers is provided by a general uniform lighting system using ceiling linear fluorescent lamps 600 mm long. The amount of illumination on the surface of the desktop in the area of documents is 300-500 lux. If these illumination values cannot be provided by the general lighting system, local table lighting with LED lamps is used. In this case, local lighting fixtures are installed in such a way as not to create glare on the screen surface, and the screen brightness does not exceed 300 lux.

At the same time, natural light is provided through the light slits, which always face northeast or north. It must provide a natural light factor of at least 1.5 %. However, in order to protect from direct sunlight, which creates glare on the surface of the screens, sun protection devices are provided, and there are curtains on the windows, blinds or windows are pasted over with foil or paper to avoid direct sunlight.

4) The noise level in the laboratory can be reduced by using more modern SSD-drives, using computer power supplies with rubber mounts, placing soundproof fences in the form of walls, partitions, cabins to reduce noise in the path of its propagation, as well as acoustic decoration of rooms - reducing the energy of reflected sound waves by increasing the area of sound absorption.

The value of the vibration characteristics in the laboratory does not exceed the permissible level that meets the requirements of DSN 3.3.6.037-99 “Sanitary standards of production noise, ultrasound and infrasound” [40]. Therefore, personnel do not need additional protection against vibration, since computers and other equipment are mounted on rubber mounts that absorb vibration.

5) To avoid electromagnetic radiation, it is necessary to replace old CRT monitors with LCD monitors, as old monitors emit harmful electromagnetic fields.

6) In premises with computer equipment, the optimal values of microclimate parameters, namely temperature, relative humidity and velocity, are provided in accordance with the requirements of the state sanitary standards DSN 3.3.6.042-99 "Sanitary norms of microclimate of industrial premises" [36] and GOST 12.1.005-88 "Occupational safety standards system. General sanitary requirements for working zone air" [37].

In the cold period of the year, at permanent workplaces, the temperature is: optimal 21-23 ℃, permissible 20-24 ℃; optimal relative humidity 40-60 %, per-missible 75 %; optimal air velocity no more than 0.1 m / s, permissible no more than 0.2 m / s;

In the cold season in non-permanent workplaces, optimum temperature 21-23 ℃, permissible 17-25 ℃; optimal relative humidity 40-60 %, permissible 75 %; air movement velocity: optimal no more than 0.1 m / s, permissible no more than 0.2 m / s;

In the warm period of the year, at permanent workplaces, the temperature is: optimal 22-24 ℃, permissible 21-28 ℃; optimal relative humidity 40-60 %, permissible 60 % at a temperature of 27 ℃; air movement velocity: optimal no more than 0.2 m / s, permissible no more than 0.1-0.3 m / s;

In the warm period of the year, at non-permanent workplaces, the tempera-ture is: optimal 22-24 ℃, permissible 19-30 ℃; relative humidity optimal 40-60 %, permissible 60 % at a temperature of 27 ℃; air movement velocity: optimal no more than 0.2 m / s, permissible 0.1-0.3 m / s.

In winter, air conditioning and district heating are used to maintain the optimum temperature in the laboratory.

In summer, air conditioning and natural ventilation of the premise by opening windows and doors are used to maintain an optimal temperature in the laboratory.

According to the sanitary and hygienic standards GN 2152-80 "Sanitary and hygienic standards of permissible levels of air ionization of industrial and public premises"

[35], the levels of positive and negative ions in the air of rooms with computer equipment comply with the standards.

The optimal levels of positive (n^+) and negative (n^-) ions in the air are: n^+ = 1500-30000, n^- = 3000-5000 (Pieces per 1 cm^3). Maintaining the optimal level of light positive and negative air ions in the air at workplaces is ensured with the help of bipolar corona air ionizers.

7) To prevent psychophysiological hazards, it is necessary not to overstrain the organs of vision, to take breaks more often to distract from the monitor, and it is also necessary to replace the old monitor with a more modern one, on which there will be a high-quality image and the eyes will not get tired.

8) To improve the ergonomics of the workplace in accordance with the requirements of NPAOP 0.00-1.28-10 "Labor protection rules for the operation of electronic computers" [50], where the specified prohibition of cluttering the workplace, compliance with the standards for the plane of the workplace per employee. Also, the requirements for the organization of the workplace specified in GOST 12.2.032-78 "Occupational safety standards. Workplace when performing work while sitting. General ergonomic requirements” [51].

The design of the workplace, its dimensions and the mutual arrangement of its elements must correspond to the anthropometric, physiological and psychophysiological characteristics of a person, as well as the nature of the work.

Equipped in accordance with the requirements of standards, the workplace provides a comfortable position for a person. This is achieved by adjusting the position of the chair, the height and angle of the footrest when used, or the height and dimensions of the working surface.

