Ministry of Education and Science of Ukraine
Ternopil Ivan Pul'uj National Technical University
(full name of higher education institution)
Faculty of Applied Information Technologies and Electrical Engineering
(faculty name)
Electrical engineering department
(full name of department)

QUALIFYING PAPER

For the degree of

Bachelor
(educational-proficiency level)

topic: **Ensuring the reliability of the power supply system of a research institute**

Submitted by: fourth year student group IEE-42

Specialism (field of study) 141 Electrical Power Engineering, Electrical Engineering and Electromechanics
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Ministry of Education and Science of Ukraine
Ternopil Ivan Puluj National Technical University

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« » 2022

ASSIGNMENT
FOR QUALIFYING PAPER

for the degree of Bachelor
(degree name)

specialty 141 Electrical Power Engineering, Electrical Engineering and Electromechanics
(code and name of the specialty)

student Felix Nyado Junior
(surname, name, patronymic)

1. Paper topic Ensuring the reliability of the power supply system of a research institute

Paper supervisor *Ivan Sysak, Ph.D.*
(surname, name, patronymic, scientific degree, academic rank)

Approved by university order as of «*11*» *01* 2022 № *4/7-8*

2. Student’s paper submission deadline 06.2022
3. Initial data for the paper Power of consumers
4. Paper contents (list of issues to be developed)

ANALYTICAL SECTION
CALCULATION AND RESEARCH SECTION
PROJECT DESIGNING SECTION
LABOUR OCCUPATIONAL SAFETY AND SECURITY IN EMERGENCY SITUATIONS

5. List of graphic material (with exact number of required drawings, slides)

Presentation

6. Advisors of paper chapters

Chapter	Advisor's surname, initials and position	Signature, date	
		assignment was given by	assignment was received by
Labour occupational safety and security in emergency situations	*Ph.D., Assistant professor Okipnij I.B.*		
Compliance check	*Ph.D. Sysak I.M.*		

7. Date of receiving the assignment ______________________

TIME SCHEDULE

LN	Paper stages	Paper stages deadlines	Notes
1	Preparation of the «ANALYTICAL SECTION»	11.01.22 – 20.01.22	
2	Preparation of the «CALCULATION AND RESEARCH SECTION»	21.01.22 – 20.02.22	
3	Preparation of the «PROJECT DESIGNING SECTION»	21.02.22 – 30.03.22	
4	Preparation of the «LABOUR OCCUPATIONAL SAFETY AND SECURITY IN EMERGENCY SITUATIONS»	01.04.22 – 20.04.22	
5	Preparation of introduction, conclusions, Content and summary.	20.04.22 – 05.05.22	
6	Preparation, execution and printing graphic material	05.05.22 – 10.06.22	
7	Getting feedback and review	11.06.22 – 24.06.22	

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ABSTRACT

Nyado Felix Junior. Ensuring the reliability of the power supply system of a research institute. Ternopil Ivan Puluj National Technical University. Faculty of Applied Information Technologies and Electrical Engineering. Department of Electrical Engineering, group IEE-42. – Ternopil.: TNTU, 2022.

Pages – 70; Tables – 13; Illustrations – 4; Sources – 17; Blueprints – 15; Additions – 14.

An analysis of ways to increase the reliability of the power supply system was carried out. An analysis of electricity consumers was carried out according to the reliability of the electricity supply system, which made it possible to select the number and power of transformers. The estimated load was determined for the workshops and for the institute as a whole, which amounted to 17 MVA. The choice of compensating devices is substantiated, taking into account the full design load was 14.6 MVA. The power line voltage of 35 kV and distribution network voltage of 10 kV were selected. A cartogram of loads was built, which made it possible to determine the center of electrical loads of the institute. The choice of transformers of the main and central transformer substations is justified, taking into account the installed compensating devices. Three variants of schemes were drawn up, which made it possible to ensure a reliable power supply system of the institute. Selection of the cross-section of power line wires, selection of cross-section and brand of cable lines. Calculation of short-circuit currents was carried out, which made it possible to select devices and current-carrying parts of the substation.

Keywords: electricity, reliability, outage, availability, energy, power system, system interconnection.

CONTENT

INTRODUCTION

Reliability is characterized by the ability of the power supply system and its elements, which include overhead and cable lines, power transformers, electrical appliances, to provide consumers with electricity of proper quality without emergency breaks, leading to violations of the production plan, accidents in electrical and technological parts of equipment.

The reliability of the power supply system depends on the construction of its scheme, the degree of redundancy and the reliability of individual elements, taking into account their overload capacity.

When assessing the degree of reliability, it is necessary to combine both electrical and technological part of the mechanism, units or installations. The category of consumer reliability should be determined taking into account the redundancy in the technological part of the unit. It is impractical to reserve the electrical part of the unit or its power supply circuit in the absence of a reserve in the technological part.

1 ANALYTICAL SECTION

Reliability is one of the most important criteria which must be considered during all parts or phases of the power system planning, designing or operation. Reliability defines the ability of a system to perform what is required under its known functions for a specified period of time. The systems are installed to upport the required business functions of the building so it is essential that it can be carried out without interruption. Poor reliability directly or indirectly affects the health , security and safety as well as working conditions and systems with high reliability offer less opportunities for maintenance. [2]

A reliability criterion is needed to stablish and target reliability levels and continuously analyze and compare the future reliability levels with feasible alternative expansion plans. This results in the development of comprehensive reliability evaluation and modelling techniques [1]. As a measure of power reliability evaluation in generation expansion planning and energy production, three fundamental indices are widely developed and used around the world. [17]

The first reliability index is the loss of load expectation (LOLE) which denotes the expected average number of days per year which the sytem is being on power outages (load exceeds the available generating capacity). [17]

The second index is the expected demand not supplied (DNS) which measures the load that has been lost because of severe outage occurences. [17]

The third index is the expected energy not supplied (ENS) which is understood as the expected size of energy not being supplied cause of the generating units residing in the system during the period considered due to the capacity deficit or unexpected severe power outages. [17]

There are two basic concepts usually considered in network reliability named violation of quality and violation of continuity. [17]

The first concept considers violation of voltage limits and violation of line rating and violation of line rating or carrying capacity while the second concept assumes lines are of infinite capacity. [3]

The objective of this paper is to highlight the impact of the reliability on each stage of the whole life cycle of building and electric power supply systems to enable re designed processes and methodologies to develop to improve the whole life performance of the systems.

1.1 Types of system outages and deficits

The amount of the generation reserve and the likelihood of severe outages must be taken into account in a bulk generation model. When a generating unit malfunctions, the unit must be taken out of service and fixed or replaced. Such interruptions may jeopardize the system's capacity to meet the load, which will have an impact on system dependability. Depending on the specified margins of generation, an outage may or may not result in a service interruption. A unit may experience outages as a result of scheduled maintenance or other tasks that are necessary to keep it in excellent working order. Two types of outages can be distinguished:

a) When a component is purposefully pulled out of service for preventative maintenance or scheduled repairs, there is a planned outage that follows.

b) a forced outage brought on by unforeseen and urgent circumstances that necessitate taking the producing unit out of service

A generating unit's status is defined as morphing into one of the several potential states, as seen in Figure 1.1.

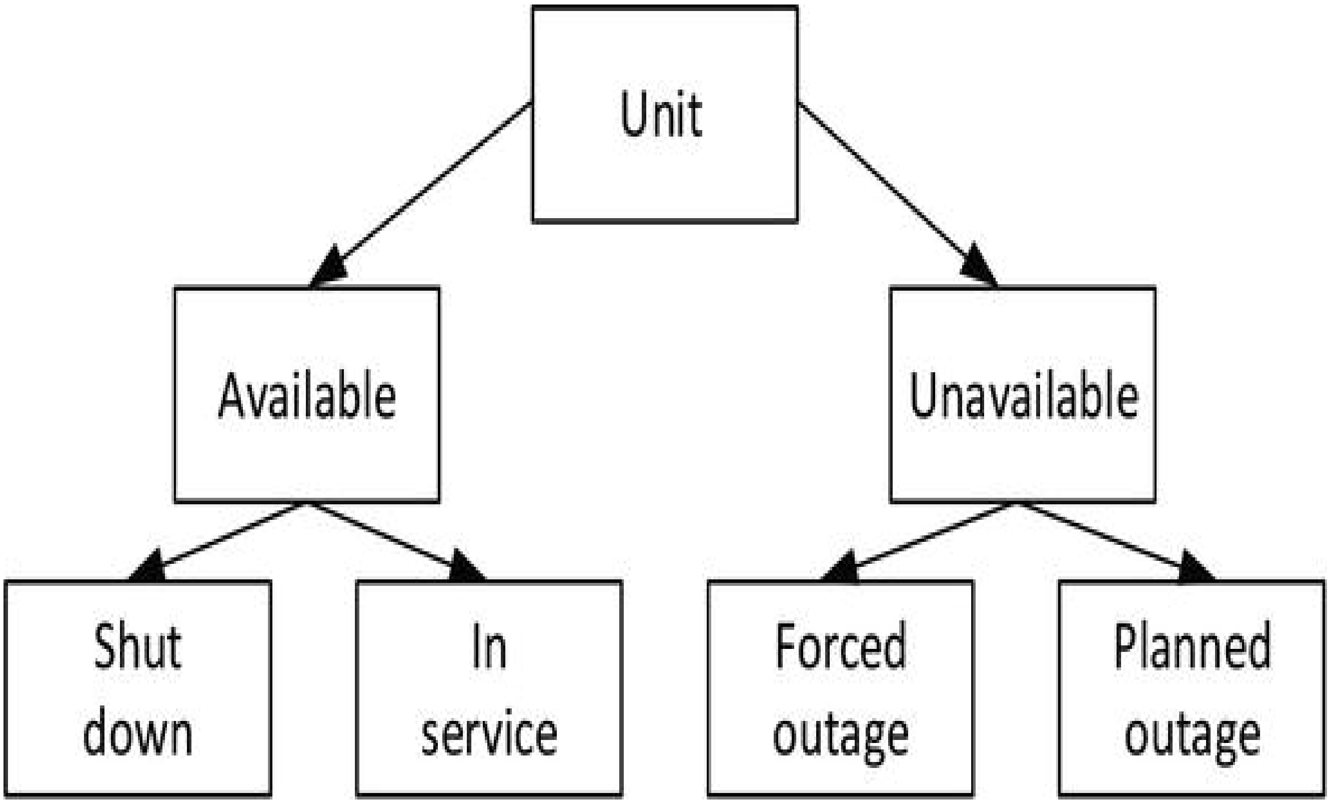

Figure 1.1

Creating likely unit states. It is critical to understand a unit's likelihood of existing in each condition, as shown in Figure 1, in order to study its impact on system generation dependability. So, some fundamental probability ideas are introduced in the part that follows.

1.2 Introduction to power system reliability evaluation

1.2.1 Availability (AV) and forced outage rate (FOR)

Experience has taught us that no machine is so trustworthy and dependable that it is always accessible and running successfully. That indicates that the machine must be taken out of service (out of commission) for repair or that there may be other issues preventing it from operating (see Figure 1.1). Therefore, both forced and planned outages are considered to be in an off-service position. Planned outages, also known as scheduled outages, occur when a unit is intentionally turned off or removed from service for upkeep or replacement. Forced outages are those that occur when a unit or units are taken out of service due to a malfunction (also called unscheduled or unplanned outage). The last one is the most severe and significant element in the design and operation of the power system.

Forced outage rate FOR= sum of time unit being out of service Total time considered for unit service.

FOR = t 1 + t 2 + t 3 Total time

Also, availability can be defined as: Availability AV= Time unit is being in service Total time considered for unit service.

AV+FOR=1

This can be seen in Figure 1.2

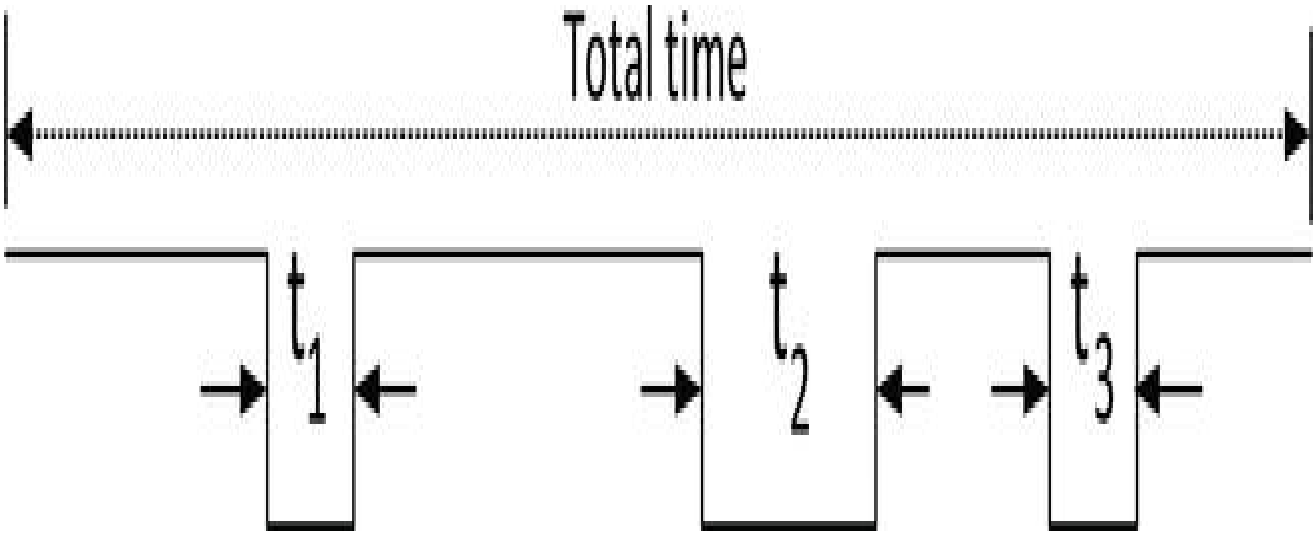

Figure 1.2 - Unit being available and unavailable.

The two terms ‘availability and forced outage rate’ represent the probability of successful and/or failure event occurrences. According to the probability theory it is known that the product $AV_1 \times AV_2$ represents the probability that both unit 1 and unit 2 are simultaneously in operation during a specified interval of time, and, also, $AV_1 \times AV_2 \times AV_3$ means 1 and 2 and 3 are in operation at the same time, and $FOR_1 \times FOR_2 \times FOR_3$ means that units 1, 2, and 3 are out of service in the same time.[17]

Also, $AV_1 \times FOR_2$ means the probability that unit 1 is available (in service) and unit 2 is unavailable (out of service) in the same time. [17]

Two models, namely, capacity model and load model, are required for system generation reliability evaluation (including system expansion planning and/or systems interconnection); they are illustrated and further explained in the next two parts. [17]

1.2.2 Capacity model

The capacity model is known as the "Capacity Outage Probability Table (COPT)" It lists all capacity statuses (available and unavoidable) according to the severity of the outage. The corresponding chance is doubled by each outage (capacity status). The binomial distribution can be employed if the system has identical units.

Capacity expansion models simulate generation and transmission capacity investment, given assumptions about future electricity demand, fuel prices, technology cost and performance, and policy and regulation. [17]

1.2.3 Load model

Tbe load model is known as 'load duration curve (LDC)' This one should be used instead of the standard load variation curve since it is the most advantageous. There are several LDC facts that you should be aware of, and they are as follows:

All load levels are arranged in the LDC in descending order of magnitude.

The system's energy requirements are represented by the area underneath the LDC (consumed).

LDC can be applied to reliability assessment, power system planning, and power system operation.

In comparison to the standard timely load fluctuation curve, it is easier to manage.

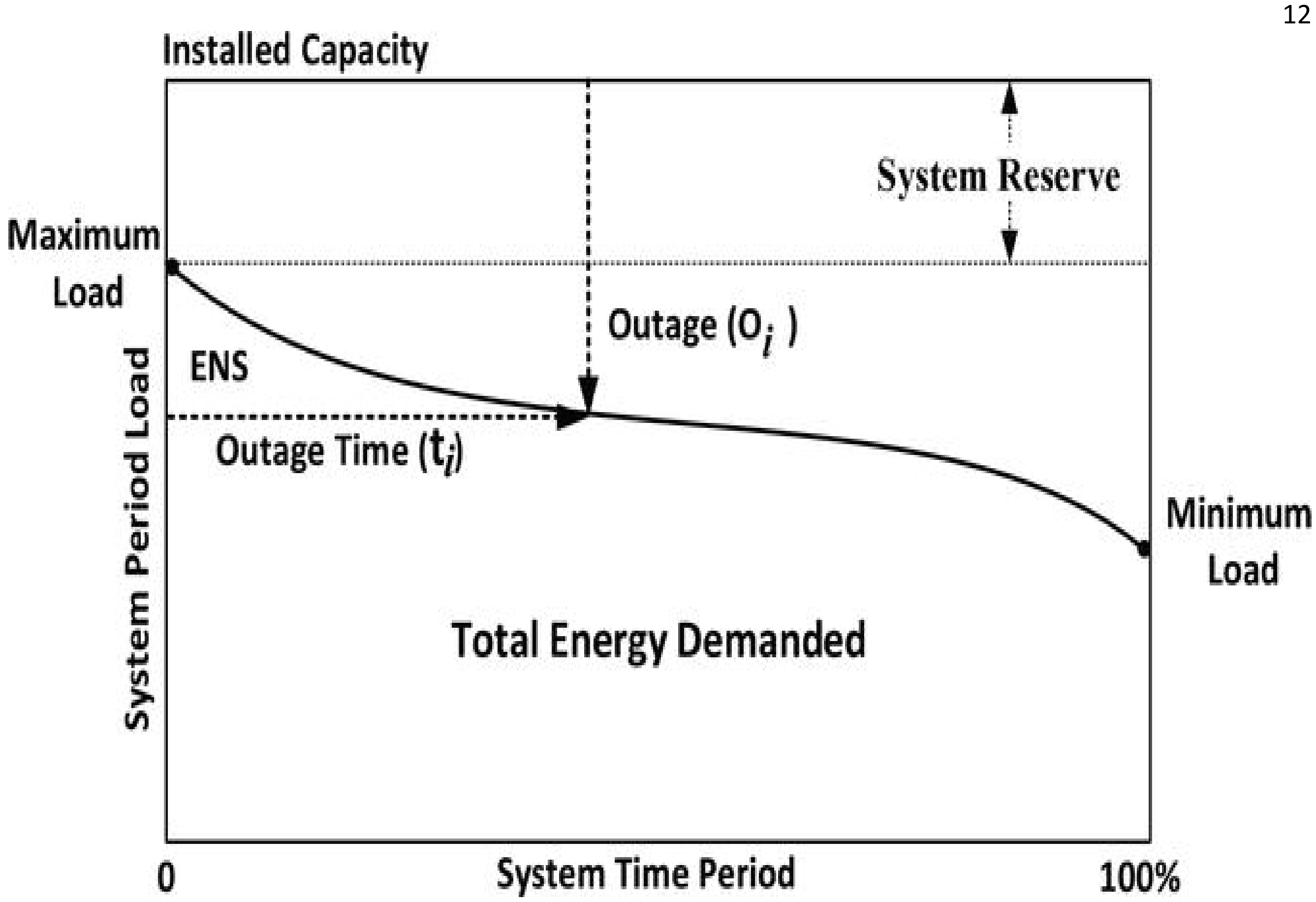

Figure 1.3 - Illustrates the load duration curve discussed previously and includes all necessary subtitles.

