CZECH TECHNICAL UNIVERCITY IN PRAGUE

Faculty of Electrical Engineering

Department of Economics, Management and Humanities

Technical and economic studies of application of cables with insulation from cross-linked polyethylene in the case of reconstruction of schemes and networks of power supply objects

Study program: Electrical engineering, power engineering and management

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Scientific advisor: Ing. Miroslav Vitek, CSc.

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ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE

ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

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Fakulta/ústav: **Fakulta elektrotechnická**

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Název diplomové práce anglicky:

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Pokyny pro vypracování:

- výpočet elektrické zátěže mechanického provozu a celého podniku
- variantní návrh transformátorů v hlavní trafostanici a podružných stanic
- návrh průřezu kabelů
- kontrola zkratových poměrů
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- vyhodnocení variant z ekonomického hlediska

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Krupovič, V.I.: Spravočnik po projektirovanlju električeskich setej i elektrooborudovanija (elektroustanovki promyšlenych predprijatij). Energoizdat, Moskva, 1981.
Planning of Electric Power Distribution - technical principles. Erlangen, Siemens AG, 2016.

Jméno a pracoviště vedoucí(ho) diplomové práce:

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Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

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III. PŘEVZETÍ ZADÁNÍ

Diplomantka bere na vědomí, že je povinna vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

Datum převzetí zadání Podpis studentky

CVUT-CZ-ZDP-2015.1

DECLARATION

"I hereby declare that this master's thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague".

Date *Signature*

ABSTRACT

In my muster thesis I investigated the issue of the possible reconstruction of the power supply scheme in the Tomsk enterprise of heavy industry “Sibelektromotor”.

The urgency of the work lies in old-fashioned material insulation. For many years due to the alternative absence, cables with impregnated paper insulation (IPI) were applied for transmitting power. IPI cables have many evident drawbacks, that decreases reliability of power supply.

Nowadays, they are still under operation but they are being replaced by the new type of insulation material – cross-linked polyethylene (XPLE). This material has a large number of advantageous features over paper insulation, that gives a strong reason to consider the reconstruction of the system.

In the theoretical part I described the insulating materials, their technical characteristics and made a competitive analysis upon the obtained information.

The technical part contains designing of power supply systems.

The economic feasibility of the two projects is described in the economic part. This part contains calculations of the investment cost, maintenance of the cables, where losses is the essential part. I also provided sensitivity of the project to different rates.

In the last part I drew conclusion of the work upon the obtained calculations and the theoretical base and provided my recommendations.

Key words:

Cross-linked polyethylene, impregnated paper insulation, power supply system, transformer substation, cable lines, cross-section, cash flow.

CONTENTS

LIST OF ABBREVIATIONS

AAShv – A-aluminium core, A-aluminium cover, Shv- cab-tyre sheath from polyvinylchloride compound

APvV - A-aluminium core, Pv – cross-linked polyethilen wire insulation, V - polyvinylchloride compound cable shield

AS - A – Aluminum wire, S – Steel core

CAPM - Capital asset pricing model

CB – Capacitor bank

CEL - Center of electrical loads

CF – Cash flow

CIC - Consolidated indexes of cost

CIS – Commonwealth of Independent States

CL – Cable lines

CMP - construction and assembly operations

DG - Distributing gear

DP - Distribution point

EAT – Earning after taxation

EBT – Earning before taxation

EC – Electrical consumer

HV – High voltage

IPI - Impregnated-paper insulation

IRR – Internal rate of return

L - Line

LC – Load cycle

MSDS - Main step-down substation

NPV – Net present value

OFC - Oil-filled cable

OPTL - Overhead power transmission line

PSS – Power supply system

PVC – polyvinylchloride

SM - Synchronous motor

TM – Transformer

TS - Transformer substation

UKM – Ustanovki kompensatsii moshchnosti - installations of power compensation

WACC - Weighted average cost of capital

XLPE - Cross-linked polyethylene

INTRODUCTION

The main consumers of the electric power are various industries, municipal and transportation facilities of the country. At the same time, the first place by quantity of the consumed electric energy (about 65%) is taken by industrial enterprises.

Qualitative and uninterrupted power supply of enterprises is essential for their proper functioning. Consequently, the task of rational construction of power distribution schemes is becoming more complicated. Demands to reliability, efficiency, safety and convenience in operation, to power quality are getting higher.

Design of electric power supply systems requires an integrated approach to selection and optimization of schemes of electrical networks and to technical and economic feasibility, that defines structure, internal and external communication, dynamics of development, parameters and reliability of the system as a whole and its individual elements. [1]

Power cable lines is an essential link in transmission and distribution of electricity, that determine the reliability of electricity supply to consumers. In addition, cable lines are designed for transmission of information over distances. No one modern technical device, whose operation involves the use of electrical and electronic circuits, can not work without cables and wires, that form the power supply system, informatics and control operation of the device.[2]

Technical progress has created growth of demand in cable lines and necessity in creating new types of cables and wires with higher features.