The organization of workplaces should ensure the stable position and freedom of movement of the employee, the safety of performing work operations should be excluded or allowed only in some cases to work in uncomfortable positions that cause increased fatigue.

There should be nothing superfluous in the workplace; all items necessary for work should be near the employee, but not interfere with him. The organization of the workplace should provide the necessary visibility.

9) To avoid poisoning from hazardous substances, it is necessary to replace equipment such as a laser printer with a newer one that filters the emission of ozone. It is also necessary to regularly ventilate the room in which the computers are located to avoid dioxin and furan poisoning, which are present in printed circuit boards and in monitor cases. Usually these poisons are released during combustion, but there is evidence that they are released under normal conditions.

10) To avoid deterioration of vision from a bad monitor, it is necessary to replace all old monitors with more modern ones so that the picture on the screen does not flicker. It is also necessary that the monitor be able to quickly change the brightness to avoid glare and reflections.

5.2 Fire safety measures

The laboratory is equipped with computer equipment, monitors, keyboards, computer mice, as well as projectors with a lot of plastic in their construction.

There are also curtains, wooden tables and chairs in the room that can easily ignite on contact with an open fire. According to the fire safety rules of NAPB B.03.002-2007 "Standards for determining the categories of premises, buildings and outdoor installations for explosion and fire safety" [41], part of the description of category "B" - a fire hazardous room: flammable gases, flammable and hardly flammable liquids, as well as substances and / or materials capable of exploding and burning or only burning when in contact with water, oxygen and / or with each other. Based on the description of category "B" and the fact that the electrical circuits of the PC can cause fires when in contact with water, it can be concluded that the laboratory room belongs to category "B".

The degree of fire resistance of a room is set depending on its area within the fire compartment, the height of the building, the category of explosion and fire hazard, as well as its purpose.

According to the requirements of DBN V.1.1.7-2002 "Fire safety of construction objects" [42], the fire resistance of the premises (laboratory) is III degree.

When you choose fire detectors, the requirements of the national standard of Ukraine DSTU-N CEN/TS 54-14:2009 “Fire detection and fire alarm systems. Part 14: Guidelines for planning, design, installation, commissioning, use and maintenance” [43] as well as building codes, which I will indicate below.

The type of smoke detector meets the requirements of Ukrainian standards DSTU EN 54-7:2019 «Fire detection and fire alarm systems. Part 7: Smoke detectors. Point detectors using scattered light, transmitted light or ionization» [44] and DSTU EN 54-12:2004 «Fire detection and fire alarm systems. Part 12: Smoke detectors. Line detectors using an optical light beam» [45], taking into account the sensitivity to different types of smoke.

Fire detectors are used in accordance with the national standard of Ukraine DSTU EN 54-10:2004 “Fire detection and fire alarm systems. Part 10: Flame detectors. Point detectors” [46], if at the initial stage there may be an open flame or an overheated surface in the fire extinguishing zone (usually more than 600 °C). Flame detectors can be used in drying chambers and other controlled areas with overheated but non-radiating objects.

Thermal fire detectors are used in accordance with the national standard of Ukraine DSTU EN 54-5:2019 “Fire detection and fire alarm systems. Part 5: Heat detectors. Point heat detectors" [47], if heat is provided in the control zone during a fire at its initial stage and the use of other types of detectors is impractical due to factors leading to their malfunction.

When using thermal fire detectors, it is necessary to select them taking into account the classes of detectors with the values of their normal temperature of use, maximum temperature of use; minimum and maximum static operating temperature in accordance with the requirements of the national standard of Ukraine DSTU EN 54-5:2019 “Fire detection and fire alarm systems. Part 5: Heat detectors. Point heat detectors” [48].

If the dominant sign of fire detection at the initial stage is unknown in the controlled area, then in this case it is recommended to use a combination of fire detectors that respond to different signs of fire, or combined fire detectors.

Smoke detectors, which have a sound alarm in their design, can be used in case of smoke at the initial stage of a fire and the use of controlled premises for short-term residence (stay) of people (hotels, hospitals, hostels, etc.).

According to the fire safety rules of NAPB B.03.001-2004 "Typical norms for fire extinguishers" [49] for a laboratory equipped with personal computers with visual display terminals equipped with primary fire extinguishing equipment, portable carbon dioxide fire extinguishers with a charge of extinguishing agent weighing 3.5 kg (VVK - 3.5). The minimum number of fire extinguishers is 4 cylinders per room less than 25 sq.m. The distance between fire extinguishers and places of possible fires does not exceed 5 m.

A number of potential hazards such as electric shock, fire danger, insuffi-cient lighting, noise, electromagnetic field, unsatisfactory microcimate parameters, psycho-physiological overloads, ergonomic characteristics were identified. Measures on occupational safety, occupational hygiene, fire safety in accordance with DSANPIN 3.3.2.007-98, EU Directive 90/270 EEC, Arrangement of Electrical Installations (PUE), DBN V.2.5-28:2018, DSN 3.3.6.037-99, DSN 3.3.6.042-99, GOST 12.1.005-88, DBN V.1.1.7-2002, NAPB B.03.001-2 as well as other normative documents and methodical guidelines were developed to ensure safe and comfortable working conditions.