System load duration curve, where O_i is the i^{th} outage(s) state in the COPT, t_i is the number of times unit(s) is unavailable, P_i is the probability of this i^{th} unavailable, and is the energy not supplied due to severe outage(s) occurrence. [17]

1.2.4 Loss of load expectation (LOLE)

When assessing the dependability of power generation for system expansion and interconnection, the LOLE risk index is the most extensively used and recognized probabilistic measure. In the procedure, the two models—the COPT and the LDC—mentioned in the sections above are convolved (mixed). The LOLE is measured in days per year (d/y), not hours. The following mathematical formula represents the LOLE assessment method:

LOLE = ∑ i = 1 n t i · p i o i days / year L max > Reserve

By paying attention to the calculation above, the LOLE would only be valid if the maximum load (L_{max}) exceeds the system reserve.

1.2.5 Expected demand not supplied (ϵDNS)

In order to estimate the amount and magnitude of the load lost owing to severe outages a dependability index other than the LOLE may be necessary. (i.e., when the power goes out for an extended period of time, $L_{max} > system\ reserve$), Hence, the ϵDNS can be obtained as follows:

$$\epsilon DNS = \sum_{i=1}^{n} DNS_i \cdot p_i \ MW/year \quad L_{max} > Reserve$$

1.2.6. Expected energy not supplied (ϵENS)

Power systems are actually energy systems, hence it is possible to determine the expected energy not supplied index as shown in Figure 4. The energy sale, which is the actual revenue for any electric firm, is calculated using the ENS index.

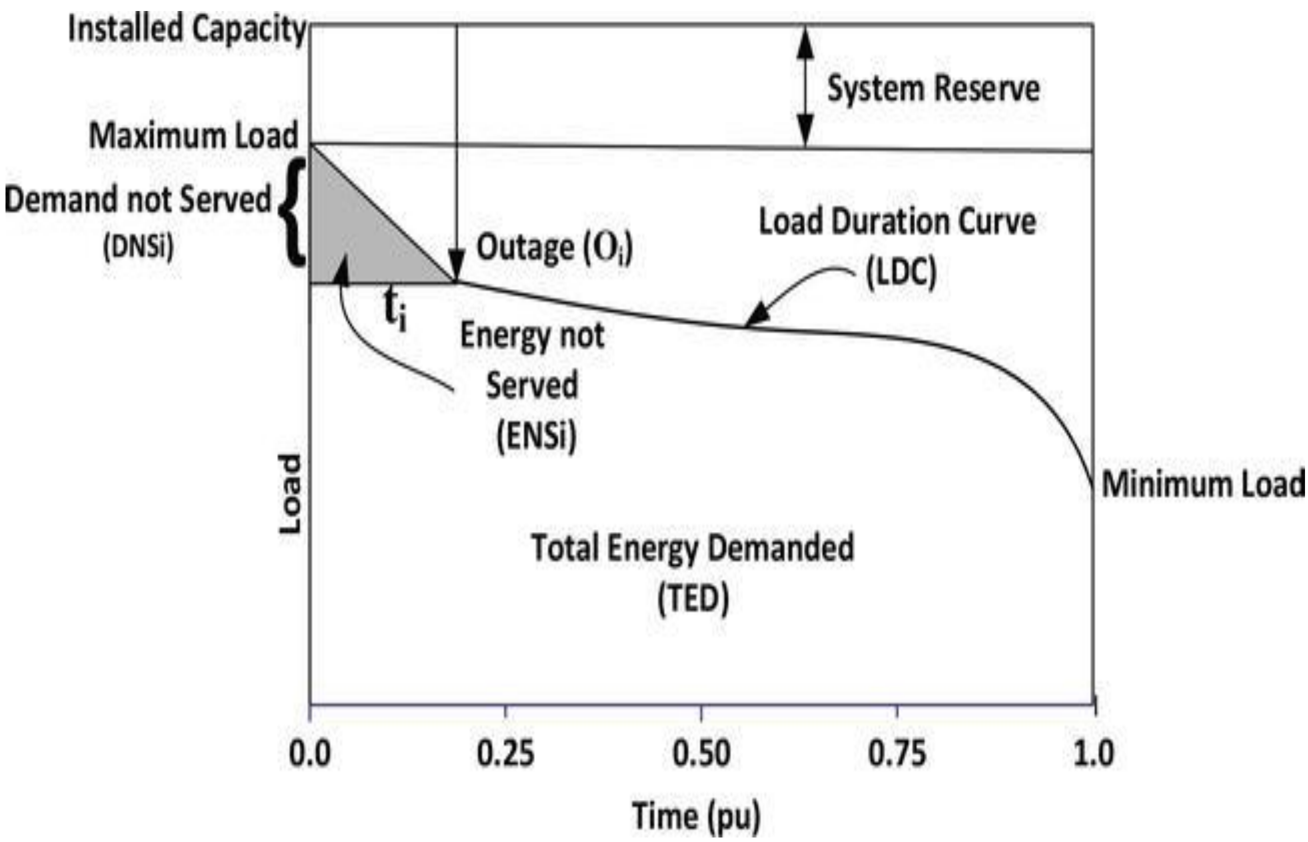

Figure 1.4

Load duration curve with energy not served.

$$\epsilon ENS = \sum_{i=1}^{n} ENS_i \cdot p_i \ MWh/year \quad L_{max} > Reserve$$

2 CALCULATION AND RESEARCH SECTION

2.1 Statement of electrical loads. Categories of consumers

Initial data for calculation:

1. General plan of the institute;
2. Information on electrical loads of the institute;
3. Power can be supplied from the substation of the power system, which has two three-winding transformers with a capacity of 15,000 kVA each, with a primary voltage of 110 kV and a secondary voltage of 35, 20, 10 and 6 kV;
4. System capacity 700 MVA; the reactance of the system on the 110 kV side, attributed to the power of the system 0.7;
5. The cost of electricity is 2.5 UAH / kWh;
6. The distance from the power system substation to the institute is 4.8 km.

According to the [10], the receivers of electricity of industrial enterprises are divided into 3 categories according to the required degree of uninterrupted power supply:

Category 1 - receivers, interruptions in the power supply of which may endanger human life and health or significant economic damage caused by damage to equipment, prolonged disruption of complex technological processes or mass shortages of products.

The first category includes special groups of receivers whose sudden power outages threaten people's lives with explosions and destruction of basic technological equipment, ie receivers that require particularly high uninterruptible power supply, as their uninterrupted operation is required to stop production. A special group includes, for example, emergency ventilation receivers, emergency lighting of some shops of some chemical industries.

2nd category - receivers, power outages which are associated only with mass shortages of products, downtime of people, machinery and industrial transport (rolling mills, electric arc furnaces, metal cutting machines, stamping presses and the like);

Category 3 - all other receivers that do not fit the definition of the 1st and 2nd category (for example, receivers of auxiliary shops, irresponsible warehouses).

Define the categories of receivers and summarize them in table. 2.1

Table 2.1 - Categories of receivers and consumers of electricity for uninterrupted power supply

№	Name of the consumer	Category	The nature of the environment
1	Administrative and economic building	II - 10%, III - 90%	Normal environment
2	Dining room	II - 10%, III - 90%	Normal environment
3	High voltage housing	II - 70%, III - 30%	Hot environment
4	Repair and mechanical shop	II - 30%, III - 70%	Hot environment
5	Low temperature laboratory Laboratory of low temperatures (10 kV)	I - 70%, II - 20%, III - 10% I - 70%, II - 20%, III - 10%	Cold environment Cold environment
6	Electrophysical body	II - 70%, III - 30%	Hot environment
7	Machine case Machine housing (10 kV)	I - 70%, II - 20%, III - 10% I - 70%, II - 20%, III - 10%	Hot environment Hot environment
8	Laboratory of special works Laboratory of special works (10 kV)	I - 70%, II - 20%, III - 10% I - 70%, II - 20%, III - 10%	Normal environment Normal environment
9	Central material composition	III - 100%	Normal environment
10	Boiler room	II - 70%, III - 30%	Hot environment
11	Pump Pump (10 kV)	I - 70%, II - 20%, III - 10% I - 70%, II - 20%, III - 10%	Normal environment Normal environment
12	Repair and construction shop	II - 30%, III - 70%	Normal environment
13	The main building of the research plant Main building of the research plant (10 kV)	I - 70%, II - 20%, III - 10% I - 70%, II - 20%, III - 10%	Normal environment Normal environment
14	Fire station	II - 10%, III - 90%	Normal environment

2.2 Determination of the estimated loads on the shops and the enterprise as a whole

The first stage of power supply design is to determine the expected electrical loads. According to the magnitude of the calculated electrical loads, the number and power of substation transformers, cross-section and brand of conductors, switching equipment are chosen at different stages of the power supply system. Capital costs, operating costs and direct reliability of electrical equipment depend on the correct assessment of expected loads.

To determine the design loads, we use the method of utilization.

We will show this calculation on an example of the administrative and economic case.

The results of the calculation for the whole enterprise are summarized in table. 2.2

Determine the estimated power load of the administrative and economic building below 1 kV [8, 13, 15]:

$$P_c = P_c \cdot K_{use} = 100 \cdot 0,5 = 50 \text{ kWt},$$
$$Q_c = P_c \cdot tg\phi = 50 \cdot 0,75 = 37,5 \text{ kVAr},$$

where Kuse - utilization factor, is from reference materials.

We find the nominal lighting power and the estimated lighting load of the housing:

$$P_{nom.l} = F \cdot P = 246 \cdot 20 = 4,92 \text{ kWt},$$
$$P_{c.l} = P_{nom} \cdot K_{use.l} = 4,92 \cdot 0,9 = 4,43 \text{ kWt},$$

whereP - from reference materials;

Kuse.l - coefficient of use for lighting, is from reference materials.

Find the full design power of the case:

$$P_{c\Sigma} = P_c + P_{c.l} = 50 + 4,43 = 54,43 \text{ kWt},$$
$$Q_{c\Sigma} = Q_c = P_c \cdot tg\phi = 50 \cdot 0,75 = 37,5 \text{ kVAr},$$

$$S_c = \sqrt{P_{c\Sigma}^2 + Q_{c\Sigma}^2} = \sqrt{54,43^2 + 37,5^2} = 66,1 \text{ kVA}.$$

The calculation of loads above 1 kV is performed similarly, but without taking into account the lighting load.

Table 2.2 - The results of the calculation for the whole enterprise

№	Shop	Power load				
		Pnom, kW	Kuse	cosφ	Pp, kW	Qp, kVAR
Up to 1 kV		1	2	3	4	5
1	Administrative and economic building	100	0,50	0,80	50,00	37,50
2	Dining room	360	0,45	0,90	162,00	78,46
3	High voltage housing	760	0,35	0,80	266,00	199,50
4	Repair and mechanical shop	360	0,50	0,80	180,00	135,00
5	Low temperature laboratory	600	0,80	0,85	480,00	297,48
6	Electrophysical body	1200	0,40	0,75	480,00	423,32
7	Machine case	1500	0,80	0,85	1200,00	743,69
8	Laboratory of special works	2100	0,80	0,80	1680,00	1260,00
9	Central material composition	200	0,35	0,80	70,00	52,50
10	Boiler room	500	0,65	0,80	325,00	243,75
11	Pump	300	0,80	0,80	240,00	180,00
12	Repair and construction shop	220	0,50	0,80	110,00	82,50
13	The main building of the research plant	690	0,80	0,80	552,00	414,00
14	Fire station	100	0,35	0,70	35,00	35,71
15	Lighting of the institute					
Together up to 1 kV		8990	8990			5830,00
Above 1 kV						
Laboratory of low temperatures (10 kV)		2900	2900	0,80	0,85	2320,00
Machine housing (10 kV)		1700	1700	0,80	0,85	1360,00
Laboratory of special works (10 kV)		2400	2400	0,80	0,80	1920,00
Pump (10 kV)		1200	1200	0,80	0,80	960,00
Main building of the research plant (10 kV)		1800	1800	0,80	0,80	1440,00
Together above 1 kV		10000	10000			8000,00
Together at the institute		18990	18990			13830,00

Continuation of table 2.2

Up to 1 kV		1	6	7	8	9
1	246,00	20,00	4,92	0,90	4,43	4.43
2	180,00	20,00	3,60	0,90	3,24	3.24
3	570,00	16,00	9,12	0,95	8,66	8.66
4	270,00	16,00	4,32	0,95	4,10	4.10
5	150,00	20,00	3,00	0,95	2,85	2.85
6	432,00	16,00	6,91	0,95	6,57	6.57
7	516,00	16,00	8,26	0,95	7,84	7.84
8	240,00	18,00	4,32	0,95	4,10	4.10
9	264,00	13,00	3,43	0,60	2,06	2.06
10	144,00	14,00	2,02	0,95	1,92	1.92
11	180,00	15,00	2,70	0,95	2,57	2.57
12	264,00	16,00	4,22	0,95	4,01	4.01
13	828,00	20,00	16,56	0,85	14,08	14.08
14	210,00	16,00	3,36	1,00	3,36	3.36
15	21822,00	2,00	43,64	1,00	43,64	43.64
Together up to 1 kV		8990	26316			113,43
Above 1 kV						
Laboratory of low temperatures (10 kV)		2900				
Machine housing (10 kV)		1700				
Laboratory of special works (10 kV)		2400				
Pump (10 kV)		1200				
Main building of the research plant (10 kV)		1800				
Together above 1 kV		10000				
Together at the institute		18990	26316			113,43

Continuation of table 2.2

Up to 1 kV		11	12	13	14
1	54,43	37,50	66,10	0,75	0.75
2	165,24	78,46	182,92	0,48	0.48
3	274,66	199,50	339,47	0,75	0.75
4	184,10	135,00	228,30	0,75	0.75
5	482,85	297,48	567,13	0,62	0.62
6	486,57	423,32	644,94	0,88	0.88
7	1207,84	743,69	1418,44	0,62	0.62
8	1684,10	1260,00	2103,28	0,75	0.75
9	72,06	52,50	89,16	0,75	0.75
10	326,92	243,75	407,78	0,75	0.75
11	242,57	180,00	302,06	0,75	0.75
12	114,01	82,50	140,73	0,75	0.75
13	566,08	414,00	701,31	0,75	0.75
14	38,36	35,71	52,41	1,02	1.02
15	43,64				
Together up to 1 kV			5943,43	4183,41	7268,1
Above 1 kV					
Laboratory of low temperatures (10 kV)		2320,00	1437,81	2729,41	0,62
Machine housing (10 kV)		1360,00	842,85	1600,00	0,62
Laboratory of special works (10 kV)		1920,00	1440,00	2400,00	0,75
Pump (10 kV)		960,00	720,00	1200,00	0,75
Main building of the research plant (10 kV)		1440,00	1080,00	1800,00	0,75
Together above 1 kV		8000,00	5520,66	9719,96	
Together at the institute		13830,0	9704,07	16988,06	

2.3 Determination of the estimated load on the enterprise as a whole, taking into account compensating devices and power losses in transformers

Initial data:

1. Total load up to 1 kV:

$$\sum P_c = 5943,43 \text{ kWt},$$

$$\sum Q_c = 4183,41 \text{ kVAr},$$

$$P_{c.l.} = 43,64 \text{ kWt}.$$

2. Total load above 1 kV:

$$\sum P_c^{'} = 8000 \text{ kWt},$$

$$\sum Q_c^{'} = 5520,66 \text{ kVAr}.$$

Determine the estimated capacity of the institute as a whole.