Earlier oil-filled cables were applied for laying cable lines with high voltage. Recently, thanks to new technologies, cables with cross-linked insulation are under operation.

Tasks, that are set when designing power supply systems of industrial enterprises: optimization of parameters of the systems by right choosing voltage, defining electrical loads and demands to power supply without failures; choosing optimal cable; rational choice of number and capacity of transformers, etc.

In the given master thesis power supply of the machine-building plant in general and particularly the mechanical shop are considered.

The purpose of the work is analysis of the cross-linked polyethylene cables application in power supply scheme.

The following issues are considered for achieving the purpose:

- Feasibility of cables with insulation of cross-linked polyethylene insulation application
- Comparative analysis of oil-filled cables and cables with cross-linked polyethylene insulation
- Calculation of power supply system of “Sibelektromotor” enterprise with traditional cables with impregnated paper insulation
- Reconstruction of the power supply scheme with the change of the cable lines for the cables with XPLE insulation
- Evaluation of economic aspects of the reconstruction project

1. LITERATURE OVERVIEW

1.1 Reliability of power supply system

Power supply system is a set of devices, intended for production, transmission and distribution of electricity (generators, transformers, electrical equipment of power distribution and power consumers control). Each of these devices is an industrial product and it must have the required level of quality and be reliable in terms of functional performance.

The quality of any technical object is a sum of its characteristics that determine consumer features associated with the ability to meet the established requirements and expectations.

In the power supply system, each element may be badly designed, constructed, assembled, that can affect reliability of its work and reliability of the whole system. Quality and reliability of technical devices are connected. By reliability of power is meant a continuous supply of electric power consumers, implementing the conversion of electricity to other forms of energy.

Electricity companies must meet the following basic requirements for certain indicators:

- quality of transmitted power;
- reliability of power supply;
- safety of electrical and nonelectrical staff in the operation of grid and electrical installations;
- profitability, i.e. reduction of costs for construction and operation of
- networks and installations;
- network configuration changes due to changes in production technology;
- reduction of electricity losses in networks;
- sustainability, i.e. the lack of harmful effect on the environment.

Most power consumers consume not only active energy (power) from the network, which is converted into other forms, but also reactive power. Transmission of reactive power through electric grids of enterprises leads to increased losses in electrical networks and to additional expenditures for electricity.

Regarding to system of power supply these properties include safety, continuity of power supply and fast recovery of elements, providing necessary quality of electricity and its minimal losses, the possibility of replacing and rearranging processing equipment.

PSS must be reliable, provide regular electricity to power consumers.

When designing the PSS of enterprises it is necessary to solve several problems that require combining a number of conflicting requirements - such as decreasing capital expenditures for the construction and operation of the PSS and its high level of quality and reliability.

When designing power supply systems great importance is paid to the quality of electricity, power quality parameters set in standard documentation. Power quality should be respected both by suppliers and consumers of electricity. [3]

While solving optimization issues of PSS, the consequences of violating the normal mode of power supply of enterprises should be determined. PSS analysis on reliability allows:

- select power scheme with higher reliability;
- select different types of equipment;
- determine the economic indicators of the system;

- set reliability requirements for newly developed systems. [4]

There are two ways of increasing reliability: improving the reliability of the elements that the considered object contain, and creating object with a high grade of reliability from relatively unreliable elements using various kinds of redundancy. In this work the first method is applied.

The basis of the optimal choice of power supply circuits must be based on minimum discounted capital costs with annual costs on operation. [5]

Consideration of these important issues is described in this work.

1.2 Designing power supply system

When designing the following basic requirements to power supply systems should take into account:

2. The power system must be reliable, i. e. to ensure continuity supply in accordance with the category of power consumers;
3. The power supply system should be simple, convenient and safe in operation;
4. The power supply system should be cost-effective, i. e. correspond to minimum discounted costs for its construction and operation.

In order to design the proper power supply system, the technical calculations should contain the following points:

1. Determination of the rated electrical loads;
2. Choice of rational voltage for shop, for plant and external for power supply;
3. Construction of cartograms and definition of conditional center of electrical loads;
4. Locating and selecting circuit of the main step-down substation;
5. Selecting the number, capacity and location of shop transformer substations based on reactive power compensation;
6. Determination of number and capacity of transformers of the main step-down substation;
7. Calculation of short circuit currents;
8. Selecting cross-section of current-carrying elements to electrical devices;
9. Choice of protection devices and designing selective tripping plan;
10. Making voltage deviation diagrams from MSDS to the most powerful and remote power consumer [6]

1.3 Urgency of the insulation material choice

Nowadays, traditional cables with impregnated-paper insulation are being replaced with new generation cables. At the present stage we can relate to them cables with plastic insulation, where as insulation cross-linked polyethylene is used. Improvement implementation of the cable insulation materials with improved dielectric and thermal properties can significantly increase the capacity of the cable lines. [7]

It is caused by improvement of production process and design of cables, that are connected with the increase of their operational reliability.