6 ECONOMIC GROUNDS FOR THE SGP DEVELOPMENT

Complete switchgear cabinet of type SGP-10 is designed for reception and transmission of electric energy. Cabinet passes the three-phase current and voltage of 10 kV network with isolated neutral. It also transmits power to electric plants in conditions of industrial production.

All data and coefficients are taken from the technical documentation of the Motor Sich JSC plant.

Technical progress in the electrical industry sets the task of developing of new designs of switchgears that would meet international technical standards with progressive design and technological solutions.

Modern switchgear designs meet high requirements in terms of reliability of the resource, the localization ability, specific consumption of construction materials, dimensions, weight characteristics, complexity of construction, etc.

The purpose of the graduation project is to improve of the existing base unit SGP-10 by increasing its protection against short-circuit currents.

The analysis of failure statistics shows that, depending on the manufacturer, as well as on operating conditions of the SGP, instances of arc fault vary from 5 to 120 cases per 1000 SGP. What is more, the arc reaches its maximum temperature of 26 000 °C almost instantly, destroying all the interior equipment, which results not only in expensive repair and restoration of equipment, but also causes damage associated with the termination of electricity supply to consumers.

The cost of restoring the equipment after the arc-fault varies widely. So, for example in the Efremov HES(heat electropower station) (ТГК - 4) Tulenergo an accident in section of 6 kV that arose in the spring of 2009, cost 3 million 400 thousand hryvnias, and at the same time very fit of HES to "zero" gave the damage of 9 million hryvnia.

Therefore, it is necessary to eliminate the arc as soon as possible.

From among the existing protections from the arc fault for the diploma project ОВОД-МД fiber optic sensor was selected, as it has the highest rate of response (7-14 ms), compared with photo-thyristor sensor (12…20 ms) and the valve sensor (100 ms). Also, the sensor has up to 28 fiber optic cables that allow it to monitor two sections with the number of cells of SGP reaching 9; under conditions that one cell would contain three fiber-optic cables.

Therefore, the use of the sensor will increase the safety and convenience of monitoring, as well as the reliability of the SGP.

General technical and economic parameters of the base unit of SGP – 10 kV are given in Table 6.1.

Table 6.1 - Technical and economic parameters of the base unit of SGP

Parameter	Value
Nominal voltage, kV	10
Nominal current, A	2000
Maximal operational voltage, kV	15
Nominal frequency, Hz	50
Time of breaking, s	0,87
Mass, kg	690

Annual production of SGP at the plant OAO “ЗЗВА” is 100 units.

6.1 Cost and price of SGP

Cost of the product is the economic and financial indicator of activity of a company that describes the effectiveness of management and serves as the basis for calculation of the price.

Product price is determined by the formula:

$$Ц = С + П, \qquad (6.34)$$

where Ц is price of the product, UAH;

С is cost of the product, UAH;

П is profit, UAH.

Cost of the product is the estimation of natural resources such as raw materials, basic materials, fuel, energy, plant and equipment, labor and other costs to manufacture and sell the products. The cost reflects the value of current expenditures that have productive, non-capital nature and provide a process of simple reproduction. Cost is an economic form of reproduction of consumed production factors. Full cost of the product is calculated as:

$$С = С_п + УПХ + АР + РС, \tag{6.35}$$

where $С_п$ is production cost of the product;

УПХ is production services, УПХ equals 3687 UAH;

АР is administrative costs, UAH;

РС is cost of sales, UAH.

The production cost of the product is determined by the formula:

$$С_п = М + К + ЗО + ЗД + ОС + ОПР, \tag{6.36}$$

where М is cost of raw materials and basic materials, UAH;

К is cost of purchased components, UAH;

ЗО is basic wage of production workers, UAH;

ЗД is additional wages of production workers, UAH;

ОС is deduction for social events from the wages of production workers, UAH;

ОПР is general production expenses UAH.

The cost of raw materials and basic materials is calculated on the basis of technically based norms for the use per unit of product, prices of the kinds of material resources, which are used in the company ООО «ЗЗВА». Transportation and procurement costs are taken into account. The sum of the costs of raw materials decreases by the directly of waste that is generated during the manufacturing process.

Table 6.2 – The cost of raw materials and basic materials

Index	Value, UAH
Raw and basic materials	6669
Packaging	283
Total	6952
Transport-procurement costs (3%)	1514
Total with transport - procurement costs	8466

Calculation of the cost of purchased components are given in Table 6.3.

The cost is calculated taking into account transport and procurement costs.