1. Total load power up to 1 kV, point 1:

$$S_{c1} = \sqrt{\left(\sum P_c + P_{\text{c.l}}\right)^2 + \sum Q_c^{\,2}} = \sqrt{\left(5943,3 + 43,64\right)^2 + 4183,41^2} = 7303,83 \text{ kVA}.$$

We take into account the losses in the shop transformer substations (CTP):

$$\Delta P_{\text{CDS}} = 0,02 \cdot S_{c1} = 0,02 \cdot 7303,83 = 146,08 \text{ kWt},$$

$$\Delta Q_{\text{CDS}} = 0,1 \cdot S_{\text{p1}} = 0,1 \cdot 7303,83 = 730,38 \text{ kVAr}.$$

2. Calculate the load at point 2:

$$P_{c2} = \sum P_c + P_{\text{c.l}} + \Delta P_{CDS} = 5943,43 + 43,64 + 146,08 = 6133,15 \text{ kWt},$$

$$Q_{\text{c2}} = \sum Q_c + \Delta Q_{\text{CDS}} = 4183,41 + 730,38 = 4913,79 \text{ kVAr},$$

$$S_{c2} = \sqrt{P_{\text{c2}}{}^2 + Q_{\text{c2}}{}^2} = \sqrt{6133,15^2 + 4913,79^2} = 7855,81 \text{ kVA}.$$

3. Calculate the load at point 3.

Total estimated capacity at point 3:

$$P_{c3} = P_{\text{c2}} + \sum P_{\text{c}}^{'} = 6133,15 + 8000 = 14133,15 \text{ kWt},$$

$$Q_{c3} = Q_{c2} + \sum Q_{с}^{'} = 4913,79 + 5520,66 = 10434,45\,\text{kVAr}.$$

$$Q_{ci} = P_{с} \cdot (tg\phi_{н} - tg\phi_{з}) = 17666,44 \cdot (0,74 - 0,35) = 6859,81\,\text{kVAr},$$

$$P_{с} = P_{с3} \cdot \frac{T_{м}}{T} = 14133,15 \cdot \frac{3000}{2400} = 17666,44\,\text{kWt},$$

$$tg\phi_{н} = \frac{Q_{с3}}{P_{с3}} = \frac{10434,45}{14133,15} = 0,74.$$

Calculate the losses in the compensating device

$$\Delta P_{ci} = 0,002 \cdot Q_{ci} = 0,002 \cdot 6859,81 = 13,72\ \text{kWt},$$

$$P'_{c} = P_{c3} * \text{k}_{\text{PM}} + \Delta \text{P}_{\text{ci}} = 14133,15 * 0,95 + 13,72 = 13440,21\ \text{kWt}$$

$$Q'_{c} = Q_{c3} * \text{k}_{\text{PM}} - \Delta \text{Q}_{\text{ci}} = 10434,45 * 0,95 - 6859,81 = 3052,92\ \text{kWt}$$

$$S_{с3} = \sqrt{P_{с3}^{\ 2} + \left(Q_{с3}\right)^2} = \sqrt{14133,15^2 + 10434,45^2} = 17567,69\ \text{kVA}.$$

Calculate the losses in the the main step-down substation:

$$\Delta P_{\text{MSS}} = 0,02 \cdot S_{с3} = 0,02 \cdot 17567,69 = 351,35\ \text{kWt},$$

$$\Delta Q_{\text{MSS}} = 0,1 \cdot S_{с3} = 0,1 \cdot 17567,69 = 1756,77\ \text{kVAr}.$$

Full estimated capacity of the enterprise taking into account the diversity of the maximum:

$$S'_{c} = \sqrt{(P'_{c} + \Delta P_{MSS})^2 + \left(Q'_{c} + \Delta Q_{\text{MSS}}\right)^2} =$$
$$= \sqrt{(13440,21 + 351,35)^2 + \left(3052,92 + 1756,77\right)^2} = 14606,18\ \text{kVA}.$$

2.4 Choice of voltage of power lines and distribution networks

Power can be supplied from the substation of the power system, which has two three-winding transformers with a capacity of 15,000 kVA each, with a primary voltage of 110 kV and a secondary voltage of 35, 20, 10 and 6 kV.

To determine the voltage of the supply line, we use two methods:

1. Using empirical formulas:

They use the power and length of the power line. Here are the most famous of them:

1) $U = 3\sqrt{3} + 0{,}5 \cdot l,$

2) $U = 3.34 \cdot \sqrt{l + 16 \cdot P},$

3) $U = 16\sqrt[4]{P \cdot l},$

4) $U = 17\sqrt{l/(16 + P)}.$

2. By nomograms:

Nomograms are a graph of the dependence of the power supply voltage of industrial enterprises on the transmitted power S, long power lines L, power supply circuit, line design and the cost of electricity.

Select the voltage of the supply line 35 kV according to the nomogram from the directory [5].

Thus, based on these solutions obtained by these two methods, we take the voltage of the distribution network equal to 10 kV.

10 kV voltage is widely used in medium-power industrial enterprises - for power supply and distribution networks, in large enterprises - in the second and subsequent stages.

According to the nomograms, we choose the primary voltage at the 35 kV main step-down substation, and the secondary 10 kV, because all high-voltage loads are designed for 10 kV.

Choice of transformer on main step-down substation [11, 14]:

$$K_{load.nom} = \frac{S_c}{S_{nom.tr}} = \frac{14606{,}18}{10000 * 2} = 0{,}7$$

$$K_{load.em} = K_{load.nom} * 2 = 0{,}7 * 2 = 1{,}4$$

2.5 Map of loads and determination of the center of electrical loads (CEL)

2.5.1 Load map

In order to determine the location of the central distribution substation or main step-down substation, as well as shop transformer substation in the design build a map of electrical loads. The cartograms are located on the general plan of the enterprises or the plan of the circle shop, the area of which corresponds to the selected scale of the design load.

The radii of the circles of the cartogram are determined by the formula:

$$r_i = \sqrt{\frac{P_i}{\pi \cdot m}},$$

where P_i - capacity of the i-th shop;

m- scale to determine the area of the circle (constant for all shops of the enterprise).

Power loads up to and above 1 kV are represented by separate circles.

Lighting load is applied in the form of a sector of the circle, which depicts the load up to 1 kV. Sector angle(α)determined from the ratio of active calculations$P_{p\sum}$ and lighting loads$P_{p\sum}$ shops.

When constructing a cartogram, it is necessary to know the full design and lighting loads of the shops, which were calculated in table. 2.2.

Table 2.3 - Full design and lighting loads of shops

№	The name of the shop	Xi, m	Yi, m	Pci, kW	Pcoi, kW	Ri, m	αi, °
Load up to 1 kV							
1	Administrative and economic corps	39	270	54,43	4,43	1,32	29,29
2	Dining room	108	291	165,24	3,24	2,29	7,06
3	High voltage housing	287,25	274,5	274,66	8,66	2,96	11,36
4	Repair and mechanical shop	459	243	184,10	4,10	2,42	8,03
5	Low temperature laboratory	36	135	482,85	2,85	3,92	2,12
6	Electrophysical body	108	165	486,57	6,57	3,94	4,86
7	Machine case	261,75	165	1207,84	7,84	6,20	2,34
8	Laboratory of special works	402	135	1684,10	4,10	7,32	0,88
9	Central material composition	456	141	72,06	2,06	1,51	10,29
10	Boiler room	48	36	326,92	1,92	3,23	2,11

Continuation of table 2.2

11	Pump	117	42	242,57	2,57	2,78	3,81
12	Repair and construction shop	219	36	114,01	4,01	1,91	12,67
13	The main building of the research plant	357	42	566,08	14,08	4,25	8,95
14	Fire station	483	45	38,36	3,36	1,11	31,53
Load above 1 kV							
1	Low temperature laboratory (10 kV)	36	135	2320	-	8,60	-
2	Machine housing (10 kV)	261,75	165	1360	-	6,58	-
3	Laboratory of special works (10 kV)	402	135	1920	-	7,82	-
4	Pump (10 kV)	117	42	960	-	5,53	-
5	The main building of the research factory (10 kV)	357	42	1440	-	6,77	-

2.5.2 Determination of the conditional center of electrical loads

The load center of a shop or enterprise is a symbolic center of electricity consumption of a shop or enterprise. The main step-down substation should be located in the CEL. This will reduce the cost of conductive material and reduce electricity losses.

The coordinates of the center of electrical loads of the entire enterprise will be determined by the formula [6]:

$$X_0 = \frac{\sum P_{ci} \cdot X_i}{\sum P_{ci}};$$

$$Y_0 = \frac{\sum P_{ci} \cdot Y_i}{\sum P_{ci}}.$$

The data obtained in the calculation will be entered in table. 2.4

Table 2.4 - Data for finding the CEL

№	The name of the shop	Xi, m	Yi, m	Pci, kW	Pci * Xi, kW m	Pci * Yi, kW
Load up to 1 kV						
1	Administrative and economic building	39,00	270,00	54,43	2122,69	14695,56
2	Dining room	108,00	291,00	165,24	17845,92	48084,84
3	High voltage housing	287,25	274,50	274,66	78897,23	75395,27
4	Repair and mechanical shop	459,00	243,00	184,10	84503,74	44737,27
5	Low temperature laboratory	36,00	135,00	482,85	17382,60	65184,75
6	Electrophysical body	108,00	165,00	486,57	52549,17	80283,46
7	Machine case	261,75	165,00	1207,84	316152,96	199294,13
8	Laboratory of special works	402,00	135,00	1684,10	677009,81	227354,04
9	Central material composition	456,00	141,00	72,06	32859,00	10160,35
10	Boiler room	48,00	36,00	326,92	15691,93	11768,95
11	Pump	117,00	42,00	242,57	28380,11	10187,73
12	Repair and construction shop	219,00	36,00	114,01	24968,80	4104,46
13	The main building of the research plant	357,00	42,00	566,08	202089,13	23775,19
14	Fire station	483,00	45,00	38,36	18527,88	1726,20
Loads above 1 kV						
1	Laboratory of low temperatures (10 kV)	36,00	135,00	2320,00	83520,00	313200,00
2	Machine housing (10 kV)	261,75	165,00	1360,00	355980,00	224400,00
3	Laboratory of special works (10 kV)	402,00	135,00	1920,00	771840,00	259200,00
4	Pump (10 kV)	117,00	42,00	960,00	112320,00	40320,00
5	Main building of the research plant (10 kV)	357,00	42,00	1440,00	514080,00	60480,00
Total				13899,79	3406720,96	1714352,19

After the calculations we get the coordinates of the CEL

$$x = 245.09;\ y = 123.34.$$

All known methods of finding the CEL come down to the fact that the center of electrical loads is defined as a fixed point on the master plan of the industrial enterprise. Studies have shown that this position cannot be considered correct and the CEL should be considered as a conditional center, as its definition does not solve the problem of choosing the location of the substation, because in fact the CEL is shifted across the enterprise. This is due to changes in power consumption by individual receivers in accordance with the schedules of their loads and with the development of the enterprise.

If for some reason it is impossible to place the power supply at a point with the found coordinates, it is shifted towards the external power supply. At the same time, the annual reduced costs for the power supply system due to this shift increase.

In this work, when detecting the CEL, it became clear that you can not put the main step-down substation in the CEL and can not be shifted towards the external power supply, as the distance between the shops does not allow you to install the main step-down substation. Therefore, it was necessary to install a main step-down substation in the CEL scattering zone, shifting it to the west, taking into account that in the western part of the enterprise there is a large undeveloped area and it is likely to be built up, which will shift the CEL. The air line 35 kV will run along the boundaries of the enterprise to the main step-down substation.

2.6 Number and power of central distribution substation transformers taking into account the capasitor installation

Preliminary selection of the number and power of transformers of shop substations is made on the basis of the necessary degree of reliability of power supply and distribution between transformer substation of electricity consumers up to 1 kV. The plant has equipment that belongs to consumers of I and II categories, and requires high reliability of power, so the shop substations are made with two working transformers. Normal mode of operation - separate operation of transformers, this is provided in order to reduce short-circuit currents and allows you to use lighter and cheaper equipment on the lower voltage side of transformers.

Nominal power of shop transformers (Snt) is selected according to the calculated capacity, based on the conditions of economic operation of transformers (60-80%) in normal mode and allowable overload (30-40%) of Snt in post-emergency mode.

According to 14209-85 and 11677-75 shop transformers have the following nominal capacities: 400, 630, 1000, 1600 kVA.

The number of transformers is determined based on the total rated capacity of the shop, the rated power of the transformer and the recommended value of the load factor.

Values are recommended for shops of I and II categories at two-transformer substations$К_З$= 0.65-0.7.

Values are recommended for category II shops with single-transformer substations$К_З$= 0.7-0.8.

Values are recommended for category III shops with single-transformer substations$К_З$= 0.9-0.95.

We use Nokian Capacitors automatic capacitor banks to compensate for reactive power consumption and power factor correction. Adjusting the power factor avoids additional financial costs associated with reactive power consumption. Automatic capacitor banks consist of the necessary set of stages controlled by a digital reactive power controller, which provides the necessary accuracy of control of the generated power of the capacitor bank.

All data of selection and calculation are summarized in table. 2.5, 2.6, 2.7.

Table 2.5 - Selection of the number and power of transformers taking into account the compensating devices (option №1)

№	№ TS	Electric consumers energy	Estimated load.		Qci, kVAR	Quantity and power of ci		Full load		Number of transformer	Cnom.tr.	Kld	Kload
			Rc, kW	Qc, kVAR		N	Qci.st	Qc, kVAR	Sc, kVA				
1	TS1	3,2	439,90	277,96	123,99	2	50	177,96	474,54	2	400	0,6	1,19
2	TS2	5,1	537,28	334,98	146,93	2	50	234,98	586,41	2	400	0,73	1,47
3	TS3	6	486,57	423,32	253,02	2	125	173,32	516,51	2	400	0,65	1,29
4	TS4	7	1207,84	743,69	320,95	2	150	443,69	1286,76	2	1000	0,64	1,29
5	TS5	8,9,4	1940,27	1447,50	768,41	2	375	747,50	2079,28	2	1600	0,65	1,30
6	TS6	10	326,92	243,75	129,33	1	125	118,75	347,81	1	400	0,87	-
7	TS7	11,12	356,58	262,50	137,70	2	50	162,50	391,86	2	400	0,51	0,98
8	TS8	13,14	604,44	449,71	238,15	2	100	249,71	653,99	2	400	0,82	1,63
9	asynchronous motor	5,7,8,11,13	8000,00	5520,66	2320,66	2	1200	3120,66	8587,11	-	-	-	-

Table 2.6 - Selection of the number and power of transformers taking into account the compensating devices (option №2)

№	№ TS	Electric consumers energy	Estimated load.		Qci, kVAR	Quantity and power. ci		Full load		Number of transformer	Cnom.tr.	Kld	Kload
			Rc, kW	Qc, kVAR		N	Qci.st	Qc, kVAR	Sc, kVA				
1	TS1	3,4,9,14	569,19	422,71	223,49	2	100	222,71	611,21	2	400	0,76	1,53
2	TS2	5	482,85	297,48	128,48	2	50	197,48	521,67	2	400	0,65	1,30
3	TS3	6	486,57	423,32	253,02	2	125	173,32	516,51	2	400	0,65	1,29
4	TS4	7	1207,84	743,69	320,95	2	150	443,69	1286,76	2	1000	0,64	1,29
5	TS5	8	1684,10	1260,00	670,56	2	325	610,00	1791,17	2	1600	0,56	1,12
6	TS6	10	326,92	243,75	129,33	1	125	118,75	347,81	1	400	0,87	0,87
7	TS7	11,12	356,58	262,50	137,70	2	50	162,50	391,86	2	400	0,51	0,98
8	TS8	13	566,08	414,00	215,87	2	100	214,00	605,18	2	400	0,76	1,51
9	asynchronous motor	5,7,8,11,13	8000,00	5520,66	2320,66	2	1200	3120,66	8587,11	-	-	-	-

Table 2.7 - Selection of the number and power of transformers taking into account the compensating devices (option №3)

№	№ TS	Electricity consumers	Estimated load.		Qci, kVAR	Quantity and power. ci		Full load		Number of transformer	Cnom.tr.	Kld	Kload
			Rc, kW	Qc, kVAR		N	Qci.st	Qc, kVAR	Sc, kVA				
1	TS1	5	482,85	297,48	128,48	2	50	197,48	521,67	2	400	0,65	1,30
2	TS2	6	486,57	423,32	253,02	1	200	223,32	535,37	1	630	0,85	0,85
3	TS3	1,2,3,7	1702,18	1059,15	463,39	2	225	609,15	1807,89	2	1600	0,56	1,13
4	TS4	4,8,9,14	1978,63	1483,21	790,69	2	375	883,21	2166,80	2	1600	0,68	1,35
5	TS5	10,11,12	683,49	506,25	267,03	2	125	256,25	729,95	2	630	0,6	1,16
6	TS6	13	566,08	414,00	215,87	2	100	214,00	605,18	2	400	0,76	1,51
7	asynchronous motor	5,7,8,11,13	8000,00	5520,66	2320,66	2	1200	3120,66	8587,11	-	-	-	-

2.7 Choice of high voltage motors

In the laboratory of low temperatures we install three high-voltage asynchronous motors, the choice is made on the established active power.

Selected - 3xAZM1-800 / 10000 UHL4 with the following technical data:

$$P_{nom} = 800\,\text{kWt},$$
$$U_{nom} = 10\text{kV},$$
$$\eta = 95{,}8\%,$$
$$N = 2970\text{rot/min},$$

$$\cos\phi = 0{,}9$$

In the machine case we install two high-voltage asynchronous motors, the choice is made on the established active power.

Selected - 1xAZM1-1000 / 10000 UHL4 with the following technical data:

$$P_{nom} = 1000\,\text{kWt},$$
$$U_{nom} = 10\text{kV},$$
$$\eta = 95,8\%,$$
$$N = 2970\text{rot/min},$$
$$\cos\phi = 0,99$$

1xAZM1-400 / 10000 UHL4:

$$P_{nom} = 400\,\text{kWt},$$
$$U_{nom} = 10\text{kV},$$
$$\eta = 95,3\%,$$
$$N = 2980\text{rot/min},$$
$$\cos\phi = 0,91$$

In the laboratory of special works we install two high-voltage asynchronous motors, the choice is made on the established active power.

Selected - 2xAZM1-1000 / 10000 UHL4 with the following technical data:

$$P_{nom} = 1000\,\text{kWt},$$
$$U_{nom} = 10\text{kV},$$
$$\eta = 95,8\%,$$
$$N = 2970\text{rot/min},$$
$$\cos\phi = 0,99$$

In the pump we install two high-voltage asynchronous motors, the choice is made on the established active power.

Selected - 2xAZM1-500 / 10000 UHL4 with the following technical data:

$$P_{nom} = 500\,\text{kWt},$$
$$U_{nom} = 10\text{kV},$$
$$\eta = 95,6\%,$$
$$N = 2980\text{rot/min},$$

$$\cos\phi = 0,92$$

In the main building of the research plant we install two high-voltage induction motors, the choice is made on the installed active power.

Selected - 1xAZM1-1000 / 10000 UHL4 with the following technical data:

$$P_{nom} = 1000\,\text{kWt},$$
$$U_{nom} = 10\text{kV},$$
$$\eta = 95{,}8\%,$$
$$N = 2970\text{rot/min},$$
$$\cos\phi = 0{,}99$$

1xAZM1-500 / 10000 UHL4:

$$P_{nom} = 500\,\text{kWt},$$
$$U_{nom} = 10\text{kV},$$
$$\eta = 95{,}6\%,$$
$$N = 2980\text{rot/min},$$
$$\cos\phi = 0{,}92.$$

2.8 Calculation of central distribution substation losses

Losses in TS are determined by active losses consisting of idling losses (IL) and short circuit (short circuit) and reactive losses consisting of reactive losses IL and short circuit.