Mass implementation of cables of new generation in power industry can be carried out when three factors are considered:

- increase of the power transferred limit;
- increase of operational reliability;
- reduction in cost of production, installation and operating costs. [8]

In order to identify the feasibility of application of cables with XLPE insulation it is necessary to make a comparative analysis of this type of cables with cables with insulation of a different material.

1.4 Problems in IPI cables operation

Almost every electrical enterprise operating 6 kV, 10 kV and above voltage uses power cable lines. In general, the cable lines have a lot of advantages in comparison to the overhead line: they have smaller dimensions, they are safer, more reliable and easy to operate. And this is one of the main reasons why most of the electricity networks of cities and large industrial enterprises consists of cable power lines.

Most of the cables laid in Russia and the CIS - have impregnated-paper insulation, and their construction practically remained unchanged for several decades. These cables have a number of drawbacks: the different laying levels, frequent damage rate, transition power limits. [9]

During the times of alternative absence, the cables with paper insulation had to put up with their weaknesses and to take additional measures to ensure the reliability of electricity supply to consumers and load requirements. Reserving lines were created, parallel cable were laid, and, of course, it led to a significant complication of the mains circuit and growth of capital investments in the network. [10]

1.5 Parameters of oil-filled cables

In my thesis I applied two types of cables with different insulation.

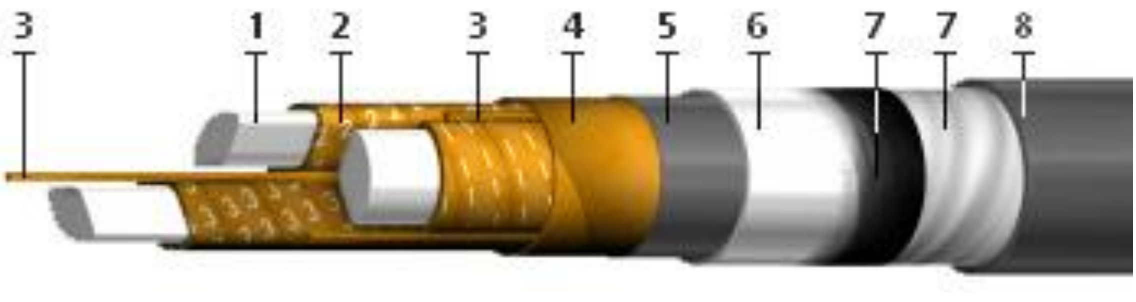
The cable, that is used in traditional power supply system is AAShv with voltage 10 kV.

Abbreviation expansion of AAShv

A-aluminium core

A-aluminium cover

Shv- cab-tyre sheath from polyvinylchloride compound



Picture 1 – The structure of the cable AAShv [11]

The structure of the cable

1. Aluminum core: single-wire (class 1) with the cross-section of 25-240 square mm, Multiwire (class 1 and 2) the cross-section of 50-800 square mm;
2. Phase paper insulation impregnated with a viscous or non-draining insulation impregnating compound, numbering of cable conductors: digital or color;
3. Paper bundles;
4. Wrapping paper insulation impregnated with a viscous or non-draining insulating impregnating compound;
5. Screen from conductive paper for cables with from 6 kV and higher voltage;
6. Aluminum sheath;
7. Underlayer of bitumen and PET film;
8. Outer cover from PVC compound.

Application

The purpose of the cables is to transfer and distribute electricity that comes to stationary installations to electrical networks with voltages up to 10 kV and frequency 50 Hz.

The cable can be operated in areas with a temperate and cold climate. AAShv can be used both in dry and in wet rooms, including in areas with high corrosive activity and the presence of ground currents. Besides, the cable can be laid in earth trenches, cable tray systems, mines and outdoors, as well as in damp, partially flooded rooms.

When organizing power grids using AAShV cables, it is necessary to avoid possibilities of mechanical damage of the cable and its excessive stretching.

An important feature of this type of the cable is that AAShV is flame-retardant if it is a single cable laying. Due to this fact, it is applied in fire and explosion-hazardous areas and track sections. In addition, AAShV can be used in areas with a high level of vibration. [12]

Specification:

Table 1 - Technical features of the cable AAShV with IPI insulation. [12]

Operating voltage	10 kV
Ambient temperature during operation	from -50 °C to +50 °C
Relative air humidity (at +35 °C)	up to 98%
Minimum cable temperature without preheating	0 °C
Maximum permissible working temperature of conductors for cables 6 - 10 kV	+70 °C
The maximum permissible temperature of heating the cores of the cables in emergency mode (or overload mode)	+90 °C
The maximum temperature of heating conductors with short-circuit	+200 °C
Minimum bending radius for laying	15 cable diameters
Lifetime	30 years

Insulation material features

Cables with impregnated-paper insulation have relatively low electric strength, that limits their application in grids with voltage more than 35 kV. It is due to the presence of air inclusions in the insulation which occur during cable operation.