Table 6.3 – Cost of purchased components

Name of purchased components	The rate of use, units	Price, UAH	Total prise, UAH
Breaker BB/TEL-10-25/2000	1	25000	25000
Microprocessor protection МРЗС-05М	1	5750	5750
Device for protection against arc-fault ОВОД-МД at the rate of one cell ofSGP	1/9	30800	3420

The calculated basic wage of production workers per unit is based on the complexity of manufacturing and cost of standard-hours.

The calculation of the basic wage per unit of output is given in Table 6.4.

Table 6.4 – Salary per unit of production

Name of operation	The rate of time, n-h	The cost of an n-h, UAH	Wages per unit of production (rate), UAH
Production of SGP	391.3	7	2739
Total	391.3	7	2739

Additional salary is paid to production workers for quantity and quality of work performed. It includes allowances and additional payments, bonuses for operating results, payment of regular and additional holidays and other. Additional salary is 46 % of the principal salary, and is calculated by the formula:

$$ЗД = ЗО \cdot \frac{К_д}{100}, \tag{6.37}$$

where $К_д$ is percentage of extra salary, $К_д$ equals 46 %.

$$ЗД = 2739 \cdot \frac{46}{100} = 1260 \text{ UAH.}$$

Accruals for social activities are a form of redistribution of income to fund social needs, they are calculated in accordance with applicable law and constitute 22 % of payroll. Accruals for social activities are calculated by the formula:

$$ОС = (ЗО + ЗД + ПП) \cdot \frac{К_{вс}}{100}, \tag{6.38}$$

where ПП is award of profits, UAH;

$К_{вс}$ is deductions for social events, %.

$$ОС = (2739 + 1260) \cdot \frac{22}{100} = 879.78 \text{ UAH.}$$

The cost of maintaining equipment is 99% of the basic salary.

$$\text{РСО} = \text{ЗО} \cdot \frac{99}{100}, \qquad (6.39)$$

$$\text{РСО} = 2739 \cdot \frac{99}{100} = 2712 \text{ UAH.}$$

Departmental spending is 280 % of basic salary.

$$\text{ЦР} = \text{ЗО} \cdot \frac{280}{100}, \qquad (6.40)$$

$$\text{ЦР} = 2739 \cdot \frac{280}{100} = 7669 \text{ UAH.}$$

The general expenses for work are the amount of 200 % of the basic salary.

$$\text{ОЗР} = \text{ЗО} \cdot \frac{200}{100}, \qquad (6.41)$$

$$\text{ОЗР} = 2739 \cdot \frac{200}{100} = 5478 \text{ UAH.}$$

Overhead costs include the costs of maintenance and operation of equipment, shop costs, and production services. The costs of maintenance and operation of the equipment are composed of maintenance costs of machinery, the cost of repair of equipment, shop tools and transport, wear low value equipment, salaries of support staff, etc. Departmental expenses for up costs associated with ongoing maintenance and depreciation of the buildings department, payroll department managers and professionals, costs of labor protection and safety in the shop, etc.

Overhead costs are on average 400 % of the basic salary and is calculated by the next formula:

$$ОПР = РСО + ЦР + ОЗР, \tag{6.42}$$

$$ОПР = 2712 + 7669 + 5478 = 15859 \text{ UAH.}$$

The above costs are production costs.

Administrative costs contain the costs associated with the contents of the administrative and business management personnel, as well as the maintenance and operation of general fixed assets for production purposes, occupational health and safety of personnel, etc. Administrative costs are on average 420 % of the basic wage of production workers and are calculated by the formula:

$$АР = ЗО \cdot \frac{\beta}{100}, \tag{6.43}$$

where β is percentage of administrative costs.

$$АР = 2739 \cdot \frac{420}{100} = 11504 \text{ UAH.}$$

Distribution costs consist of costs associated with product sales and contain costs for packaging and packing materials, shipping of finished products, advertising, market research costs, etc. Cost of sales accounts for 8 % of production costs and is calculated by the next formula:

$$РС = С_п \cdot \frac{\gamma}{100}, \tag{6.44}$$

where $С_п$ is cost of production, UAH;

γ is 8 % cost of sales.