Active and reactive losses in central distribution substation are determined by the formulas:

$$\Delta P = \Delta P_{il} + \Delta P_{sh.c} \cdot K_{load}^2$$

$$\Delta Q = \Delta Q_{il} + \Delta Q_{sh.c} \cdot K_{load}^2 = \frac{S_{nom.tr} \cdot i_{il}}{100} + \frac{S_{nom.tr} \cdot u_{sh.c}}{100} \cdot K_{load}^2$$

where K_{load} - load factor;

i_{il} - current IL in percent;

$u_{sh.c}$ - short-circuit voltage in percent.

We show the order of calculation on the example of TS 1 (3 shops for the 1st variant of the scheme):

$$\Delta P = 1{,}05 + 5{,}5 \cdot 0{,}35 = 2{,}99\,\text{kWt},$$

$$\Delta Q = \frac{400 \cdot 2{,}1}{100} + \frac{400 \cdot 4{,}5 \cdot 0{,}35}{100} = 14{,}73\ \text{kVAr}.$$

Active and reactive power, taking into account losses in the central distribution substation:

$$P_c^{'} = n \cdot \Delta P + P_c = 2 \cdot 2{,}99 + 439{,}9 = 445{,}87 \text{ kWt},$$

$$Q_c^{'} = n \cdot \Delta Q + Q_c = 2 \cdot 14{,}73 + 277{,}96 = 307{,}43 \text{kVAr}.$$

Total power, taking into account losses in central distribution substation:

$$S_c^{'} = \sqrt{P_c^{'2} + Q_c^{'2}} = \sqrt{445{,}87^2 + 307{,}43^2} = 541{,}59 \text{ kVA}.$$

All calculation data are summarized in table. 2.8, 2.9, 2.10.

Table 2.8 - Power losses in transformers (option №1)

Number	№TS	Transformer type	Snom.t	Numeric	ΔPil	ΔPsh.c	Iil%	Ush.c %
1	TS1	TM	400	2	1,05	5,5	2,1	4,5
2	TS2	TM	400	2	1,05	5,5	2,1	4,5
3	TS3	TM	400	2	1,05	5,5	2,1	4,5
4	TS4	TM	1000	2	2,45	12,2	1,4	5,5
5	TS5	TM	1600	2	2,35	18	1,3	6,5
6	TS6	TM	400	1	1,05	5,5	2,1	4,5
7	TS7	TM	400	2	1,05	5,5	2,1	4,5
8	TS8	TM	400	2	1,05	5,5	2,1	4,5

Continuation of table 2.8

Kz	Кз²	ΔP	ΔQ	Rc, kW	Qc, kVAR	P'c	Q'c	S'c
0,60	0,36	3,03	14,88	439,90	277,96	445,96	307,72	541,83
0,73	0,54	4,01	18,07	537,28	334,98	545,29	371,12	659,60
0,65	0,42	3,34	15,90	486,57	423,32	493,25	455,13	671,15
0,64	0,41	7,50	36,77	1207,84	743,69	1222,84	817,23	1470,78
0,65	0,42	9,95	64,71	1940,27	1447,50	1960,17	1576,92	2515,74
0,87	0,76	5,21	22,01	326,92	243,75	332,12	265,76	425,36
0,51	0,26	2,48	13,08	356,58	262,50	361,54	288,66	462,64
0,82	0,67	4,73	20,43	604,44	449,71	613,89	490,57	785,82

Table 2.9 - Power losses in transformers (option №2)

Number	№TS	Transformer type	Snom.t	Numeric	ΔPil	ΔPsh.c	Iil%	Ush.c %
1	TS1	TM	400	2	1,05	5,5	2,1	4,5
2	TS2	TM	400	2	1,05	5,5	2,1	4,5
3	TS3	TM	400	2	1,05	5,5	2,1	4,5
4	TS4	TM	1000	2	2,45	12,2	1,4	5,5
5	TS5	TM	1600	2	2,35	18	1,3	6,5
6	TS6	TM	400	1	1,05	5,5	2,1	4,5
7	TS7	TM	400	2	1,05	5,5	2,1	4,5
8	TS8	TM	400	2	1,05	5,5	2,1	4,5

Continuation of table 2.9

Kz	Кз²	ΔP	ΔQ	Rc, kW	Qc, kVAR	P'c	Q'c	S'c
0,76	0,58	4,26	18,91	569,19	422,71	577,71	460,52	738,80
0,65	0,43	3,39	16,05	482,85	297,48	489,63	329,59	590,22
0,65	0,42	3,34	15,90	486,57	423,32	493,25	455,13	671,15
0,64	0,41	7,50	36,77	1207,84	743,69	1222,84	817,23	1470,78
0,56	0,31	7,99	53,38	1684,10	1260,00	1700,08	1366,77	2181,36
0,87	0,76	5,21	22,01	326,92	243,75	332,12	265,76	425,36
0,51	0,26	2,48	13,08	356,58	262,50	361,54	288,66	462,64
0,76	0,57	4,20	18,70	566,08	414,00	574,47	451,40	730,60

Table 2.10 - Power losses in transformers (option №3)

Number	№TS	Transformer type	Snom.t	Numeric	ΔPil	ΔPsh.c	Iil%	Ush.c %
1	TS1	TM	400	2	1,05	5,5	2,1	4,5
2	TS2	TM	630	1	1,56	7,6	2	5,5
3	TS3	TM	1600	2	2,35	18	1,3	6,5
4	TS4	TM	1600	2	2,35	18	1,3	6,5
5	TS5	TM	630	2	1,56	7,6	2	5,5
6	TS6	TM	400	2	1,05	5,5	2,1	4,5

Continuation of table 2.10

Kz	$Кз^2$	ΔP	ΔQ	Rc, kW	Qc, kVAR	P'c	Q'c	S'c
0,65	0,43	3,39	16,05	482,85	297,48	489,63	329,59	590,22
0,85	0,72	7,05	37,62	486,57	423,32	493,61	460,94	675,37
0,56	0,32	8,10	54,00	1702,18	1059,15	1718,37	1167,14	2077,26
0,68	0,46	10,60	68,48	1978,63	1483,21	1999,83	1620,17	2573,77
0,60	0,36	4,30	25,07	683,49	506,25	692,09	556,40	888,01
0,76	0,57	4,20	18,70	566,08	414,00	574,47	451,40	730,60

2.9 Select the cross section of the power line wires

Choose the cross section of overhead wires according to the following values:

$$I_{\text{c.em}} = \frac{S_c}{\sqrt{3} \cdot U_{nom}} = \frac{14606{,}18}{\sqrt{3} \cdot 35} = 240{,}94 \text{ A},$$

$$I_{\text{c.nom}} = \frac{S_c}{2 \cdot \sqrt{3} \cdot U_{nom}} = \frac{14606{,}18}{2 \cdot \sqrt{3} \cdot 35} = 120{,}47 \text{ A}.$$

We accept the minimum admissible section on heating $S_{nom} = 100$ mm^2.

Let's check on economic current density:

$$S_e = \frac{I_{\text{c.nom}}}{j_e} = \frac{120{,}47}{1{,}3} = 92{,}67 \,\text{mm}^2.$$

We accept a wire of AC-100 with a section of 100 mm.

2.10 Choice of cross-section and brand of cable lines with voltage higher and up to 1 kV

The transmission of electricity from the power supply to the receiving point of the industrial enterprise is carried out by air or cable lines. The cross section of wires and cores is selected according to technical and economic conditions.

The technical conditions include the choice of cross section for heating by the rated current, corona conditions, mechanical strength, heating from short-term heat release by short-circuit current, voltage losses in normal and post-emergency modes.

Economic conditions of choice are to determine the cross section of the line, the costs of which will be minimal. Under the conditions of coronation, the minimum allowable cross-sections are selected only for overhead lines. For cable cores, the smallest standard cross-section ensures no corona.

The choice of the cross section for heating is based on the rated current. For parallel lines, the rated current is the post-emergency current when one power line has failed. According to the reference data, depending on the rated current, the nearest larger standard cross section is determined. This section is given for specific environmental conditions and the method of laying cables and wires.

On heating of long-admissible loading current:

$$I_c = \frac{S_c}{\sqrt{3} \cdot U_{nom}} \; ; \; I_c < I_{allow}.$$

After voltage loss:

$$L_{allow} = L_{\Delta u 1\%} \cdot \Delta U_{\text{allow}} \cdot \frac{I_{allow}}{I_{\text{c.nom}}} \geq L_{real}.$$

By economic current density:

$$S_e = \frac{I_c}{j_e}.$$

An example of the calculation of the cable line will be carried out on the line L-1 (main step-down substation-TS1), option №1. According to table. 2.7 determine the estimated rated and calculated emergency current.

$$I_{\text{c}} = \frac{S_c}{\sqrt{3} \cdot U_{nom}} = \frac{491{,}97}{\sqrt{3} \cdot 10} = 28{,}4 \text{ A},$$

$$I_{\text{c.nom}} = \frac{S_c}{n \cdot \sqrt{3} \cdot U_{nom}} = \frac{491{,}97}{2 \cdot \sqrt{3} \cdot 10} = 14{,}2 \text{ A}.$$

According to the reference book [7] we choose AAB cable with Idop = 115 A with a cross section of 35 mm2.

By current density:

$$S_e = \frac{I_{\text{c.nom}}}{j_e} = \frac{14{,}2}{1{,}6} = 8{,}88 \text{ mm}^2.$$

We accept a section of 16 mm2.

After voltage loss:

$$L_{allow} = L_{\Delta u 1\%} \cdot \Delta U_{\text{allow}} \cdot \frac{I_{\text{allow}}}{I_c} \geq L_{\text{real}},$$

$$L_{allow} = 0{,}56 \cdot 5 \cdot \frac{115}{14{,}2} = 95 \text{km},$$

where $L_{\Delta u1\%}$= 0.56 according to (Table P 4.7 of Article 342 [15]);ΔU_{allow}= 5%.

Under all conditions, the selected cable with a cross section of 35 mm2 passes. The choice of cables of other lines is summarized in the table. 2.11 (option №1), 2.12 (option №2) and 2.!3 (option №3).

In the territories of industrial enterprises, cable lines must be laid in the ground (in trenches), tunnels, blocks, canals, overpasses, galleries and on the walls of buildings. We choose the method of laying - in the trenches.

As 10 kV cables have intersections with the railway, it should be remembered that "when crossing cable lines of railways and highways, cables must be laid in tunnels, blocks or pipes along the entire width of the exclusion zone at a depth of at least 1 m from the road and not less than 0.5 m from the bottom of drainage ditches. In the absence of an exclusion zone, these laying conditions should be performed only at the intersection plus 2 m on both sides of the roadway "[10].

One of the important tasks facing the country's energy sector is to solve the problem of security of electricity supply. Power cables previously used for medium, low and high voltage networks are in many cases obsolete. Today, the domestic industry is able to meet the growing demand for new generation power cables - there is an opportunity to buy a cable with improved performance directly from manufacturers. Modern cable production offers consumers three types of power cables: with paper insulation in lead sheath, with insulation of cross-linked polyethylene and ordinary, with insulation of thermoplastic polyethylene. An important advantage of the cable with paper impregnated insulation, designed for low and medium voltage (these are the brands) - stable electrical characteristics. For 10 and 0.4 kV cables, we choose the AAB brand. Cables are intended for transmission and distribution of electric energy in stationary installations for networks on voltage 1; 6; 10 kV.

Construction: Core - soft aluminum sector wire; Insulation - paper impregnated with a viscous composition: Belt insulation - paper impregnated with a viscous composition; Screen - tape of electrically conductive paper; Shell - extruded aluminum shell; Protective cover - a pillow from creped paper and plastic tapes, two steel tapes and an external cover from glass yarn in accordance with 7006-72.

Table 2.11 - Cable selection (option №1)

Line	Appointment		Sc	N lines	Load		n cab in tranche	Length L m	Way
					Ic.nom A	Ic.em A			
10 kV line									
L 1	MSS	TS 1	491,97	2	14,20	28,40	2	195,00	trench
L 2	MSS	TS 2	608,97	2	17,58	35,16	2	260,00	trench
L 3	MSS	AM (5)	2729,41	3	52,53	157,58	6	228,00	trench
L 4	MSS	TS 3	534,20	2	15,42	30,84	4	156,00	trench
L 5	MSS	TS 4	1327,73	2	38,33	76,66	4	105,00	trench
L 6	MSS	AM (7)	1600,00	2	46,19	92,38	2	65,00	trench
L 7	MSS	TS 5	2147,38	2	61,99	123,98	6	315,00	trench
L 8	MSS	AM (8)	2400,00	2	69,28	138,56	6	220,00	trench
L 9	MSS	TS 6	360,72	1	20,83	20,83	6	270,00	trench
L 10	MSS	TS 7	407,80	2	11,77	23,54	2	156,00	trench
L 11	MSS	AD (11)	1200,00	2	34,64	69,28	2	208,00	trench
L 12	MSS	TS 8	679,18	2	19,61	39,21	6	300,00	trench
L 13	MSS	AD (13)	1800,00	2	51,96	103,92	2	145,00	trench
0.4 kV line									
L 14	TS 2	DB 1	66,10	1	95,40		1	110,00	trench
L 15	TS 1	DB 2	182,92	1	264,02		1	145,00	trench
L 16	RP 4	DB 3	228,30	1	329,52		1	65,00	trench
L 17	TS 5	DB 4	89,16	1	128,69		1	40,00	trench
L 18	TS 7	DB 5	140,73	1	203,13		1	90,00	trench
L 19	TS 8	DB 6	52,41	1	75,64		1	50,00	trench
L20	TS7	TS6	122,34	1	176,58		1	80,00	trench

Continuation of table 2.11

Ksn	Id.allow A	Permissible load		Sd.opl. mm2	Se mm2	SΔU	Brand	Lallow	LΔU1%
		I 'd.allow.nom.	I 'd.allow.em						
10 kV line									
0,90	115,00	103,50	134,55	35,00	8,88	35,00	AAB (3x35)	22,67	0,56
0,90	115,00	103,50	134,55	35,00	10,99	35,00	AAB (3x35)	18,32	0,56
0,75	165,00	123,75	160,88	70,00	32,83	70,00	AAB (3x70)	12,33	0,785
0,80	115,00	92,00	119,60	35,00	9,64	35,00	AAB (3x35)	20,88	0,56
0,80	115,00	92,00	119,60	35,00	23,96	35,00	AAB (3x35)	8,40	0,56
0,90	115,00	103,50	134,55	35,00	28,87	35,00	AAB (3x35)	6,97	0,56
0,75	140,00	105,00	136,50	50,00	38,74	50,00	AAB (3x50)	7,45	0,66
0,75	165,00	123,75	160,88	70,00	43,30	70,00	AAB (3x70)	9,29	0,78
0,75	115,00	86,25	112,13	35,00	13,02	35,00	AAB (3x35)	15,46	0,56
0,90	115,00	103,50	134,55	35,00	7,36	35,00	AAB (3x35)	27,35	0,56
0,90	115,00	103,50	134,55	35,00	21,65	35,00	AAB (3x35)	9,30	0,56
0,75	115,00	86,25	112,13	35,00	12,25	35,00	AAB (3x35)	16,42	0,56
0,90	115,00	103,50	134,55	35,00	32,48	35,00	AAB (3x35)	6,20	0,56
0,4 kV line									
1,00	165,00	165,00		50,00		50,00	AAB (4x50)	0,17	0,02
1,00	345,00	345,00		185,00		185,00	AAB (4x185)	0,22	0,034
1,00	345,00	345,00		185,00		185,00	AAB (4x185)	0,18	0,034
1,00	165,00	165,00		50,00		50,00	AAB (4x50)	0,13	0,02
1,00	240,00	240,00		95,00		95,00	AAB (4x95)	0,15	0,026
1,00	165,00	165,00		50,00		50,00	AAB (4x50)	0,22	0,02
1,00	200,00	200,00		70,00		70,00	AAB (4x70)	0,12	0,022

Table 2.12 - Cable selection (option №2)

Line	Appointment		Sc	N lines	Load		n cab in tranche	Length L m	Way
					Ic.nom A	Ip.em A			
10 kV line									
L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1
L 2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	L 2
L 3	L 3	L 3	L 3	L 3	L 3	L 3	L 3	L 3	L 3
L 4	L 4	L 4	L 4	L 4	L 4	L 4	L 4	L 4	L 4
L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5
L 6	L 6	L 6	L 6	L 6	L 6	L 6	L 6	L 6	L 6
L 7	L 7	L 7	L 7	L 7	L 7	L 7	L 7	L 7	L 7
L 8	L 8	L 8	L 8	L 8	L 8	L 8	L 8	L 8	L 8
L 9	L 9	L 9	L 9	L 9	L 9	L 9	L 9	L 9	L 9
L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10
L 11	L 11	L 11	L 11	L 11	L 11	L 11	L 11	L 11	L 11
L 12	L 12	L 12	L 12	L 12	L 12	L 12	L 12	L 12	L 12
L 13	L 13	L 13	L 13	L 13	L 13	L 13	L 13	L 13	L 13
0,4 kV line									
L 14	L 14	L 14	L 14	L 14	L 14	L 14	L 14	L 14	L 14
L 15	L 15	L 15	L 15	L 15	L 15	L 15	L 15	L 15	L 15
L 16	L 16	L 16	L 16	L 16	L 16	L 16	L 16	L 16	L 16
L 17	L 17	L 17	L 17	L 17	L 17	L 17	L 17	L 17	L 17
L 18	L 18	L 18	L 18	L 18	L 18	L 18	L 18	L 18	L 18
L 19	L 19	L 19	L 19	L 19	L 19	L 19	L 19	L 19	L 19
L20	L20	L20	L20	L20	L20	L20	L20	L20	L20