When in operation the cable is subjected to periodic heating and cooling (load starting and load shedding). When heated all the elements of the cable (including impregnating compound) increase in volume. After cooling the cable shield due to the residual strain is not able to exert pressure on the impregnating composition that is required to return it to its former position. As a result, after several heating and cooling cycles air slugs may appear.

If the air slugs are formed at the point of insulation, where the electric field strength exceeds the start of partial discharge strength, then slugs ionization starts, accompanied by temperature increase in this place. Ionization causes accelerated aging of the insulation, that is accompanied by changes of physical and chemical properties and reduction of dielectric strength of impregnated paper insulation.

If the air slugs are in place where the electric field intensity is insufficient for the ionization occurrence, however over time the electrical insulation resistance is significantly reduced, as slugs movement in the direction from the cover to the core occur under the cyclic thermal loads, i. e. in the area of the greatest electric field strength in the cable insulation.

In order to increase the electric strength of impregnated paper insulation, it is necessary either to create the conditions that exclude the appearance of gas inclusions in it, or increase the electric strength of existing slugs, for example, by means of increasing pressure in them or by filling these slugs with gas, that has increased electrical strength.

Electric strength and reliability of the oil-filled cable lines are provided (along with other requirements) upon condition that the oil will keep its high dielectric properties (low dielectric losses and high electric strength). In order to ensure stability of dielectric insulation properties and prevent development of ionization processes in it, oil, that is generally intended for oil-filled cable lines, is exposed deep degasification.

Unlike conventional cable lines, the operation of oil-filled cable lines is connected with the systematic control of the state of oil-filling devices, control of the oil state (quality) in cable lines, ensuring high integrity of the entire system and preventing from air getting into cable and arising gas due to oil decomposition. [13]

The problem of oil leak from the cable shield accompanies through all history of the cables' existence with paper-impregnated insulation. Mainly due to the difficulty of this problem elimination, the transition to solid extruded insulation, for example, cross-linked polyethylene is determined. However, namely cables with IPI insulation have the highest share today.

Oil leaking leads to sharp deterioration of insulation, drop of dielectric characteristics, and the ability to heat abstraction. Ultimately, the formation of leaks lead to the failure of the cable line. And the solution to the problem of oil leaks is the main issue for extending the lifetime of this cable type.

Leaking oil from the cable shield is determined by several factors:

- Height difference when laying the cable;

- Thermal expansion of metal caused by changes in operating conditions, including the presence of emergency operation;

- The level of impregnation of the paper insulation by mineral oil or nonflowing composition;

- External mechanical impact on the cable, and so on.

But stable condition for the absence of leaks is one - complete sealing of the cable along its entire length, including couplings and, especially, cable ends as, perhaps, the most vulnerable places in IPI insulated cables. [14]

Cables with paper-impregnated insulation have the following disadvantages:

1. Cable manufacturing process is complicated and time-consuming, that's the reason of the high price; [15]

2. When laying cables on vertical or steeply inclined tracks with a large difference of laying levels of rosin composition, that impregnates paper insulation, has a feature to drain, and the paper insulation worsens and has a tendency to premature deterioration. In order to minimize this effect, use cables with non-draining impregnating composition [16];

3. High damage rate;

4. The cable construction has a big weight, because the necessary element of the cable is the metal cover that protects the impregnated paper, that loses its insulation properties when contacting with moisture. [15]

The building length of a cable depends on the weight of a cable. As IPI cables are much heavier, the length, when laying the cable, is more limited, than XPLE cables' length.

For many technical and operational characteristics of gives isolation XLPE, in connection with which there is a replacement material.

This type of insulation is exceeded in many technical and operational features in comparison to cross-linked polyethylene insulation. Therefore, the replacement is held.

1.6 Features of XLPE cables implementation

The cable, that I chose for reconstruction of power supply system is APvV with voltage 10 kV.

Abbreviation expansion of APvV

A-aluminum core
Pv – cross-linked polyethylene wire insulation
V - polyvinylchloride compound cable shield

Picture 2 – The structure of the cable APvV [17]

The structure of the cable

1. Round multiwire compacted conductor from aluminum:

Cross-section: from 50 to 800 square meters. mm (A);

2. Conductor screen from extruded semiconducting cross-linked polyethylene;
3. XLPE insulation (Pv);
4. Screen on insulation from extruded semiconducting cross-linked polyethylene;
5. Separating layer;
6. A screen made of copper wires fastened with a copper band:
7. Separating layer;
8. Sheath made from PVC compound (V). [17]

Application

Cables are intended for transmission and distribution of electrical energy in stationary installations, for nominal alternating voltage of 10 kV at a frequency of 50 Hz for grids with insulated or ground neutral.