By formula (6.36) cost of production is calculated:

$$С_п = 8466 + 46484 + 2739 + 1580 + 1476 + 15859 = 76604 \text{ UAH.}$$

By formula (6.44) the cost of sales is calculated:

$$РС = 76604 \cdot \frac{8}{100} = 6128 \text{ UAH.}$$

The total cost is calculated by the formula (6.35):

$$С = 76604 + 3687 + 11504 + 6128 = 97923 \text{ UAH.}$$

Profit is 5 % of the total cost and is calculated by the formula:

$$П = С \cdot \frac{Р}{100}, \qquad (6.45)$$

where P is profitability of the product, %.

$$П = 97923 \cdot \frac{5}{100} = 4896 \text{ UAH.}$$

By formula (6.33) the price of SGP is calculated:

$$Ц = 97923 + 4896 = 102819 \text{ UAH}$$

Value-added tax according to law is 20 % of the wholesale price and is calculated by the formula:

$$ПДВ = Ц \cdot \frac{Н_{пдв}}{100}, \qquad (6.46)$$

where $Н_{пдв}$ is standard value-added tax, %.

$$ПДВ = 102819 \cdot \frac{20}{100} = 20564 \text{ UAH}.$$

Sale price of the product is calculated as:

$$Ц_{пр} = Ц + ПДВ, \tag{6.47}$$

$$Ц_{пр} = 102819 + 20564 = 123383 \text{ UAH}.$$

Fixed costs for the entire production volume are calculated by the formula:

$$S_{пост} = ОПР + АР + РС\ , \tag{6.48}$$

$$S_{пост} = 15859 + 11504 + 6168 = 33531 \text{ UAH}.$$

Variable costs per unit of output are calculated by the formula:

$$S_{пер} = М + К + ЗО + ЗД + ОС, \tag{6.49}$$

$$S_{пер} = 8466 + 46484 + 2739 + 1260 + 1580 = 60529 \text{ UAH}.$$

Costing and pricing of the product is shown in Table 6.5.

Table 6.5 – Costing and pricing of the product

Expenditures	Amount, UAH
Raw and basic materials	8,466
Purchased components	46,484
Production services	3,687
The basic wage of production workers	2,739
Additional wages of production workers (46%)	1,260
Deductions for social events from the wages of production workers (39,5%)	1,580
Overhead costs	15,859
Cost of production	97,923
Administrative expenses (420%)	11,504
Cost of sales (8%)	6,128
Total cost	76,604
Profit (5%)	4,896
Wholesale price	102,819
Value-added tax (20%)	20,564
Sale price	123,383
Variable costs	60,529
Fixed costs	33,531

6.2 Estimation of the costs

6.2.1 Capital costs

Additional capital costs are research and development of technical documentation, setting up of ОВОД-МД fiber-optic sensor and ИН-3 voltage indicator. Their costs are shown in Table 6.6.

Table 6.6 – Additional capital costs on research and development

Name of costs	Value ΔК, UAH
Research work	850
Development of technical documentation	450
Setting up of ОВОД-МД	200
Setting up of ИН-3	200
Total	1700

Related capital investment by the consumer for the SGP includes: cost of major repair; cost of the foundation; cost of production area.

The cost of repair is 50 % of the cost of the product, the cost of the foundation is 15 % of the cost of the product.

Cost of production area is calculated by the next formula:

$$В_{пл} = Ц_{пл} \cdot S \cdot К_{пл}, \tag{6.50}$$

where $В_{пл}$ is cost of production area;

$Ц_{пл}$ is cost of 1 m^2 of area ($Ц_{пл}$ is equal to 500 UAH.);

S is production area that occupies one unit, m^2, S is equal to 0.975 m^2 ;

$К_{пл}$ is factor that takes into account the additional space ($К_{пл}$ is equal to 1.15).

$$В_{пл} = 500 \cdot 0.975 \cdot 1.15 = 560 \text{ UAH.}$$

Results of the calculation are given in Table 6.7.

Table 6.7 – Related capital investment by the consumer

Name of capital investment	Value, UAH
Cost of major repair	82,781
Cost of the foundation	24,834
Cost of production area	560
Total	108,176

6.2.2 Operating costs

Operating costs are as follows:

- costs for electricity;
- costs for current repair (the cost of materials and spare parts, wages).

Costs for electricity ($В_{ел}$) are determined by the next formula:

$$В_{эл} = P \cdot T \cdot Ц_{ел}, \tag{6.51}$$

where P is nominal power of SGP, kW;

T is annual fund of operation of the equipment, h.;

$Ц_{ел}$ is cost of 1 kW·hof electro energy, UAH.

$$В_{эл} = 20 \cdot 0.2 \cdot 8760 = 35040 \text{ UAH}.$$

The costs of current repair are calculated by the next formula:

$$\text{В}_\text{р} = S_\text{р} \cdot n_\text{р}, \quad (6.52)$$

where $\text{В}_\text{р}$ is costs for current repair, UAH;

$S_\text{р}$ is cost of one current repair, UAH;

$n_\text{р}$ is the number of current repairs per year.

$$\text{В}_\text{р} = 250 \cdot 3 = 750 \text{ UAH.}$$

The results of calculations of costs of SGP are in Table 6.8.

Table 6.8 – Operating costs of a consumer

The composition of current costs of consumers	Value, UAH
Costs for electricity	35,040
Costs for current repair	750
Total	35,790

6.2.3 Economic efficiency of the project

Cost savings in production cost are calculated on the basis of specific types of materials, labor and other resources. Calculation of cost savings is shown in table 6.9.