Continuation of table 2.12

Ksn	Id.allow A	Permissible load		Sd.opl. mm2	Se mm2	SΔU	Brand	Lallow	LΔU1%
		I 'd.allow.nom.	I 'd.allow.em						
10 kV line									
0,9	115	103,50	134,55	0,9	115	103,50	134,55	0,9	115
0,9	115	103,50	134,55	0,9	115	103,50	134,55	0,9	115
0,75	165	123,75	160,88	0,75	165	123,75	160,88	0,75	165
0,9	115	103,50	134,55	0,9	115	103,50	134,55	0,9	115
0,8	115	92,00	119,60	0,8	115	92,00	119,60	0,8	115
0,9	115	103,50	134,55	0,9	115	103,50	134,55	0,9	115
0,75	115	86,25	112,13	0,75	115	86,25	112,13	0,75	115
0,8	140	112,00	145,60	0,8	140	112,00	145,60	0,8	140
0,75	115	86,25	112,13	0,75	115	86,25	112,13	0,75	115
0,9	115	103,50	134,55	0,9	115	103,50	134,55	0,9	115
0,75	115	86,25	112,13	0,75	115	86,25	112,13	0,75	115
0,75	115	86,25	112,13	0,75	115	86,25	112,13	0,75	115
0,9	115	103,50	134,55	0,9	115	103,50	134,55	0,9	115
0,4 kV line									
1	165	165		1	165	165		1	165
0,9	240	216		0,9	240	216		0,9	240
0,9	345	310,5		0,9	345	310,5		0,9	345
1	240	240		1	240	240		1	240
1	305	305		1	305	305		1	305
1	165	165		1	165	165		1	165
1	240	240		1	240	240		1	240

Table 2.13 - Cable selection (option №3)

Line	Appointment		Sc	N lines	Load		n cab in tranche	Length L m	Way
					Ic.nom A	Ip.em A			
10 kV line									
L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1	L 1
L 2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	L 2	L 2
L 3	L 3	L 3	L 3	L 3	L 3	L 3	L 3	L 3	L 3
L 4	L 4	L 4	L 4	L 4	L 4	L 4	L 4	L 4	L 4
L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5	L 5
L 6	L 6	L 6	L 6	L 6	L 6	L 6	L 6	L 6	L 6
L 7	L 7	L 7	L 7	L 7	L 7	L 7	L 7	L 7	L 7
L 8	L 8	L 8	L 8	L 8	L 8	L 8	L 8	L 8	L 8
L 9	L 9	L 9	L 9	L 9	L 9	L 9	L 9	L 9	L 9
L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10	L 10
L 11	L 11	L 11	L 11	L 11	L 11	L 11	L 11	L 11	L 11
0,4 kV line									
L12	L12	L12	L12	L12	L12	L12	L12	L12	L12
L13	L13	L13	L13	L13	L13	L13	L13	L13	L13
L14	L14	L14	L14	L14	L14	L14	L14	L14	L14
L15	L15	L15	L15	L15	L15	L15	L15	L15	L15
L16	L16	L16	L16	L16	L16	L16	L16	L16	L16
L17	L17	L17	L17	L17	L17	L17	L17	L17	L17
L18	L18	L18	L18	L18	L18	L18	L18	L18	L18
L19	L19	L19	L19	L19	L19	L19	L19	L19	L19
L20	L20	L20	L20	L20	L20	L20	L20	L20	L20
L21	L21	L21	L21	L21	L21	L21	L21	L21	L21
L22	L22	L22	L22	L22	L22	L22	L22	L22	L22

Continuation of table 2.13

Ksn	Id.allow A	Permissible load I 'd.allow.nom.	I 'd.allow.em	Sd.opl. mm2	Se mm2	SΔU	Brand	Lallow	LΔU1%
10 kV line									
0,8	115	92	119,6	0,8	115	92	119,6	0,8	115
0,8	165	132	171,6	0,8	165	132	171,6	0,8	165
0,75	115	86,25	112,125	0,75	115	86,25	112,125	0,75	115
0,9	115	103,5	134,55	0,9	115	103,5	134,55	0,9	115
0,8	115	92	119,6	0,8	115	92	119,6	0,8	115
0,9	140	126	163,8	0,9	140	126	163,8	0,9	140
0,9	140	126	163,8	0,9	140	126	163,8	0,9	140
0,8	115	92	119,6	0,8	115	92	119,6	0,8	115
0,8	115	92	119,6	0,8	115	92	119,6	0,8	115
0,75	115	86,25	112,125	0,75	115	86,25	112,125	0,75	115
0,75	115	86,25	112,125	0,75	115	86,25	112,125	0,75	115
0,4 kV line									
1	165	165		1	165	165		1	165
0,9	270	243		0,9	270	243		0,9	270
0,85	345	293,25		0,85	345	293,25		0,85	345
0,85	345	293,25		0,85	345	293,25		0,85	345
1	345	345		1	345	345		1	345
0,9	305	274,5		0,9	305	274,5		0,9	305
1	165	165		1	165	165		1	165
0,9	345	310,5		0,9	345	310,5		0,9	345
0,9	345	310,5		0,9	345	310,5		0,9	345
1	270	270		1	270	270		1	270
1	240	240		1	240	240		1	240

3 PROJECT DESIGNING SECTION

3.1 Calculation of short circuit currents

The main reason for the violation of the normal operation of the power supply system is the occurrence of short circuits in the network or in the elements of electrical equipment due to damage to insulation or improper actions of maintenance personnel. To reduce the damage caused by the failure of electrical equipment during short-circuit currents, as well as to quickly restore normal operation of the power supply system, it is necessary to correctly determine short-circuit currents and choose electrical equipment, protective equipment and short-circuit current limiters. In the event of a short circuit, there is an increase in currents in the phases of the power supply system or installations in comparison with their value in normal operation. In turn, this causes a decrease in voltage in the system, which is especially large near the short circuit.

In the three-phase network there are the following types of short circuits: three-phase, two-phase, single-phase and double earth faults. The three-phase short-circuit is usually considered to be the design type of short circuit for selecting or checking the parameters of electrical equipment.

The calculation of short-circuit currents is carried out in relative units (Ohms).

Given that both sections of tires are loaded evenly, we will consider only one section of tires. Choose the most loaded and remote branch and calculate the possible values of short-circuit currents (graphic part).

Let's make the scheme of substitution shown in graphic part.

We will accept:

$$S_{basic} = 100 \text{ MVA};$$

$$U_{bI} = 37 \text{ kV};$$

$$U_{bII} = \frac{U_{bI}}{к_{т1}} = \frac{37 \cdot 10,5}{37} = 10,5kV;$$

$$U_{bIII} = \frac{U_{bII}}{к_{т2}} = \frac{10,5 \cdot 0,4}{10,5} = 0,4kV;$$

$$I_{\text{bI}} = \frac{S_b}{\sqrt{3} \cdot U_{\text{bI}}} = \frac{100}{\sqrt{3} \cdot 37} = 1,56kA;$$

$$I_{\text{bII}} = \frac{S_b}{\sqrt{3} \cdot U_{\text{bII}}} = \frac{100}{\sqrt{3} \cdot 10,5} = 5,5kA;$$

$$I_{\text{bIII}} = \frac{S_b}{\sqrt{3} \cdot U_{\text{bIII}}} = \frac{100}{\sqrt{3} \cdot 0,4} = 144,34kA;$$

Calculate the support of the elements of the system:

$$x_l = x_0 \cdot l \cdot \frac{S_b}{\text{U}_{\text{bI}}{}^2} = 0,33 \cdot 4,8 \cdot \frac{100}{37^2} = 0,12$$

$$r_l = \frac{x_l \cdot R_0}{x_0} = \frac{0,12 \cdot 0,4}{0,33} = 0,15$$

$$x_{\text{l7}} = x_0 \cdot l \cdot \frac{S_b}{\text{U}_{\text{bII}}{}^2} = 0,095 \cdot 0,22 \cdot \frac{100}{10,5^2} = 0,019$$

$$r_{\text{l7}} = \frac{x_{l7} \cdot R_0}{x_0} = \frac{0,019 \cdot 0,84}{0,095} = 0,17$$

$$x_{\text{l13}} = x_0 \cdot l \cdot \frac{S_b}{\text{U}_{\text{bII}}{}^2} = 0,095 \cdot 0,156 \cdot \frac{100}{10,5^2} = 0,013$$

$$r_{\text{l13}} = \frac{x_{l13} \cdot R_0}{x_0} = \frac{0,013 \cdot 0,84}{0,095} = 0,12$$

$$x_{\text{l11}} = x_0 \cdot l \cdot \frac{S_b}{\text{U}_{\text{bII}}{}^2} = 0,099 \cdot 0,208 \cdot \frac{100}{10,5^2} = 0,019$$

$$r_{\text{l11}} = \frac{x_{l11} \cdot R_0}{x_0} = \frac{0,019 \cdot 1,17}{0,099} = 0,22$$

$$x_{\text{l8}} = x_0 \cdot l \cdot \frac{S_b}{\text{U}_{\text{bII}}{}^2} = 0,09 \cdot 0,22 \cdot \frac{100}{10,5^2} = 0,018$$

$$r_{\text{l8}} = \frac{x_{l11} \cdot R_0}{x_0} = \frac{0,018 \cdot 0,59}{0,09} = 0,12$$

$$x_{\text{l6}} = x_0 \cdot l \cdot \frac{S_b}{\text{U}_{\text{bII}}{}^2} = 0,095 \cdot 0,065 \cdot \frac{100}{10,5^2} = 0,0056$$

$$r_{\text{l6}} = \frac{x_{l11} \cdot R_0}{x_0} = \frac{0,056 \cdot 0,84}{0,095} = 0,049$$

$$x_{l3} = x_0 \cdot l \cdot \frac{S_b}{U_{bII}^{\ 2}} = 0,086 \cdot 0,228 \cdot \frac{100}{10,5^2} = 0,018$$

$$r_{l3} = \frac{x_{l3} \cdot R_0}{x_0} = \frac{0,018 \cdot 0,42}{0,086} = 0,088$$

$$x_{T1} = \frac{U_{sh.c}}{100} \cdot \frac{U_{nom}^{\ 2}}{S_{nom}} \cdot \frac{S_b}{U_{bI}^{\ 2}} = \frac{7,5}{100} \cdot \frac{37^2}{10 \cdot 10^6} \cdot \frac{100 \cdot 10^6}{37^2} = 0,75$$

$$r_{T1} = \frac{\Delta P_k \cdot S_b}{S_{nom\,т}^{\ 2}} = \frac{46,5 \cdot 10^3 \cdot 100 \cdot 10^6}{\left(10 \cdot 10^6\right)^2} = 0,047$$

$$z_{Tp1} = \sqrt{0,75^2 + 0,047^2} = 0,75$$

$$x_{T2} = \frac{U_{sh.c}}{100} \cdot \frac{U_{nom}^{\ 2}}{S_{nom}} \cdot \frac{S_b}{U_{bII}^{\ 2}} = \frac{6,5}{100} \cdot \frac{37^2}{1600 \cdot 10^3} \cdot \frac{100 \cdot 10^6}{10,5^2} = 4,06$$

$$r_{T2} = \frac{\Delta P_k \cdot S_b}{S_{nom\,т}^{\ 2}} = \frac{2,35 \cdot 10^3 \cdot 100 \cdot 10^6}{\left(1600 \cdot 10^3\right)^2} = 0,092$$

$$z_{Tp1} = \sqrt{4,06^2 + 0,092^2} = 4,06$$

13 lines (2 800 kWt motors)

$$\mathrm{x}_{mot13} = \frac{1}{I_{mot}} \left(\frac{S_b}{S_{nom}} \right) \cdot \left(\frac{U_{nom}}{U_{bII}} \right)^2 = \frac{1}{5,2} \cdot \left(\frac{100 \cdot 10^6}{927860} \right) \cdot \left(\frac{10 \cdot 10^3}{10,5 \cdot 10^3} \right)^2 = 18,8$$

$$S_{nom} = \frac{P_{nom}}{\cos\phi \cdot \eta} = \frac{800 \cdot 10^3}{0,9 \cdot 0,958} = 927860\mathrm{VA}$$

$$E_m = \frac{U_m}{U_{bI}} = \frac{37}{37} = 1$$

$$E_{mot13}'' = \sqrt{\left(U \cdot \cos\phi\right)^2 + \left(U \sin\phi - I_0 \mathrm{x}_{mot}\right)^2} = 1,74$$

$$U_{mot} = \frac{U_{nom.mot}}{U_{bII}} = \frac{10}{10,5} = 0,95$$

$$\sin\varphi = \sqrt{1 - \cos^2\varphi} = \sqrt{1 - 0,9^2} = 0,44$$

$$I_0 = \frac{I_0}{I_{bII}} = \frac{S_{mot}}{\sqrt{3} \cdot U_{nom} \cdot I_{bII}} = \frac{927860}{\sqrt{3} \cdot 0,95 \cdot 10^3 \cdot 5,5 \cdot 10^3} = 0,1$$

$$z_{mot13} = \sqrt{\left(x_{l13} + x_{mot13}\right)^2 + \left(r_{l13} + r_{mot13}\right)^2} = \sqrt{\left(0,013 + 18,8\right)^2 + \left(0,12 + 1,34\right)^2} = 18,87$$

$$r_{mot13} = \frac{x_{mot13}}{14} = \frac{18,8}{14} = 1,34$$

11 line (400 kWt motor)

$$\mathrm{x}_{\mathrm{mot11}} = \frac{1}{I_{mot}}\left(\frac{S_b}{S_{nom}}\right)\cdot\left(\frac{U_{nom}}{U_{bII}}\right)^2 = \frac{1}{7}\cdot\left(\frac{100\cdot 10^6}{461238}\right)\cdot\left(\frac{10\cdot 10^3}{10,5\cdot 10^3}\right)^2 = 28,01$$

$$S_{nom} = \frac{P_{nom}}{\cos\phi\cdot\eta} = \frac{400\cdot 10^3}{0,91\cdot 0,955} = 461238\mathrm{VA}$$

$$E_m = \frac{U_m}{U_{\mathrm{bI}}} = \frac{37}{37} = 1$$

$$E_{\mathrm{mot11}}'' = \sqrt{(U\cdot\cos\phi)^2 + (U\sin\phi - I_0\mathrm{x}_{mot})^2} = 1,03$$

$$U_{mot} = \frac{U_{nom.mot}}{U_{\mathrm{bII}}} = \frac{10}{10,5} = 0,95$$

$$\sin\varphi = \sqrt{1-\cos^2\varphi} = \sqrt{1-0,91^2} = 0,42$$

$$I_0 = \frac{I_0}{I_{\mathrm{bII}}} = \frac{S_{mot}}{\sqrt{3}\cdot U_{nom}\cdot I_{\mathrm{bII}}} = \frac{461238}{\sqrt{3}\cdot 0,95\cdot 10^3\cdot 5,5\cdot 10^3} = 0,05$$

$$z_{mot11} = \sqrt{(x_{\mathrm{l}11} + x_{mot11})^2 + (r_{\mathrm{l}11} + r_{\mathrm{mot}11})^2} = \sqrt{(0,019+28,01)^2 + (0,22+2,01)^2} = 28,2$$

$$r_{\mathrm{mot11}} = \frac{x_{mot11}}{14} = \frac{28,01}{14} = 2,01$$

8 line (1000 kWt motor)

$$\mathrm{x}_{\mathrm{mot8}} = \frac{1}{I_{mot}}\left(\frac{S_b}{S_{nom}}\right)\cdot\left(\frac{U_{nom}}{U_{bII}}\right)^2 = 15,47$$

$$S_{nom} = \frac{P_{nom}}{\cos\phi\cdot\eta} = 1172855\mathrm{VA}$$

$$E_m = \frac{U_m}{U_{\mathrm{bI}}} = \frac{37}{37} = 1$$

$$E_{\mathrm{mot8}}'' = \sqrt{(U\cdot\cos\phi)^2 + (U\sin\phi - I_0\mathrm{x}_{mot})^2} = 2,17$$

$$U_{mot} = \frac{U_{nom.mot}}{U_{\mathrm{bII}}} = \frac{10}{10,5} = 0,95$$

$$\sin\varphi = \sqrt{1-\cos^2\varphi} = 0,46$$

$$I_0 = \frac{I_0}{I_{\mathrm{bII}}} = \frac{S_{mot}}{\sqrt{3}\cdot U_{nom}\cdot I_{\mathrm{bII}}} = 0,19$$

$$z_{mot8} = \sqrt{(x_{\mathrm{l}8} + x_{mot8})^2 + (r_{\mathrm{l}8} + r_{\mathrm{mot}8})^2} = 15,53$$

$$r_{\text{mot8}} = \frac{x_{mot8}}{14} = 1{,}1$$

Line 6 (500 kWt motor)

$$\text{x}_{\text{mot6}} = \frac{1}{I_{mot}}\left(\frac{S_b}{S_{nom}}\right)\cdot\left(\frac{U_{nom}}{U_{bII}}\right)^2 = 26{,}59$$

$$S_{nom} = \frac{P_{nom}}{\cos\phi\cdot\eta} = 568491\text{VA}$$

$$E_m = \frac{U_m}{U_{\text{bI}}} = \frac{37}{37} = 1$$

$$E_{\text{mot6}}'' = \sqrt{\left(U\cdot\cos\phi\right)^2 + \left(U\sin\phi - I_0\text{x}_{mot}\right)^2} = 1{,}19$$

$$U_{mot} = \frac{U_{nom.mot}}{U_{\text{bII}}} = \frac{10}{10{,}5} = 0{,}95$$

$$\sin\varphi = \sqrt{1-\cos^2\varphi} = 0{,}39$$

$$I_0 = \frac{I_0}{I_{\text{bII}}} = \frac{S_{mot}}{\sqrt{3}\cdot U_{nom}\cdot I_{\text{bII}}} = 0{,}06$$

$$z_{mot6} = \sqrt{\left(x_{\text{l6}} + x_{mot6}\right)^2 + \left(r_{\text{l6}} + r_{\text{mot6}}\right)^2} = 26{,}67$$

$$r_{\text{mot6}} = \frac{x_{mot6}}{14} = 1{,}89$$

3 line (500 kWt motor)

$$\text{x}_{\text{mot3}} = \frac{1}{I_{mot}}\left(\frac{S_b}{S_{nom}}\right)\cdot\left(\frac{U_{nom}}{U_{bII}}\right)^2 = 26{,}59$$