Cables are applied for single laying in cable facilities and industrial areas.

Cables can be laid in dry ground (sand, sandy clay and normal soil with a moisture content of at least 14%).

Cables are designed for laying on the tracks without any limits on the difference in levels. [18]

Specification:

Table 2 - Technical features of the cable APvV with XPLE insulation. [18]

Operating voltage	10 kV
Ambient temperature during operation	from -50 °C to +50 °C
Relative air humidity (at +35 °C)	up to 98%
Minimum cable temperature without preheating	-15 °C
Maximum permissible working temperature of conductors	+90 °C
The maximum permissible temperature of heating the cores of the cables in emergency mode (or overload mode)	+130 °C
The maximum temperature of heating conductors with short-circuit	+250 °C
Minimum bending radius for laying	12 cable diameters
Lifetime	30 years

First cables with plastic insulation with voltage 110-220 kV appeared in the late 60s. These cables had a thermoplastic polyethylene insulation. Afterwards, insulation from cross-linked (vulcanized) polyethylene started being used more and more frequently and, finally, in the early 80s cables of this type became the basic type, successfully replacing oil-filled cables. In 1986-1988 first samples of cables with XLPE insulation with voltage 400 and 500 kV were produced.

While having the basic features of the electrical conventional polyethylene, cross-linked composition has increased heat resistance, stress cracking resistance and ageing resistance, increased mechanical characteristics. One of the most important features is the resistance of cross-linked polyethylene to short-term overheatings (150-200 C), that lets using this material as power cable insulation, exposed to short-circuit currents. [19]

This material has a molecular structure with cross linkage, that is performed chemically with the additives of vulcanizing agent (organic peroxide) or by insulation exposure to high-energy microparticles.

During crosslinking, cross connections are formed between macromolecules of polyethylene, that create three-dimensional structure of the material. Due to this structure, the polyethylene has high performance of electrical and mechanical features, a big range of operating temperatures and less hygroscopic.

One of the main characteristics of insulation materials is permissible heating temperature of conductors, the maximum temperature at which the insulating material does not lose its properties for a long time. Since XLPE is thermosetting material, its long-term permissible heating temperature is much higher in comparison with other materials for power cable insulation have. With permissible temperature 90°C (that is 20°C higher in comparison with PVC and IPI insulations), cables with XLPE insulation have permissible current loads 20% higher. [20]

Many energy companies, having highly appreciated the positive aspects of operation of the cables with medium and high voltage from XLPE, are also focused on using this type of cables when laying new cable lines and replacing or major repairs of old ones. Besides, in order to make the connection between cables with impregnated paper insulation and XLPE insulation specially designed joint sleeves are used. It significantly reduces the problem of repair and reconstruction of electrical networks.

Russian producers, who have already upgraded their technology, established production of such cables for domestic consumers.

It is due to high technical and operational parameters of XLPE cables:

1. By increasing the permissible conductor temperature, big cable capacity is reached (depending on laying conditions the permissible load currents are 1/6 - 1/3 times higher than paper insulated cables);

2. High resistance to moisture, at the same time there’s no need in metallic sheath;

3. When short-circuit current happens, rated short-circuit current is provided. High current of thermal resistance at shirt circuit, that is extremely important, when the cross-section is chosen only by nominal current of shirt circuit.

4. Insulating electrical properties are higher and dielectric losses are lower;

5. Allowable cable bend radius is smaller;

6. As for insulation and cable-sheath polymer materials are applied, preheating of cables when laying them at temperature of -20 ° C is not required;

7. Unlimited possibilities for laying cables on lines with any difference of levels;

8. XLPE cable has a smaller sizes and weight, as a consequence, laying of cable becomes easier;

9. The ambient temperature, when cable is in exploitation, can be from +50 to -50 °C;

10. The operation lifetime not less than 30 years.

11. Long building lines – till 2000 – 4000 metres for cables 6-35 kV and till 1500 metres for cables 110 kV;

12. Decreasing of operational expenses, especially in comparison to IPI cables with high pressure. There is no need in complex oil control system and operation staff.

13. Absence of environmentally damaging oil;

14. Decreasing of labor efforts when installing. Oil freezing by liquid nitrogen is not needed;

15. Fire explosion safety;

11. Absence of liquid components (oil under pressure), and as a consequence expensive recharging equipment, that leads to significant shortening of operational expenses, simplification of installation equipment, shortening of installation time and cost of work on laying and installing [21]

Nevertheless, the basic advantage of this material in comparison to paper ones is a low failure rate. The percentage of electrical breakdown is two-three times lower. [22]

As we can see, there are a lot of advantages of XPLE application, but it would be fair to reflect the drawbacks, too.