Payback period for capital costs is calculated as follows:

$$T_\text{ок} = \frac{\Delta\text{К}}{\text{Е}_\text{год}}, \quad (6.53)$$

Table 6.9 – Saving of operational costs

The composition of current costs of a consumer	Device		Saving, UAH
	Basic SGP	New SGP	
Costs for current repair	1,000	750	250
Costs for device servicing per year	23,352	11,235	12,117
Total			12,367

where ΔK is amount of additional capital investment, UAH;

$E_{год.}$ is annual cost-effectiveness of the consumer.

By formula (6.53):

$$T_{ок} = \frac{1700}{12367} = 0.14 \text{ years.}$$

The critical amount of production is calculated by the formula:

$$N_{кр} = \frac{S_{пост} \cdot N}{Ц_{опт} - S_{пер}}, \quad (6.54)$$

where $S_{пост}$, $S_{пер}$ are fixed and variable costs per unit of output, UAH;

N is the number of products released by the company per year, units;

$Ц_{опт}$ is wholesale price of product.

$$N_{кр} = \frac{33531 \cdot 100}{102819 - 60529} = 80 \text{ units.}$$

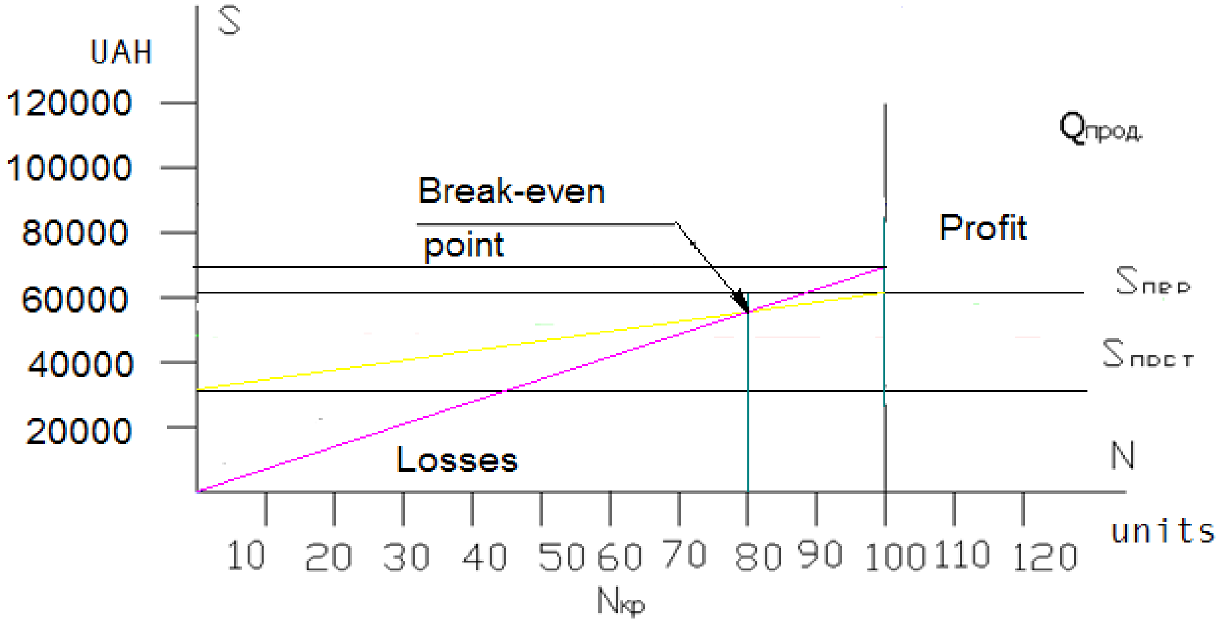


Figure 6.1 – The graph on break-even production of 100 units of SGP

In this section the economic study of the project has been carried out. Economic indicators of SGP have been calculated. Due to application of optical fiber protection and voltage indicator savings in maintenance costs of the switchgear and wages of workers have been achieved.

Additional capital investments have amounted to 1,700 UAH (Table 6.6).

The cost of the new product is more than the cost of the base one by 3,154 UAH (see Table 6.5).

To achieve profit the manufacturer should produce at least 80 units.

Annual cost-effectiveness of the consumer is 12,367 UAH.

Return on the additional capital investment is achieved through annual cost-effectiveness of the consumer. Payback period for additional capital investment is 0.14 years.

CONCLUSION

As a result of this work a DSP on 10 kV at nominal current 2000A with a vacuum breaker is designed. The main parameters of the switchgear have been calculated.

In the developed switchgear the vacuum circuit breaker of BB/TEL-10-31.5 / 2000 type is used, it's mounted on the breaker with a drive, and current transformers of ТОЛ–10 type ТОЛ–10, mounted on a roll-out cart.