$$S_{nom} = \frac{P_{nom}}{\cos\phi\cdot\eta} = 568491\text{VA}$$

$$E_m = \frac{U_m}{U_{\text{bI}}} = \frac{37}{37} = 1$$

$$E_{\text{mot3}}'' = \sqrt{\left(U\cdot\cos\phi\right)^2 + \left(U\sin\phi - I_0\text{x}_{mot}\right)^2} = 1{,}19$$

$$U_{mot} = \frac{U_{nom.mot}}{U_{\text{bII}}} = \frac{10}{10{,}5} = 0{,}95$$

$$\sin\varphi = \sqrt{1-\cos^2\varphi} = 0{,}39$$

$$I_0 = \frac{I_0}{I_{\text{bII}}} = \frac{S_{mot}}{\sqrt{3} \cdot U_{\text{nom}} \cdot I_{\text{bII}}} = 0,06$$

$$z_{mot3} = \sqrt{\left(x_{l3} + x_{mot3}\right)^2 + \left(r_{l3} + r_{\text{mot3}}\right)^2} = 26,68$$

$$r_{\text{mot3}} = \frac{x_{mot3}}{14} = 1,89$$

$$z_{\text{eq}} = \frac{z_{13,13} \cdot z_{11,8,6,3}}{z_{13,13} + z_{11,8,6,3}} = \frac{4,86 \cdot 13,34}{4,86 + 13,34} = 3,56$$

$$E_{\text{eq}} = \frac{1,19 \cdot 4,8 + 1,75 \cdot 13,34}{4,8 + 13,34} = 1,6$$

x_{13}=18,81 r_{13}=1,46

x_{11}=28,11 r_{11}=2,23

x_{8}=15,49 r_{8}=1,22

x_{6}=26,5 r_{6}=1,95

x_{3}=26,61 r_{3}=1,98

x_{eq}=4,5 r_{eq}=0,44

1 point K1(graphic part)

$$z_{01} = \sqrt{\left(x_{l7} + x_{Tr2}\right)^2 + \left(r_{l7} + r_{Tr2}\right)^2} = \sqrt{\left(0,019 + 4,06\right)^2 + \left(0,17 + 0,092\right)^2} = 4,09$$

r_{01}=4,08

x_{01}=0,26

$$z_{02} = \frac{z_{eq} \cdot z_{01}}{z_{eq} + z_{01}} = \frac{3,56 \cdot 4,09}{3,56 + 4,09} = 1,9$$

$$r_{02} = \frac{r_{01} \cdot r_{eq}}{r_{01} + r_{eq}} = 0,16$$

$$x_{02} = \frac{x_{01} \cdot x_{eq}}{x_{01} + x_{eq}} = 2,14$$

$$z_{03} = z_{02} + z_{Tr1} = 2,65$$

$$x_{03} = x_{02} + x_{Tr1} = 2,89$$

$$r_{03} = r_{02} + r_{Tr1} = 0,21$$

$$z_l = \sqrt{\left(x_l\right)^2 + \left(r_l\right)^2} = \sqrt{\left(0,12\right)^2 + \left(0,15\right)^2} = 0,19$$

$$E'_{\text{eq}} = \frac{E_{eq} \cdot z_{01} + 0}{z_{01} + z'_{eq}} = \frac{1,67 \cdot 4,09}{4,09 + 3,56} = 0,86$$

$$I_{\text{sh.c1}} = \frac{E_m}{z_l} + \frac{E'_{eq}}{z_{03}} = \frac{1}{0,19} + \frac{0,86}{2,65} = 5,59$$

$$I_{no1} = I_{\text{sh.c1}} \cdot I_{\text{bI}} = 5,59 \cdot 1,56 = 7,15$$

Searched shock circuit current:

a) from the system

$$T_a = \frac{x_l}{\omega \cdot \text{r}_l} = \frac{0,12}{314 \cdot 0,15} = 0,0026$$

$$\kappa_{sh} = 1 + e^{-t/T_a} = 1 + 2,72^{-0,01/0,0026} = 1,02$$

$$i_{\text{sh.c}} = \sqrt{2} \cdot \kappa_{sh} \cdot I = \sqrt{2} \cdot 1,02 \cdot \frac{1}{0,19} = 7,59$$

b) from the engine

$$T_a = \frac{x_{03}}{\omega \cdot \text{r}_{03}} = \frac{2,89}{314 \cdot 0,21} = 0,044$$

$$\kappa_{sh} = 1 + e^{-t/T_a} = 1 + 2,72^{-0,01/0,044} = 1,8$$

$$i_{\text{sh.mot}} = \sqrt{2} \cdot \kappa_{sh} \cdot I_{double} = \sqrt{2} \cdot 1,8 \cdot \frac{0,86}{2,65} = 0,83$$

$$i_{\text{sh.shc1}} = \left(i_{\text{shc}} + i_{\text{sh.mot}}\right) I_{\text{bI}} = \left(7,59 + 0,83\right) \cdot 1,56 = 13,1$$

2 point K2(graphic part)

$$z_{04} = \sqrt{\left(x_l + x_{Tr1}\right)^2 + \left(r_l + r_{Tr1}\right)^2} = \sqrt{\left(0,12 + 0,75\right)^2 + \left(0,5 + 0,47\right)^2} = 1,07$$

r_{04}=0,87

x_{04}=0,62

$$I_{\text{sh.c2}} = \frac{E_m}{z_{04}} + \frac{E'_{eq}}{z_{02}} = \frac{1}{1,07} + \frac{0,86}{1,9} = 1,39$$

$$I_{no2} = I_{\text{sh.c2}} \cdot I_{\text{bII}} = 1,39 \cdot 5,5 = 7,65$$

a) from the system

$$T_a = \frac{x_{04}}{\omega \cdot \text{r}_{04}} = \frac{0,87}{314 \cdot 0,62} = 0,0053$$

$$\kappa_{sh} = 1 + e^{-t/T_a} = 1 + 2,72^{-0,01/0,0053} = 1,15$$

$$i_{\text{sh.c}} = \sqrt{2} \cdot \kappa_{sh} \cdot I = \sqrt{2} \cdot 1,15 \cdot \frac{1}{1,07} = 1,52$$

b) from the engine

$$T_a = \frac{x_{02}}{\omega \cdot \mathrm{r}_{02}} = \frac{2{,}14}{314 \cdot 0{,}16} = 0{,}043$$

$$\kappa_{sh} = 1 + e^{-t/T_a} = 1{,}79$$

$$i_{\text{sh.mot}} = \sqrt{2} \cdot \kappa_{sh} \cdot I_{double} = \sqrt{2} \cdot 1{,}79 \cdot \frac{0{,}86}{1{,}9} = 1{,}15$$

$$i_{\text{sh.shc2}} = \left(i_{\text{sh.c}} + i_{\text{sh.mot}}\right) I_{\text{bII}} = \left(1{,}52 + 1{,}15\right) \cdot 5{,}5 = 14{,}69$$

3 point K3

$$z_{05} = \frac{z_{04} \cdot z_{eq}}{z_{eq} + z_{04}} = 1 \quad r_{05} = \frac{r_{04} \cdot r_{eq}}{r_{04} + r_{eq}} = 0{,}29$$

$$x_{05} = \frac{x_{04} \cdot x_{eq}}{x_{04} + x_{eq}} = 0{,}73$$

$$z_{l3} = \sqrt{\left(x_{l7}\right)^2 + \left(r_{l7}\right)^2} = \sqrt{\left(0{,}019\right)^2 + \left(0{,}17\right)^2} = 0{,}172$$

$$z_{06} = z_{05} + z_{l7} = 1 + 0{,}172 = 1{,}172 \quad x_{06} = x_{05} + x_{l7} = 0{,}73 + 0{,}019 = 0{,}75$$

$$r_{06} = r_{05} + r_{l7} = 0{,}29 + 0{,}17 = 0{,}46$$

$$E'_{\text{eq1}} = \frac{E_{eq} \cdot z_{04} + E_c \cdot z_{\text{eq}}}{z_{04} + z_{eq}} = 1{,}14$$

$$I_{\text{sh.c3}} = \frac{E'_{eq1}}{z_{06}} = \frac{1{,}14}{1{,}172} = 0{,}97$$

$$I_{no3} = I_{\text{sh.c3}} \cdot I_{\text{bII}} = 0{,}97 \cdot 5{,}5 = 5{,}34$$

$$T_a = \frac{x_{06}}{\omega \cdot \mathrm{r}_{06}} = \frac{0{,}75}{314 \cdot 0{,}46} = 0{,}0052$$

$$\kappa_{sh} = 1 + e^{-t/T_a} = 1{,}15$$

$$i_{sh} = \sqrt{2} \cdot \kappa_{sh} \cdot I_{\text{по3}} = \sqrt{2} \cdot 1{,}15 \cdot 5{,}34 = 8{,}68$$

4 point K4(graphic part)

$$z_{07} = z_{05} + z_{01} = 1 + 4{,}09 = 5{,}09$$

$$x_{07} = x_{05} + x_{01} = 4{,}81$$

$$r_{11} = r_{05} + r_{01} = 0{,}55$$

$$I_{\text{sh.c4}} = \frac{E'_{eq1}}{z_{11}} = \frac{1{,}14}{5{,}09} = 0{,}22$$

$$I_{no4} = I_{\text{sh.c4}} \cdot I_{\text{bIII}} = 0{,}22 \cdot 144{,}34 = 31{,}75$$

$$T_a = \frac{x_{11}}{\omega \cdot \mathrm{r}_{11}} = \frac{4,81}{314 \cdot 0,55} = 0,028$$

$$\kappa_{sh} = 1 + e^{-t/T_a} = 1,99$$

$$i_{\text{sh4}} = \sqrt{2} \cdot \kappa_{sh} \cdot I_{\text{по4}} = \sqrt{2} \cdot 1,99 \cdot 31,75 = 89,35$$

Once we have found the short-circuit current, you can check the cables for thermal stability.

a) power lines

$$S_{t.s.1} = I_\infty \cdot \alpha \cdot \sqrt{t_n} = 7,15 \cdot 12 \cdot 0,08 = 24,3mm^2$$

where α is the temperature coefficient depending on the material of the core. For aluminum α = 12

t_n- the given time of protection operation.

I_∞ - constant value of periodic stump short cirtcuit I.

The selected cross section of the veins is thermal stability.

b) 10 kV lines

$$S_{t.s.2} = I_\infty \cdot \alpha \cdot \sqrt{t_n} = 7,65 \cdot 12 \cdot \sqrt{0,08} = 25,96mm^2$$

The minimum cross section for 10 kV must be 35 mm2.

c) 10 kV lines

$$S_{t.s.3} = I_\infty \cdot \alpha \cdot \sqrt{t_n} = 5,34 \cdot 12 \cdot \sqrt{0,08} = 18,12mm^2$$

The minimum cross section for 10 kV must be 25 mm2.

Thus, we accept the minimum cross section of 35 mm2.

d) 0.4 kV lines

$$S_{t.st.4} = I_\infty \cdot \alpha \cdot \sqrt{t_n} = 31,75 \cdot 12 \cdot \sqrt{0,02} = 49,3mm^2$$

The minimum cross section of 0.4 kV must be 50 mm2.

3.2 Selection of devices and live parts

3.2.1 Selection and inspection of main step-down substation tires

Initial data:

S_c=14606,18 kVA;

U_c=10 kV,

I_{sh2}=14,69 kA;

$t_п$=2,1 s.

1. Determine the current on the busbar [12]:

$$I_c = \frac{S_c}{\sqrt{3} \cdot U_m} = \frac{14606,18}{\sqrt{3} \cdot 10} = 843,29 \text{ A.}$$

2. Determine the allowable current on the busbar, taking into account the correction factors:

$$I_{allow}^{e} = k_1 \cdot k_2 \cdot k_3 \cdot I_{allow} \geq I_c ,$$

where k1 = 0,95 - correction factor when the tires are horizontal (reverse);

k2 = 1,0 - for single-lane tires;

k3 = 1,0 - correction factor for tires at an ambient temperature of 25 ° C.

$$I_{allow} \geq \frac{I_c}{k_1 \cdot k_2 \cdot k_3} = \frac{843,29}{0,95 \cdot 1,0 \cdot 1,0} = 887,67 \text{ A.}$$

We choose rigid single-strip aluminum tires of rectangular section (80x8) mm2 with I_{allow} = 1320 A.

3. Check the busbar for electrodynamic stability:

a) determine the calculated force from the dynamic action of the short-circuit current:

$$F_{calc} = 1,76 \cdot i_{sh}^2 \cdot \frac{l}{a} \cdot 10^{-2} = 1,76 \cdot 14,69^2 \cdot \frac{2000}{100} \cdot 10^{-2} = 75,96 \text{ kgs}$$

where l is the length of the span between the insulators, mm;

a = 2h = 2 · 50 = 100 mm - the distance between the axes of the busbar.

b) determine the moment of resistance of one strip:

$$W = \frac{bh^2}{10} = \frac{0,8 \cdot 8^2}{10} = 5,12 \text{ cm3.}$$

c) determine the maximum rated voltage in the tires:

$$\sigma_{сфдс} = \frac{F_{сфдс} \cdot l}{10W} = \frac{75,96 \cdot 200}{10 \cdot 5,12} = 296,72 \text{ kgs / sm2}$$

For aluminum track tires, the allowable bending stress is accepted$\sigma_{доп}$= 650 kgs / sm2. Becauseσ_{calc}<σ_{allow}, the selected busbar is electrodynamically stable.

4. Check the busbar for mechanical resonance:

Determine the frequency of natural oscillations:

$$f_m = 5,02 \cdot 10^5 \cdot \frac{h}{l^2} = 5,02 \cdot 10^5 \cdot \frac{8}{200^2} = 100,4\,\text{Hz}.$$

5. Check the busbar for thermal stability:

$$S_{t.s.} = I_\infty \cdot \alpha \cdot \sqrt{t_n} = 7,65 \cdot 12 \cdot \sqrt{2,1} = 133,03 \text{ мм}^2$$

$$S_{calc} = 80x8 = 640 > S_{t.s.}$$

3.2.2 Selection and testing of main and sectional switches

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{S_c}{\sqrt{3} \cdot U_m} = \frac{14606,18}{\sqrt{3} \cdot 10} = 843,29\text{ A}$$

High-voltage switches are selected by rated current, rated voltage, type, type of installation, with a comparison of technical and economic indicators and tested for electrodynamic, thermal stability and disconnectivity in short circuit mode.

We plan to install a high-voltage vacuum switch Siemens 3AH5-10-1250-20 with the following parameters [9]:

U_{nom} = 10 kV;

I_{nom} = 1250 A;

$I_{dis.nom.}$ = 20 kA;

$I_{t.nom}$ = 20 kA

$T_{t.norm}$ = 4 s;

$i_{p.con.}$ = 65 kA;

$I_{p.con.}$ = 20 kA;

$I_{con.nom.}$ = 65 kA;

$I_{con.nom}$. = 20 kA;

$T_{disc.v}$ = 0,08 s

1) Under the conditions of working long mode we have:

U_{nom} = 10 kV = $U_{network}$ = 10 kV

I_{nom} = 1250 A > $I_{work.n}$ = 843,29 A.

2) Check of the switch on disconnecting ability

$I_{disc.n}$ = 20 kA > I_{po} = 7,65 kA

3) On electrodynamic stability

$I_{p.con}$. = 20 kA > I_{po} = 7,65 kA

$$I_{p.con.} = 65\ kA > i_{sh2} = 14{,}69\ kA.$$

4) Check the switch for thermal stability [4, 16]

$$I_{t.m.}^2 \cdot t_{t.} \geq B_k\,,$$

where B_k is the calculated thermal current pulse of the short circuit

$$B_k = I_{po}^2(t_{c.z} + t_{vl.v} + T_a) = 7{,}65^2 \cdot (0{,}1 + 0{,}08 + 0{,}0053) = 10{,}8\ kA^2 \cdot s$$

$$I_{t.s.}^2 \cdot t_{discon.} = 20^2 \cdot 4 = 1600\ kA^2 \cdot s$$

$$1600\ kA^2 \cdot s > 10{,}8\ kA^2 \cdot s$$

Conclusion: the selected switch satisfies all test conditions.

3.2.3 Selection and testing of high-voltage switches for protection of central distribution substation and induction motors

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{k_{per.}S_{nom.tr.}}{\sqrt{3} \cdot U_m} = \frac{1{,}4 \cdot 1600}{\sqrt{3} \cdot 10} = 129{,}32\ \mathrm{A}$$

Choose a vacuum switch type Siemens 3AH5-10-1250-20 with the following parameters:

$$U_{nom} = 10\ kV;$$

$$I_{nom} = 1250\ A;$$

$$I_{disc.nom}. = 20\ kA;$$

$$I_{t.nom} = 20\ kA;$$

$$T_{t.norm} = 4\ s;$$

$$I_{p.con}. = 65\ kA;$$

$$I_{p.con}. = 20\ kA;$$

$$I_{con.nom.} = 65\ kA;$$

$$I_{con.nom.} = 20\ kA;$$

$$T_{disc.vl} = 0{,}08\ s$$

a) at rated voltage

$$U_{nom} = 10\ кВ = U_{net} = 10\ kV$$

b) at rated current

$$I_{nom} = 1250\ A > I_{work.nom} = 129{,}32\ A.$$

2) Check of the switch on disconnecting ability

$$I_{disc.nom} = 20\ kA > I_{po} = 7{,}65\ kA$$

3) On electrodynamic stability

$$I_{p.con.} = 20\ kA > I_{po} = 7{,}65\ kA$$

$$I_{p.con.} = 65\ kA > i_{sh2} = 14{,}69\ kA.$$

4) Check the switch for thermal stability

$$I_{t.m.}^{2} \cdot t_{t.} \geq B_{k}\,,$$

where B_k is the calculated thermal current pulse of the short circuit

$$B_k = I_{po}^2 (t_{c.z} + t_{vl.v} + T_a) = 7{,}65^2 \cdot (0{,}1 + 0{,}08 + 0{,}0053) = 10{,}8\ kA^2 \cdot s$$

$$I_{t.s.}^2 \cdot t_{disc.} = 20^2 \cdot 4 = 1600\ kA^2 \cdot s$$

$$1600\,\kappa A^2 \cdot c > 10{,}8\ kA^2 \cdot s$$

Conclusion: the selected switch satisfies all test conditions.