During manufacturing stage air microcavity may occur in cables with XLPE insulation, internal mechanical damages and various inclusions, that result in decreasing electrical resistance and reduction of insulation lifetime.

In addition, when designing electrical supply of industrial enterprises, production cycle, that is connected to the occurrence in voltage on bus-bars of their switchgears (SG) high-frequency components of voltages and currents, it’s necessary to take into consideration special measures to prevent the effects of the harmonic components on electrical supply network, and namely, cable lines. The presence of high-frequency currents leads to significant negative consequences. There is overheating and accelerated thermal deterioration of the insulation. [23]

1.7 Comparative analysis of XLPE and IPI materials

Despite of all the above benefits mentioned before, putting into operation of cables with XLPE insulation is accompanied with high investment cost. Therefore, it is also necessary to perform a technical and economic justification of XLPE cables implementation.

For clarity, I have made a comparative table of technical characteristics of cables with different types of insulation.

Table 3 - Technical characteristics of cables with XLPE and IPI insulations.

Cable features	XLPE	IPI
Long-term operation temperature, ^oC	90	85
Temperature in emergency mode, ^oC	130	90
Maximal core temperature at short circuit current, ^oC	250	200
Permissible 1 second short circuit current density, ^oC For copper wire For aluminum wire	 144 93	 101 67
Specific inductive capacity at temperature 20 ^oC	2,4	3,3
Dielectric loss tangent at temperature 20 ^oC	0,001	0,004

Thus, cables with XLPE insulation exceed cables with IPI insulations on many features, therefor the application of this cables lets solve a lot of pressing issue of reliability of power supply, simplification and optimization of systems, reduction of expenses on lines maintenance. [22]

For more concrete information I compared two cables, that I used in my work, with different insulation materials. comparison characteristics are shown in the table below.

Table 4 – Comparison characteristics of the cables with 10 kV voltage.

Comparison parameters	Cable with IPI AAShv (3x35)	Cable with XPLE insulation APvV (3x35)
Permissible temperature of wire heat, ^{o}C	70	90
Permissible temperature of wire heat at emergency mode, ^{o}C	90	130
Minimum installation bending radius, outer cable diameter	15	15
Maximum temperature of wire heat at short circuit, ^{o}C	200	250
Ambient temperature during operation, ^{o}C	from -50 to +50	from -50 to +50
Minimum laying cable temperature without preheating, ^{o}C	0	-15
Permissible difference of levels, m	15	No limits
Weight, kg	3170	2699

The cable features are taken from [24], [25].

Upon this information, I can make a comparative analysis of the following advantages and disadvantages, that are presented in the tables below.

Table 5 – Advantages and disadvantages of oil-filled cables.

Advantages	**Disadvantages**
Comparatively low price	Low ecological safety
Resistant to aging	Fire risk
	Complicated installation and repair
	High operational demands
	Big operational expenses (installation of additional charging equipment)
	Presence of liquid components

Table 6 – Advantages and disadvantages of cross-linked polyethylene cables.

Advantages	**Disadvantages**
Big capacity	Higher capital expenses
Low weight, small diameter	Temperature control for keeping operational features
Ability of big building lengths application	
Wider temperature range	
Ecologically more safe	
Less operational expenses	
Low damage rate	

According to the represented data, the technical features of XPLE cable are higher. It is explained by more expensive materials and production technology. It obtains equal distribution of electrical field, that causes electrical strength increase.

Based on the above comparison analysis, I can make the following conclusions about feasibility and effectiveness of XPLE cables application:

- In spite of higher investment costs, the operational costs are extremely low.
- XPLE cable is recommended for application, when IPI cable with maximum cross-section doesn't meet the required capacity. As the capacity of XPLE cable is higher.
- It's more reasonable to use one cable of bigger cross-section. It concerns the cases of parallel cable laying, when instead of two parallel cables of 200 mm^2, it is more feasible to lay one cable with cross-section 400 mm^2.
- If there is a big difference of levels when laying cables, it is preferable to use XPLE cables. When using IPI cables, the drying of insulation in high points may occur, that can cause breakdown. At the same time, even small difference of laying levels may become a reason of numerous damages in cable lines.
- Application of XPLE cables is necessary when there are special demands to reliability of power supply, as the damage rate is extremely low. [26]

Thus, upon the stated information, it follows that, the implementation of insulation materials with higher dielectric and thermal features lets essentially increase capacity of cable lines and, by means of that, improve the reliability of power supply to customers.