Copper buses of rectangular cross section are used as the main circuit conductors.

An МРЗС–05М multifunctional device of microprocessor protection is used as the relay protection and measurement of quality of electric energy.

Additional protection from SC includes fibre optic detector of SC ОВОД–МД type, and the device for voltage indication with ИН 3–10Р–00–УЗ built-in relay that provide high safety level for maintenance and equipment, decreases costs of repair and non–operating regimes.

In the design of DSP t all safety regulations to ensure safe operation were taken into account

In a result of the analysis of the performed data it can be concluded that the new design of DSP corresponds to the requirements of the diploma project.

LIST OF REFERENCE

1. ВАТ Самарский завод «Електрощит» [Електронний ресурс] – Режим доступу: https://www.electroshield.ru/

2. ТОВ «АВВ» [Електронний ресурс] – Режим доступу: https://voltline.ua/oborudovanie-nizkogo-napryazheniya/

3. ТОВ «Таврида Електрик» [Електронний ресурс] – Режим доступу: http://tavrida-ua.com/

4. ТОВ «АВМ АМПЕР» [Електронний ресурс] – Режим доступу: https://abm-amper.com/

5. ВАТ «ЗЗВА» (Запорізький завод високовольтної апаратури) [Електронний ресурс] – Режим доступу: http://zva.zp.ua/

6. ДСТУ 15150-69 Машины, приборы и другие технические изделия. Исполнения для различных климатических районов. Категории, условия эксплуатации, хранения и транспортирования в части воздействия климатических факторов внешней среды [Текст]

7. Полтев В.К. Справочное руководство электрика [Текст], Свердловск: Металлургиздат,1960 – 491 с.

8. Андрієнко П. Д. Методичні вказівки до виконання дипломного проєкту бакалавра студентами спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» (освітні програми «Електричні та електронні апарати» та «Електромеханічне обладнання енергоємних виробництв») всіх форм навчання. / Укл.: П. Д. Андрієнко, Л. Б. Жорняк, В. В. Василевський. – Запоріжжя: НУ «Запорізька політехніка», 2020. – 66 с.

9. Жорняк Л. Б. Методичні вказівки до виконання курсового проєкту з дисципліни «Основи проєктування електромеханічних пристроїв та систем» студентами спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» (освітні програми «Електричні та електронні апарати» та «Електромеханічне обладнання енергоємних виробництв») всіх форм навчання. / Укл.: Л. Б. Жорняк, О. О. Каплієнко, С.І. Шило. – Запоріжжя: НУ «Запорізька політехніка», 2020. – 40 с.

10. Методичні вказівки до виконання курсового проєкту з дисципліни «Основи проєктування електромеханічних пристроїв та систем» студентами спеціальності 141 «Електроенергетика, електротехніка та електромеханіка» (освітні програми «Електричні та електронні апарати» та «Електромеханічне обладнання енергоємних виробництв») всіх форм навчання / уклад.: Л. Б. Жорняк, О. О. Каплієнко, І.С. Шило. – Запоріжжя: НУ «Запорізька політехніка», 2020. – 40 с.

11. ТОВ «ПТК «Энергомаш» [Електронний ресурс] – Режим доступу: http://www.em.dn.ua/

12. Гринчук Ф.Ф., Хавроничев С.В. Комплектные распределительные устройства напряжением 6, 10 кВ. Часть II [Текст]. – М.: Энергия, 2006 – 104 с.

13. Чернобровов Н.В. Релейная защита. Учебное пособие для техникумов [Текст]. – М.: Энергия, 1971. – 624 с.

14. Буткевич Г.В. Задачник по электрическим аппаратам [Текст]. – М.:Высш. шк., 1987. – 232 с.

15. Сахаров П.В. Проектирование электрических аппаратов [Текст]. – М.: Энергия, 1974. – 554 с.

16. Правила улаштування електроустановок (ПУЕ) [Текст] – Київ, 2014

17. Гайсаров Р.В. Выбор электрических аппаратов и проводников: Учебное пособие [Текст]. - Челябинск: ЮУрГУ. - 58 с.

18. ТОВ «ТЕРМА – ЕНЕРГО» [Електронний ресурс] – Режим доступу: https://termaenergo.ru/

19. Афанасьев В.В. Справочник по электрическим аппаратам высокого напряжения [Текст]. – Л.: Энергоатомиздат, 1987. – 544 с.

20. Г.Н. Александров. Теория электрических аппаратов [Текст]. / Г.Н.Александров, В.В.Борисов, В.И. Иванов и др.; - М.: Высшая школа, 1985. 312 с.

21. Г.В. Дружинин. Теория надежности радиоэлектронных систем в примерах и задачах [Текст]. – М.: Энергия, 1976. – 448 с.