3.2.4 Choosing a transformer for your own needs

1. Determine the preliminary power of the transformer own needs.

Assume that the company's own needs spend 1% of the estimated capacity of the company:

$$S_c^{'} = 0{,}01 \cdot S_c = 0{,}01 \cdot 14606{,}18 = 146{,}06\,\text{kVA}$$

Then $S_{nom.tr.} \geq \dfrac{S_c^{'}}{2 \cdot k_{load}} = \dfrac{146{,}06}{2 \cdot 0{,}7} = 104{,}33\ \text{kVA}.$

Choose a transformer type TM-120/10-U1 with $S_{nom.\text{tr.}}$= 120 kVA

2. At rated voltage:

$$U_{nom} = 10\ kV = U_{net} = 10\ kV$$

3. Determine the load factors of transformer of own use in normal and emergency modes:

$$k_{load.nom.} = \frac{S_c^{'}}{2 \cdot S_{nom.tr.}} = \frac{146{,}06}{2 \cdot 120} = 0{,}61$$

$$k_{load.em.} = \frac{S_c^{'}}{S_{nom.tr.}} = \frac{146{,}06}{120} = 1{,}22$$

The load factor in emergency mode does not exceed 1.4.

Conclusion: the selected transformer of own needs satisfies all design conditions.

3.2.5 Selection and testing of a fuse to protect the transformer of own use

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{S_{c.tr.}}{\sqrt{3} \cdot U_m} = \frac{120 \cdot 10^3}{\sqrt{3} \cdot 10 \cdot 10^3} = 6,93\,\text{A}$$

2. Choose a fuse type PKT-101-10-8-20U3:

U_{nom}=10 kV;

$I_{nom.}$=8 A;

$I_{disc.nom.}$=20 kA.

a) at rated voltage

$$U_{nom} = 10\ kV = U_{net} = 10\ kV$$

b) at rated current

$$I_{nom} = 8\ A > I_{work.nom} = 6,93\ A.$$

3. Check the fuse for disconnection:

$$I_{disc.nom} = 20\ kA > I_{po} = 7,65\ kA$$

Conclusion: the fuse satisfies the test conditions.

3.2.6 Selection and testing of voltage transformer

1. Choose a voltage transformer type NTMI-10, which has the following characteristics:

$U_{nom.HV}$=10 kV;

K=0,5;

S_{nom}=150 VA;

S_{max}=1000 VA

At rated voltage:

$$U_{nom} = 10\ kV = U_{net} = 10\ kV$$

2. Check the selected voltage transformer for secondary load:

$$S_{nom} \geq S_{2\Sigma},$$

where $S_{2\Sigma}$ - load of all measuring instruments and relays connected to the voltage transformer, VA.

$$S_{2\Sigma} = \sqrt{P_{inst}^2 + Q_{inst}^2},$$

$$P_{inst} = \Sigma S_{inst} \cdot \cos\phi_{inst} = 52 \cdot 0,85 = 44,2\,\text{Wt}$$

$$Q_{inst} = \Sigma S_{inst} \cdot \sin\phi_{inst} = 52 \cdot 0,53 = 27,56 \text{ Wt, then}$$

$$S_{2\Sigma} = \sqrt{44,2^2 + 27,56^2} = 52,088 \text{VA}$$

150 VA>52,088 VA.

Conclusion: the selected voltage transformer satisfies all test conditions.

3.2.7 Selection of a fuse to protect the voltage transformer

Choose a fuse type PKN-001-10U3 with U_{nom} = 10 kV, I_{nom} = 50.80 A.

At rated voltage

$$U_{nom} = 10\ kV = U_{nom} = 10\ kV$$

Conclusion: the selected fuse satisfies the selection condition.

3.2.8 Selection of nonlinear surge arrester

Choose a nonlinear surge arrester type OPNp-10/12/10/1 (2) UHL2.

at rated voltage

$$U_{nom} = 10\ kV = U_{net} = 10\ kV$$

Conclusion: the chosen overvoltage limiter satisfies the conditions of choice.

3.2.9 Selection and testing of current transformer

Selection and testing of current transformer is presented in Applications A

3.2.10 Selection and testing of load switches for protection of TS-10 / 0,4

Selection and testing of load switches for protection of TS-10 / 0,4 is presented in Applications A

3.2.11 Selection and testing of a fuse for central distribution substation

Selection and testing of a fuse for central distribution substation is presented in Applications A

3.2.12 Selection of circuit breakers

Selection of circuit breakers is presented in Applications A

3.2.13 Selection and testing of high-voltage switches for protection of power transformers

Selection and testing of high-voltage switches for protection of power transformers is presented in Applications A

3.2.14 Selection and testing of disconnectors for 35 kV overhead lines

Selection and testing of disconnectors for 35 kV overhead lines is presented in Applications A

3.2.15 Selection of measuring instruments

Selection of measuring instruments is presented in Applications A

3.3 Selection of schemes of the distribution network of the enterprise. Load distribution by power points TS-10 / 0.4 kV; DB-0.4 kV

3.3.1 Selection of schemes of the distribution network of the enterprise

Selection of schemes of the distribution network of the enterprise is presented in Applications A

3.3.2 Load distribution by power points TS-10 / 0.4 kV; DB-0.4 kV

Load distribution by power points TS-10 / 0.4 kV; DB-0.4 kV is presented in Applications A

4 LABOUR OCCUPATIONAL SAFETY AND SECURITY IN EMERGENCY SITUATIONS

4.1 Electric shock Hazards in workplace

What is electric shock? electric shock is a sudden stimulation of the body nervous system by an electric current which can cause pain, injury, or death. although it is usually painful, electric shock is not always associated with actual damage to the body tissues. the most common sensation is stabbing and numbing pain at the points of current entry and exit and sometimes along the path of the current through the body.

Places of work generally have power nominally supplied at 230 volt (single phase) and 400 volt (3 phase) although some larger workplaces will receive electricity at a higher supply voltage. The information below relates to workplaces using 230 and 400 volt supplies. Any time a person comes in contact with an energized conductor there is a potential for electrical shock. as in the example, current will flow through the human body if it becomes part of an electric circuit when the potential difference (voltage) is adequate to overcome the body`s resistance in the example, the man became part of the circuit because his body became a path of least resistance to ground.

The main hazards with electricity are: contact with live parts causing shock and burns, faults which could cause fires; fire or explosion where electricity could be the source of ignition in a potentially flammable or explosive atmosphere.

The five principal ways that people experience electrical shock:

1. contact with a normally bare energized conductor,

2. contact with a normally insulated conductor on which the insulation has deteriorated or been damaged so that it is no longer protective,

3. equipment failure that results in an open or short-circuit, which, in turn causes the current to flow in an unexpected manner,

4. static electricity discharge,

5. lightning strike.

The risk of injury from electricity is strongly linked to where and how it is used and there is greater risk in wet and/or damp conditions.

Basics of Contact with Electricity

It is the level of voltage the body is exposed to and the resistance to flow of electrical current offered by the body that determines the impact of exposure to electricity. The following factors determine the severity of the effect electric shock has on your body:

The level of voltage

The amount of body resistance you have to the current flow

The path the current takes through your body

The length of time the current flows through your body

If a worker has come into contact with electricity the worker may not be able to remove themselves from the electrical source. The human body is a good conductor of electricity. If you touch a person while they are in contact with the electrical source, the electricity will flow through your body causing electrical shock. Firstly attempt to turn off the source of the electricity (disconnect). If the electrical source can not readily and safely be turned off, use a non-conducting object, such as a fibre glass object or a wooden pole, to remove the person from the electrical source.

We must ensure that Extension cables and other flexible leads which are particularly prone to damage to plugs and sockets and to their connections are visually checked, maintained and where necessary replaced before using portable equipment. The ends of flexible cables should always have the outer sheath of the cable firmly clamped to stop the wires (particularly the earth) pulling out of the terminals.

Use the correct cable connectors or couplers to join lengths of cables together and do not allow taped joints.

Electrical installations are installed and maintained by a competent person and checked regularly

Socket Outlets are not overloaded by the use of adaptors

Electrically powered equipment provided is suitable for use

Fixed electrical equipment should have a clearly identified switch to cut off power in an emergency that portable equipment labelled as being double insulated has had the live and neutral connected properly to the plug by a competent person unless the plug is of a moulded type.

Controlling the Risk

Reduce the Voltage

Often portable equipment is available that is powered from a 110 volt supply through a simple transformer and these are often centre tapped to earth so that the maximum voltage between a live conductor and earth (the most common cause of electric shocks from equipment) is limited to 55V.

Battery operated tools such as drills, screwdrivers etc can replace mains powered equipment.

Temporary and hand held lighting can be provided at 12, 25, 50 or 110 volts.

Ensure Fuses are correctly fitted

The fuse protects the device from over current. It is designed to ‘blow’ and cut off the electricity when the current exceeds its rated capacity. It is important to ensure the correct fuse is used for the appliance. As a general guide 3 amp fuses are used in equipment up to 700 watts (W). For equipment with a rating greater than 700 watts (W) a 13-amp fuse will be required. Some equipment requires a 5 amp fuse e.g. some televisions and, other equipment like some printers require 10 amp fuses. Always read the manufacturer’s instructions.

Electrical consumer products and appliances in the administrative building are also potential sources of shock if protective covers are damaged or removed. typically, some conductors inside electrical equipment are not insulated because unskilled human contact is not expected. when unskilled or unsuspecting people dismantle or break through protective enclosures, there is a potential for shock.

In many cases a conductor is covered with an insulating material that keeps a current from passing to another conductor, including the human body. if, however, the insulation is defective by design, deterioration, or damage, there is a high potential for equipment failure or electric shock. deterioration or damage.

The heat may also be part of the operating environment. for example, the insulating materials used in or near equipment that produces high temperature as a normal part of operation must be capable of withstanding the heat for the designed life of the system. essentially, circuit designs that require very low operating energies or design precautions that immediately cut power when an overload occurs are good preventive measures. processes involving high temperatures as a normal operating characteristic call for cooling system to remove heat.

Cold environment can also damage insulating materials. some insulating materials may become brittle when exposed to cold environments. if you live in a cold climate, think of what happens when you leave a garden hose out for the winter. it becomes brittle and cracked. similarly, fluctuation in temperature may also effect an insulator. temperature fluctuations can expand and contract the insulating materials and possibly result in their mechanical failure and breakdown of the insulating properties.

Equipment failure that results in an open or short circuit:

Any time a conducting element in a circuit comes in contact with another conductor, whether it is part of the designed circuitry or not, a short circuit or very low impedance connection can occur. if you have ever driven behind a car on which the tail lights kept dimming or randomly blinking, you have likely witnessed the results of a short circuit. a common scenario with vehicle electrical systems as they age is the breakdown and deterioration of the insulation covering wires throughout the vehicle. if the conducting wire touches the frame or another conductor, the current will flow in unexpected paths and reduce or eliminate the current from the intended path, such as to the tail lights. similarly, if a conductor is severed, or if a path in a circuit is opened by other means, the open circuit may cause current to increase in other parts of the circuit, and to overload components, which may cause failure. although failed vehicle tail lights certainly create a hazardous situation.

Effects of shock on the human body:

If you are outside during an electrical storm, you can do several things to protect yourself from injury. if an all metal shelter or structure that has lightning protection is available, seek shelter within the structure. once inside, however, avoid contact with metal surfaces any part of a metal structure or electrical equipment that may become energized in the event of a lightning strike. the interior of the steel body of an automobile is considered an excellent shelter during an electrical storm, even if a high voltage line is touching it the rubber tires insulate the vehicle from ground. if you attempt to leave the car while the line is energized, however, you will provide the path to ground and will be severely, probably fatally, shocked.

5 to 25mA

Current in this range is referred to as let-go current threshold can be defined as the maximum current at which a person holding an electrode in each hand can still let them go. average let-go levels range from 9 to 16 milliamperes for men and 6 to 10.5 milliamperes for women. when a person threshold has been exceeded, the affected muscles freeze and it is impossible to voluntarily release the conductor. when this happens, the person may be exposed to current for a longer period, and the potential for injury is increased. the let-go threshold for direct currents occurs at 300 milliamperes or greater.

20 to 75 mA

Currents in this range can be very painful and injurious. prolonged contact may result in a fall always a potential source of injury unconsciousness, and death as inhibition of the respiratory muscles stops breathing. cessation of breathing can be caused by prolonged contraction of the respiratory muscles or by inhibition of the breathing control centers of the central nervous system.

When breathing stops because of respiratory muscle inhibition, it usually resumes once the current is stopped or after first aid assistance is given. death from asphyxiation will occur unless resuscitation is performed within 3 or 4 minutes maximum. respiratory arrest of a central nervous system origin is rare an requires two things: a passage of current through the brain, and a higher current.

Controlling the shock Hazard:

Equipment directly in contact with the heart muscle. a shock hazard that would pose little danger in a normal environment can be lethal in these situations. in certain industries or situations, therefore, special precautions, through design and procedure, are needed to minimize shock hazard.

Isolation:

Enclosures or barriers should be used to isolate unauthorized or untrained personnel from shock hazards, especially from high voltage systems. the isolating barriers must be so designed and located to eliminate contact with energized equipment and must be available only to trained and authorized people.

Marking:

Warnings posted at points of access to hazardous electrical systems should be marked with appropriate hazard information. As a designer, you should design to eliminate hazards. some equipment is however, inherently hazardous, especially if other hazard control methods are bypassed, as often happens during maintenance procedures. warning information, both written and color coded, must be located so that personnel will be informed at critical points during operation, installation, or maintenance procedures.

Warning devices:

Warning devices, such as sound or light, may be connected to an electrical system to indicate when it is energized. these are important in complicated, multi-function systems for which an operator must monitor a number of system is actually energized.

Grounding:

The earth can be looked at as an infinite store for electrons. given a conductive path to earth, or ground; a charge difference will eather draw electrons from or return them to the soil. the idea that the earth is an infinite electrical sump is not true. all current must flow in loops any current that enters the earth must also leave. in fact this is often the current path in electrocution or shock incidents, the person becomes part of the circuit.

Carry out preventative maintenance

All electrical equipment and installations should be maintained to prevent danger.

This should include an appropriate system of visual inspection and, where necessary, testing. By concentrating on a simple, inexpensive system of looking for visible signs of damage or faults, most of the electrical risks can be controlled.

It is recommended that fixed installations are inspected and tested periodically by a competent person. The frequency of inspections and any necessary testing will depend on the type of installation, how often it is used, and the environment in which it is used.

Users can help by reporting any damage or defects they find.

Ensure that people who are working with electricity are competent to do the job. Even simple tasks such as wiring a plug can lead to danger - ensure that people know what they are doing before they start.

GENERAL CONCLUSIONS

The project of an electric distribution network for a reliable power supply system of a research institute is proposed in the thesis.

The following results were obtained:

1. An analysis of ways to increase the reliability of the power supply system was carried out;

2. An analysis of electricity consumers was carried out according to the reliability of the electricity supply system, which made it possible to select the number and power of transformers;

3. The estimated load was determined for the workshops and for the institute as a whole, which amounted to 17 MVA;

4. The choice of compensating devices is substantiated, taking into account the full design load was 14.6 MVA;

5. The power line voltage of 35 kV and distribution network voltage of 10 kV were selected;

6. A cartogram of loads was built, which made it possible to determine the center of electrical loads of the institute;

7. The choice of transformers of the main and central transformer substations is justified, taking into account the installed compensating devices;

8. Three variants of schemes were drawn up, which made it possible to ensure a reliable power supply system of the institute;

9. Selection of the cross-section of power line wires, selection of cross-section and brand of cable lines;

10. Calculation of short-circuit currents was carried out, which made it possible to select devices and current-carrying parts of the substation.

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Applications

Applications A

Selection and testing of current transformer

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{S_c}{\sqrt{3} \cdot U_m} = \frac{14606{,}18}{\sqrt{3} \cdot 10} = 843{,}29 \text{ A}$$

Choose a current transformer type TVLM-10/1500, which has the following characteristics:

U_{nom} = *10 kV;*

I_{nom} = *1,5 kA;*

$i_{p.con}$. = *165 kA;*

$I_{t.s}$ = *24 kA;*

$t_{t.s}$ = *10 s*

a) at rated voltage

U_{nom} = *10 kV* = U_{net} = *10 kV*

b) at rated current

I_{nom} = *1,5 kA* > $I_{work.nomb}$ = *843,29 A.*

2. Check the selected current transformer:

a) on electrodynamic stability.

The electrodynamic stability of bus current transformers is determined by the stability of the busbars of the distribution substation, as a result, such transformers are not tested under this condition.

b) the multiplicity of thermal stability:

$$(k_t \cdot I_{nom})^2 \cdot t_{per} \geq I_{po}^2 \cdot t_{np},$$

$$(65 \cdot 1{,}5)^2 \cdot 1 = 12939\ kA^2 \cdot s \geq 7{,}65 \cdot 2{,}2 = 128{,}75\ kA^2 \cdot s$$

Conclusion: the selected current transformer satisfies all test conditions.

Selection and testing of load switches for protection of TS-10 / 0,4

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{k_{per.} S_{nom.tr.}}{\sqrt{3} \cdot U_m} = \frac{1{,}4 \cdot 1600}{\sqrt{3} \cdot 10} = 129{,}32 \text{ A}$$

Choose a load switch type VNP-17:

$$U_{nom} = 10\ kV;$$

$$I_{nom} = 400\ A;$$

$$I_{p.con.} = 25\ kA;$$

$$I_{p.con.} = 14{,}5\ kA;$$

$$I_{disc.nom.} = 20\ kA;$$

$$I_{t.s.} = 6{,}7\ kA;$$

$$t_{t.s.} = 10\ s;$$

$$I_{con.nom.} = 20\ kA;$$

$$T_{con.nom.} = 0{,}5\ s;$$

$$T_{disc.} = 1\ s$$

a) at rated voltage

$$U_{nom} = 10\ kV = U_{net} = 10\ kV$$

b) at rated current

$$I_{nom} = 400\ A > I_{work.nom} = 129{,}32\ A.$$

2. Check the selected load switch

a) on the ability to disconnect

$$I_{disc.nom} = 20\ kA > I_{po} = 5{,}34\ kA$$

a) inclusive ability

$$I_{con.nom} = 20\ kA > I_{po} = 5{,}34\ kA$$

c) on electrodynamic stability

$$I_{p.con.} = 14{,}5\ kA > I_{po} = 5{,}34\ kA$$

$$I_{p.con.} = 25\ kA > i_{sh3} = 8{,}68\ kA.$$

4) Check the switch for thermal stability

$$I_{t.m.}^2 \cdot t_{t.} \geq B_k\ ,$$

where Bk is the calculated thermal current pulse of the short circuit

$$B_k = I_{po}^2 (t_{c.z} + t_{vl.v} + T_a) = 5{,}34^2 \cdot (0{,}1 + 0{,}1 + 0{,}0052) = 5{,}85\ kA^2 \cdot s$$

$$I_{t.s.}^2 \cdot t_{disc.} = 6{,}7^2 \cdot 1 = 44{,}89\ kA^2 \cdot s$$

$$44{,}89\ kA^2 \cdot s > \ 5{,}85\ kA^2 \cdot s$$

Conclusion: the selected load switch satisfies all test conditions.