1.8 Urgency of the cable cross-section choice

When designing power supply networks it is necessary to calculate losses in cables. When solving design issues, this calculation is important for choosing a cable with the optimum cross-sectional area of the core. Incorrect cable selection can cause the quick fail of a system or it can simply not start operating. That is why when designing, it is necessary to calculate the losses in the cable.

The power loss in the cable also depends mainly on the cable resistance. Excessive dissipation of energy in the cable can lead to significant energy losses. Excess heat goes to the heating of a cable, therefore at high loads, an incorrect calculation of energy losses in a cable can lead to a strong heating of a cable and damage of insulation, which is unsafe for people's lives.

Also, if a line has a significant length, it can lead to an increased consumption of electricity. If it lasts for a long time, it can affect the electricity costs. Incorrect calculation of voltage losses in the cable can cause incorrect operation of the equipment during signal transmission.

Losses in cables can be reduced by increasing the cable cross-sectional area, reducing the cable length or reducing the load. Very often the length of the cable or the load can not be reduced, so it is necessary to increase the cross-sectional area of the cable core to reduce its resistance.

On the other hand, the use of a cable in which the cross-sectional area is too large leads to an increase in costs. The apparent small difference between the prices for two cables with different cross-sectional area becomes noticeable with multi-kilometer cable systems. Therefore, when designing, it is necessary to choose the cable of the required cross-section, and for that it is necessary to calculate the power losses in cables. [27]

[18] When transmitting electrical energy through cables losses take place, according to Lenz-Joul law, the capacity, that losses in one phase of the line with its active resistance r, will be equal I^2r, and for three phases - $3I^2r$.

Using the capacity formula, we can find:

$$I = \frac{P}{\sqrt{3} \cdot U \cdot \cos\varphi} \text{ A}$$

Where: P- line load; U-voltage; cosφ-power factor.

Thus, for losses of capacity in line ΔP we get the following expression:

$$\Delta P = \frac{P^2 \cdot r}{U^2 \cdot \cos^2 \varphi} \text{ kW}$$

Where: P- line load; U-voltage; cosφ-power factor; r-active resistance of line.

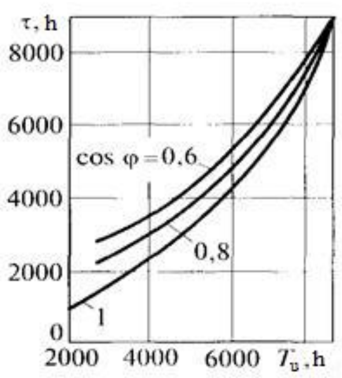
As line load is not constant, the expression for energy losses for time t is the following:

$$\Delta W = \frac{r}{U^2 \cdot \cos^2 \varphi} \int_0^t p^2 dt \text{ kW}$$

Where: P- line load; U-voltage; cosφ-power factor; r-active resistance of line.

It's possible to define losses by this formula, if the mathematical equation of load diagram is known, rather dependence of P and t, that usually doesn't happen in reality.

For this reason practical losses are determined another way. P_m values (the biggest load value according to the graph 1) are set instead of P values and value τ (time of losses, that is chosen according to the following condition: if the constant load P_m will be transferred through the line within τ time) is put in. Value τ is defined through curves of the graph 1.



Picture 3 – Curves for defining “time of losses”.[6]

Formula for losses definition in line:

$$\Delta W = \frac{P_m{}^2 \cdot \tau}{U^2 \cdot \cos^2 \varphi} r \cdot 10^{-3} \text{ kW}\cdot\text{h}$$

Where: P_m - maximum load; U-voltage; cosφ-power factor; r-active resistance of line; τ - losses time.

As we see, the losses are proportional to active resistance of the line (on one phase) r.

As it is known

$$r = \rho \frac{l}{S}$$

where ρ – specific resistance of cable, l – length of cable, S – cross-section; losses are inversely related to cross-section of the cable and, therefore, can be decreased down by increasing it. But it will lead to big wire metal usage. Consequently, technical and economical calculations of power supply systems should give more reasonable task solution, that includes the following contradictions: the more the cable cross-section, the less the operating expenditures, but the capital expenditures increase. The choice of a cross-section is carried out by the condition - minimum total evaluated expenditures.

Practically, cross-section is chosen by economic current density. Having chosen economic current density and having divided by it the biggest calculated load current, I obtain the necessary wire cross-section.

The found wire cross-section is checked for:

a) heating – if the rated current doesn’t exceed the permissible current for the given cross-wire.
b) voltage drop.

The energy, that is lost in wires, turn into heat and heat them. By means of calculations I defined limit values of currents, that are permitted by the heating conditions for wires with different cross-sections and different materials. Checking the chosen wire for heating comes down to comparison of its rated current with permissible current value in the table in [6].

2. TECHNICAL PART

The purpose of the work is to identify the more feasible variant of power supply system for the enterprise “Sibelektromotor”.