22. Гук Ю.Б. Теория надежности в электроэнергетике [Текст]. – Л.: Энергоатомиздат, 1990. – 208 с.

23. Александрова Г.Н. Проектирование электрических аппаратов [Текст]. – М.: Энергоатомиздат, 1987. – 352 с.

24. Методичні вказівки до курсового та дипломного проектування для студентів спеціальності 8.092206.02 Електричні апарати всіх форм навчання [Текст]. / Укл.: О.І. Афанасьєв. – Запоріжжя: ЗНТУ, 2006 – 22с.

25. Холявский Г.Б. Расчет электродинамических усилий в электрических аппаратах [Текст]. – М.: Энергия, 1971. – 156 с.

26. Чунихин А.А. Аппараты высокого напряжения [Текст]. / Чунихин А.А., Жаворонков М.Ф. – М.: Энергоатомиздат, 1985. – 432 с.

27. Чунихин А.А. Электрические аппараты. Общий курс [Текст]. / А.А. Чунихин – М.: Энергоатомиздат, 1988. – 720 с.

28. Буткевич Г.В. Задачник по электрическим аппаратам: Учеб. пособ. для вузов по спец. «Электрические аппараты» [Текст]. / Г.В.Буткевич, А.Г. Сливинская, В. Г. Дегтярь и др. – 2-е изд., перераб. и доп. – М.: Высшая школа, 1987. – 232 с.

29. Таев И.С. Основы теории электрических аппаратов: Учебник для ВУЗов по спец. «Электрические аппараты» [Текст]. / И.С. Таев, Б.К. Буль, А.Г. Гeджелло и др.; Под ред. И.С. Таева. – М.: Высшая школа, 1975. – 352 с.

30. Сахаров П.В. Проектирование электрических аппаратов [Текст]. / П.В. Сахаров – М.: Энергия, 1977. – 560 с.

31. State Standard ГОСТ 12.0.003-74 «Система стандартів безпеки праці. Небезпечні і шкідливі виробничі фактори. Класифікація» [Текст].

32. НПАОП 40.1-1.01-97. «Правила безпечної експлуатації електроустановок» [Текст].

33. ДСанПіН 3.3.2.007-98 «Гігієнічні вимоги до організації роботи з візуальними дисплейними терміналами електронно-обчислювальних машин» [Текст].

34. EU Directive 90/270 EEC – display screen equipment. [Електронний ресурс] – Режим доступу: https://osha.europa.eu/en/legislation/directives/5.

35. ГН 2152-80. «Санітарно-гігієнічні норми допустимих рівнів іонізації повітря виробничих і громадських приміщень» [Текст].

36. ДСН 3.3.6.042-99 «Санітарні норми мікроклімату виробничих приміщень» [Текст].

37. ГОСТ 12.1.005-88 «Система стандартів безпеки праці. Загальні санітарно-гігієнічні вимоги до повітря робочої зони» [Текст].

38. ДБН В.2.5-28:2018 «Природне і штучне освітлення» [Текст].

39. ДСН 3.3.6-039-99 «Державні санітарні норми виробничої загальної та локальної вібрації» [Текст].

40. ДСН 3.3.6-037-99 «Санітарні норми виробничого шуму, ультразвуку та інфразвуку» [Текст].

41. NAPB B.03.002-2007 "Standards for determining the categories of premises, buildings and outdoor installations for explosion and fire safety" [Текст].

42. DBN V.1.1.7-2002 "Fire safety of construction objects" [Текст].

43. DSTU-N CEN/TS 54-14:2009 “Fire detection and fire alarm systems. Part 14: Guidelines for planning, design, installation, commissioning, use and maintenance” [Текст].

44. DSTU EN 54-7: 2019 IDT DSTU EN 54-7: 2019 “Fire detection and fire alarm systems. Part 7: Smoke detectors. Point detectors using scattered light, transmitted light or ionization " [Текст].

45. DSTU EN 54-12: 2004" Fire detection and fire alarm systems. Part 12: Smoke detectors. Linear detectors using an optical light beam " [Текст].

46. DSTU EN 54-10: 2004 “Fire detection and fire alarm systems. Part 10: Flame detectors. Point detectors" [Текст].

47. DSTU EN 54-5: 2019 “Fire detection and fire alarm systems. Part 5: Heat detectors. Point heat detectors" [Текст].

48. DSTU EN 54-5: 2019 “Fire detection and fire alarm systems. Part 5: Heat detectors. Point heat detectors" [Текст].

49. NAPB B.03.001-2004 "Typical standards for fire extinguishers" [Текст].

50. NPAOP 0.00-1.28-10 "Labor protection rules for the operation of electronic computers" [Текст].

51. GOST 12.2.032-78 “Occupational safety standards. Workplace when performing work while sitting. General ergonomic requirements” [Текст].