Selection and testing of a fuse for central distribution substation

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{k_{per.} S_{nom.tr.}}{\sqrt{3} \cdot U_m} = \frac{1,4 \cdot 1600}{\sqrt{3} \cdot 10} = 129,32\,\text{A}$$

2. Choose a fuse type PKT-103-10-160-20U3:

U_{nom}=10 kV;

$I_{nom.}$=160 A;

$I_{disc.nom.}$=20 kA

a) at rated voltage

$$U_{nom} = 10\ kV = U_{nom} = 10\ kV$$

b) at rated current

$$I_{nom} = 160\ A > I_{work.nom} = 129,32\ A.$$

3. Check the fuse for disconnection:

$$I_{disc.nom} = 20\ kA > I_{po} = 5,34\ kA$$

Conclusion: the fuse satisfies the test conditions.

Selection of circuit breakers

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{k_{per.} S_c}{\sqrt{3} \cdot U_c} = \frac{1,4 \cdot 1600}{\sqrt{3} \cdot 10} = 129,3\,\text{A}$$

We choose the Schneider Electric Compact LS 380-1600-150 circuit breaker

$U_{nom} = 380\ V;$

$I_{nom} = 1600\ A;$

$I_{disc.nom.} = 150\ kA;$

Let's check the switch

a) at rated voltage

$$U_{nom} = 380\ V = U_{net} = 400\ V$$

b) at rated current

$$I_{nom} = 1600\ A > I_{work.nom} = 129{,}3\ A.$$

c) on the ability to disconnect

$$I_{disc.nom} = 150\ kA > I_{po} = 31{,}75\ kA$$

Selection and testing of high-voltage switches for protection of power transformers

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{S_c}{\sqrt{3} \cdot U_m} = \frac{14606{,}18}{\sqrt{3} \cdot 35} = 240{,}94\,\text{A}$$

High-voltage switches are selected by rated current, rated voltage, type, type of installation, with a comparison of technical and economic indicators and tested for electrodynamic, thermal stability and disconnectivity in short circuit mode.

We plan to install a high-voltage vacuum switch Siemens 3AH5-35-1250-16 with the following parameters:

$$U_{nom} = 35\ kV;$$

$$I_{nom} = 1250\ A;$$

$$I_{disc.nom.} = 16\ kA;$$

$$I_{t.nom} = 16\ kA$$

$$T_{t.norm} = 4\ s;$$

$$I_{p.con.} = 40\ kA;$$

$$I_{p.con.} = 16\ kA;$$

$$I_{con.nom.} = 40\ kA;$$

$$I_{con.nom}. = 16\ kA;$$

$$T_{disc.} = 0{,}08\ s$$

1) Under the conditions of working long mode we have:

$$U_{nom} = 35\ kV = U_{net} = 35\ kV$$

$$I_{nom} = 1250\ A > I_{work.nomb} = 240{,}94\ A.$$

2) Check of the switch on disconnecting ability

$$I_{disc.nom} = 16\ kA > I_{po} = 7{,}15\ kA$$

3) On electrodynamic stability

$$I_{p.con.} = 16\ kA > I_{po} = 7{,}15\ kA$$

$$I_{p.con.} = 40\ kA > i_{sh2} = 13{,}1\ kA.$$

4) Check the switch for thermal stability

$$I^2_{t.m.} \cdot t_{t.} \geq B_k\,,$$

where B_k is the calculated thermal current pulse of the short circuit

$$B_k = I^2_{po}(t_{c.z} + t_{vl.v} + T_a) = 7{,}15^2 \cdot (0{,}1 + 0{,}08 + 0{,}0053) = 9{,}47\ kA^2 \cdot s$$

$$I^2_{t.s.} \cdot t_{disc.} = 16^2 \cdot 4 = 1024\ kA^2 \cdot s$$

$$1024\ kA^2 \cdot s > 9{,}47\ kA^2 \cdot s$$

Conclusion: the selected switch satisfies all test conditions.

Selection and testing of disconnectors for 35 kV overhead lines

1. Determine the maximum operating current:

$$I_{work.nom} = \frac{S_c}{\sqrt{3} \cdot U_m} = \frac{14606{,}18}{\sqrt{3} \cdot 35} = 240{,}94\,\text{A}$$

The choice of disconnectors is performed by design, number of grounding knives and installation location. By rated voltage and current.

We plan to install high-voltage disconnector RNDZ-1-35 / 1000 U1 with the following parameters:

$$U_{nom} = 35\ kV;$$

$$I_{nom} = 1000\ A;$$

$$I_{t.nom} = 25\ kA$$

$$I_{p.con.} = 63\ kA;$$

1) Under the conditions of working long mode we have:

$$U_{nom} = 35\ kV = U_{net} = 35\ kV$$

$$I_{nom} = 1000\ A > I_{work.nomb} = 240{,}94\ A.$$

2) On electrodynamic stability

$$I_{p.con.} = 25\ kA > I_{po} = 7{,}15\ kA$$

$$I_{p.con.} = 63\ kA > i_{sh2} = 13{,}1\ kA.$$

3) Check the disconnector for thermal stability

$$I_{t.m.}^2 \cdot t_{t.} \geq B_k \,,$$

where B_k is the calculated thermal current pulse of the short circuit

$$B_k = I_{po}^2 \cdot t_{c.z} = 7{,}15^2 \cdot 1 = 51{,}12\; kA^2 \cdot s$$

$$I_{t.s.}^2 \cdot t_{disc.} = 25^2 \cdot 1 = 625\; kA^2 \cdot s$$

$625\; kA^2 \cdot s > 51{,}12\; kA^2 \cdot s$

Conclusion: the selected disconnector satisfies all test conditions.

Selection of measuring instruments

Ammeter: E-390

Voltmeter: E-390

Wattmeter: D-390

Warmeter: D-345

Watt-hour counter: SAU-I670

Volt-ampere-hour counter: SR-I673

All selected devices and the conditions of their verification are summarized in table. 3.1.

Table 3.1 - Selected electrical devices

Electrical apparatus or conductor	Terms of selection and verification
MSS tire 80x8 mm	Size = 80x8 = 640> $S_{t.s.}$ I_{allow} = 1320 A.> I_c= 887.67 A. σc= 296.72 kgs / sm2 < σ_{allow}= 650 kgs / sm2
NTMI-10 voltage transformer	$U_{nom} = 10\ kV = U_{nom} = 10\ kV$ 150 VA> 52,088 VA.
Fuse PKN001-10U3	$U_{nom} = 10\ kV = U_{nom} = 10\ kV$
Nonlinear surge arrester OPNp-10/12/10/1 (2) UHL2	$U_{nom} = 10\ kV = U_{nom} = 10\ kV$
TVLM-10/1500 current transformers	$U_{nom} = 10\ kV = U_{nom} = 10\ kV$ $I_{nom} = 1.75\ kA > I_{work.nomb} = 843.29\ A.$
Transformer of own needs TM-120/10-U1	$U_{nom} = 10\ kV = U_{nom} = 10\ kV$
Fuse PKT101-10-8-20U3	$U_{nom} = 10\ kV = U_{nom} = 10\ kV$ $I_{nom} = 8\ A > I_{work.nom} = 6.93\ A.$ $I_{disc} = 20\ kA > I_{po} = 7.65\ kA$
GNP-17 load switch	$U_{nom} = 10\ kV = U_{nom} = 10\ kV$ $I_{nom} = 400\ A > I_{work.nom} = 129.32\ A.$ $I_{disc} = 20\ kA > I_{po} = 5.34\ kA$ $I_{con.nom} = 20\ kA > I_{po} = 5.34\ kA$ $I_{p.con}. = 14.5\ kA > I_{po} = 5.34\ kA$ $I_{p.con}. = 25\ kA > i_{sh3} = 8.68\ kA.$

Continuation of table 3.1

High-voltage switch Siemens 3AH5-10-1250-20	U_{nom} = 10 kV = U_{nom} = 10 kV I_{nom} = 1250 A> $I_{work.nomb}$ = 843.29 A. I_{disc} = 20 kA> I_{po} = 7.65 kA $I_{p.con}$. = 20 kA> I_{po} = 7.65 kA $I_{p.con}$. = 65 kA> i_{sh2} = 14.69 kA.
High-voltage switch Siemens 3AH5-10-1250-20	U_{nom} = 10 kV = U_{nom} = 10 kV I_{nom} = 1250 A> $I_{work.nom}$ = 129.32 A. I_{disc} = 20 kA> I_{po} = 7.65 kA $I_{p.con}$. = 20 kA> I_{po} = 7.65 kA $I_{p.con}$. = 65 kA> i_{sh2} = 14.69 kA.
High-voltage switch Siemens 3AH5-35-1000-16	U_{nom} = 35 kV = U_{nom} = 35 kV I_{nom} = 1000 A> $I_{work.nom}$ = 240.94 A. I_{disc} = 16 kA> I_{po} = 7.15 kA $I_{p.con}$. = 16 kA> I_{po} = 7.15 kA $I_{p.con}$ = 40 kA> i_{sk2} = 13.1 kA.
Fuse PKT103-10-160-20U3	U_{nom} = 10 kV = U_{nom} = 10 kV I_{nom} = 160 A> $I_{work.nom}$ = 129.32 A. I_{disc} = 20 kA> I_{po} = 5.34 kA
Schneider Electric Compact LS 380-1600-150 circuit breaker	U_{nom} = 380 V = U_{nom} = 400 V I_{nom} = 1600 A> $I_{work.nom}$ = 129.3 A. I_{disc} = 150 kA> I_{po} = 31.75 kA
High voltage disconnector RNDZ-1-35 / 1000 U1	U_{nom} = 35 kV = U_{nom} = 35 kV I_{nom} = 1000 A> $I_{work.nom}$ = 240.94 A. I_{disc} = 25 kA> I_{po} = 7.15 kA $I_{p.con}$. = 63 kA> i_{sh2} = 13.1 kA.

Selection of schemes of the distribution network of the enterprise. Load distribution by power points TS-10 / 0.4 kV; DB-0.4 kV

A characteristic feature of the schemes of internal distribution of electricity is the large branching of the network and the presence of a large number of switching and protection equipment, which has a significant impact on technical and economic performance and reliability of the power supply system. In order to create a rational scheme of distribution of electricity requires comprehensive consideration of many factors, such as the design of network nodes of the scheme, the method of transmission of electricity, short-circuit currents in different variants, etc.

When designing the scheme, it is important to properly address the power supply and lighting loads at night, on weekends and holidays. For mutual redundancy, it is recommended to use bus and cable jumpers between the nearest substations, as well as between the ends of low-voltage networks powered by different transformers.

In the general case, the schemes of internal distribution of electricity have a stepwise construction. It is considered inexpedient to use circuits with more than two or three stages, because in this case it is difficult to switch and protect the circuit. It is recommended to use single-stage schemes at small enterprises.

The scheme of distribution of the electric power should be connected with the technological scheme of object. Power supply of electricity receivers of different parallel technological flows must be carried out from different sources: substations, substations, different bus sections of one substation. This is necessary so that both technological flows do not stop in the event of an accident. At the same time, interconnected technological units must be connected to one power supply, so that all power receivers are simultaneously de-energized in the event of a power failure.

When building a general scheme of in-plant power supply, it is necessary to take options that ensure the rational use of cells of switchgear, the minimum length of the distribution network, the maximum savings of switching and protection equipment.

Selection of schemes of the distribution network of the enterprise

In-plant distribution of electricity is performed on the main, radial or mixed scheme. The choice of the scheme is determined by the category of reliability of electricity consumers, their territorial location, features of operating modes.

Radial circuits are those in which electricity from the power supply is transmitted directly to the receiving point. Most often, the radial scheme is used with no more than two degrees.

Single-stage radial circuits are used in small-capacity enterprises to supply concentrated consumers (pumping stations, furnaces, converters, shop substations), located in different directions from the power center. Radial circuits provide deep sectioning of the entire power supply system, from power sources to busbars up to 1 kV shop substations.

Power supply of large substations or substations with the predominance of category I consumers is carried out by at least two radial lines departing from different sections of the power supply.

Separately located single-transformer substations with a capacity of 400-630 kVA receive power on single radial lines without redundancy, if there are no consumers of the first and second categories and under the conditions of simple laying of the line and its possible rapid repair. If the separate substations have consumers of the II category, their power supply should be carried out by two cable lines.

Main electricity distribution schemes are used in the case when there are many consumers and radial schemes are not appropriate. The main advantage of the backbone is the reduction of switching links. They should be used in the location of substations on the territory of the enterprise, which facilitates the direct passage of the highway from the power source to the consumer and thus reduce the length of the highway.

The disadvantages of the main circuit is the lower reliability because it is impossible to reserve at lower voltage single-transformer substations when feeding them on one line. It is recommended to supply from one highway no more than two or three transformers with a capacity of 2500-1000 kVA and no more than four or five - with a capacity of 400-630 kVA.

There are many varieties and modifications of trunks, which, depending on the degree of reliability are divided into single and double through.

In the practice of design and operation are rarely used schemes of internal distribution of electricity, built only on the radial or only on the main principle. The combination of the advantages of radial and trunk circuits allows to achieve the creation of power supply systems with the best technical and economic indicators. Three variants of power supply schemes are presented in graphic part.

Load distribution by power points TS-10 / 0.4 kV; DB-0.4 kV

The distribution of electricity consumption with voltage up to and above 1 kV between the shop transformers of the substation and switchgear is performed in table. 5.1, 5.2, 5.3 on the basis of the cartogram of electrical loads on the principle of disaggregation of TP.

The location of the TP is shown in the general plan of the plant in graphic part.

Table 3.2 - Load distribution by supply points (option №1)

№	Name of power point	Electricity consumers	Location of the power supply point according to the general plan	Note
1	TS-1	Shop 3.2	Shop 3	2xTM 400-10 / 0.4
2	TS-2	Shop 5.1	Shop 5	2xTM 400-10 / 0.4
3	TS-3	Shop 6	Shop 6	2xTM-400-10 / 0.4
4	TS-4	Shop 7	Shop 7	2xTM 1000-10 / 0.4
5	TS-5	Shop 8,4,9	Shop 8	2xTM 1600-10 / 0.4
6	TS-6	Shop 10	Shop 10	1xTM 400-10 / 0.4
7	TS-7	Shop 11,12, jumper 10	Shop 11	2xTM 400-10 / 0.4
8	TS-8	Workshop 13, 14	Shop 13	2xTM 400-10 / 0.4
9	DB-1	Shop 1	Shop 1	from TS-2
10	DB-2	Shop 2	Shop 2	from TS-1
11	DB-3	Shop 4	Shop 4	Magician from DB-4
12	DB-4	Shop 9	Shop 9	from TS-5
13	DB-5	Shop 12	Shop 12	from TS-7
14	DB-6	Shop 14	Shop 14	from TS-8

Table 3.3 - Distribution of loads by power points (option №2)

№	Name of power point	Electricity consumers	Location of the power supply point according to the general plan	Note
1	TS-1	Shop 3,4,9,14	Shop 3	2xTM 400-10 / 0.4
2	TS-2	Shop 5, jumper 10	Shop 5	2xTM 400-10 / 0.4
3	TS-3	Shop 6,1,2	Shop 6	2xTM-400-10 / 0.4
4	TS-4	Shop 7	Shop 7	2xTM 1000-10 / 0.4
5	TS-5	Shop 8	Shop 8	2xTM 1600-10 / 0.4
6	TS-6	Shop 10	Shop 10	1xTM 400-10 / 0.4
7	TS-7	Shop 11.12	Shop 11	2xTM 400-10 / 0.4
8	TS-8	Shop 13	Shop 13	2xTM 400-10 / 0.4
9	DB-1	Shop 1	Shop 1	Magician from DB-2
10	DB-2	Shop 2	Shop 2	from TS-3
11	DB-3	Shop 4	Shop 4	from TS-1
12	DB-4	Shop 9	Shop 9	Magician from DB-3
13	DB-5	Shop 12	Shop 12	from TS-7
14	DB-6	Shop 14	Shop 14	Magician from DB-4

Table 3.4 - Distribution of loads by power points (option №3)

№	Name of power point	Electricity consumers	Location of the power supply point according to the general plan	Note
1	TS-1	Shop 5	Shop 5	2xTM 400-10 / 0.4
2	TS-2	Shop 6	Shop 6	1xTM 630-10 / 0.4
3	TS-3	Shop 7,1,2,3, jumper 6	Shop 7	2xTM-1600-10 / 0.4
4	TS-4	Shop 8,4,9,14	Shop 8	2xTM 1600-10 / 0.4
5	TS-5	Shop 11,10,12	Shop 11	2xTM 630-10 / 0.4
6	TS-6	Shop 13	Shop 13	2xTM 400-10 / 0.4
7	DB-1	Shop 1	Shop 1	Magician from DB-2
8	DB-2	Shop 2	Shop 2	Magician from DB-3
9	DB-3	Shop 3	Shop 3	Magician from DB-4
10	DB-4	Shop 3	Shop 3	from TS-3
11	DB-5	Shop 4	Shop 4	Magician from DB-6
12	DB-6	Shop 9	Shop 9	from TS-4
13	DB-7	Shop 10	Shop 10	Magician from DB-8
14	DB-8	Shop 10	Shop 10	from TS-5
15	DB-9	Shop 12	Shop 12	from TS-5
16	DB-10	Shop 14	Shop 14	Magician from DB-6