Two variants are under consideration:

1. Power supply system with the traditional impregnated-paper insulation cables.
2. Power supply system with XLPE insulation cables.

With all the mentioned above features cables with impregnated-paper insulation demand less capital costs at the moment of purchasing, but more operational costs, as it demands repairing and replacement more often.

2.1 Initial data of the enterprise “Sibelektromotor”

The enterprise “Sibelectromotor” is located in Tomsk, Russia. There are producing and non-productive shops in the enterprise. The last aren't directly involved in production process, but carry out various support functions. These are clearing water station, compressor rooms, instrumental building and also various administrative and household and entertainment complexes.

Features of power supply of “Sibelektromotor” plant

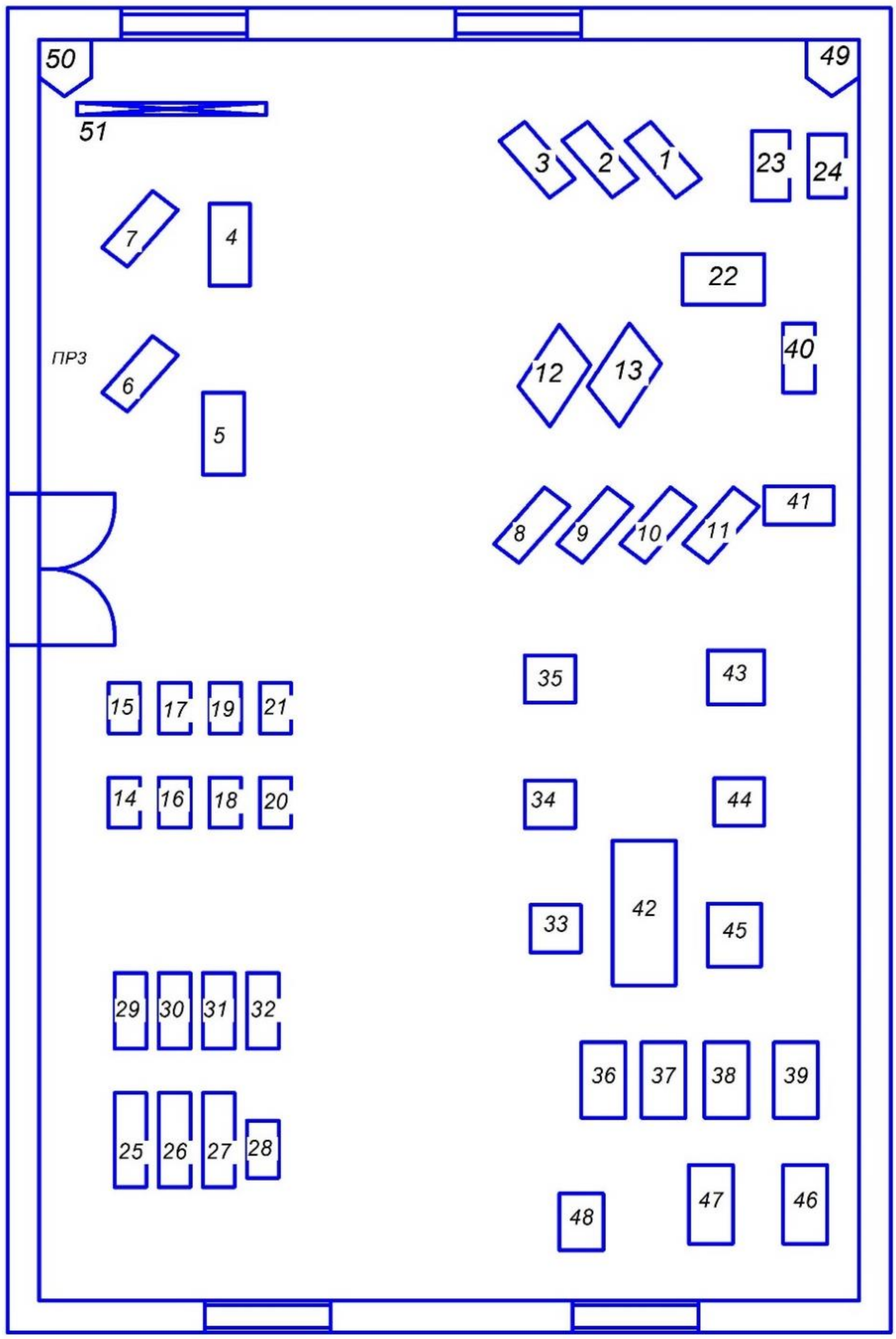
There are shops that belong to the II category of reliability. Therefore the enterprise feeds from a two-chain air-line of an electricity transmission 2,2 km long. Feeding is carried out by GRES2.

Data on electric loadings of the enterprise are presented in table 7.

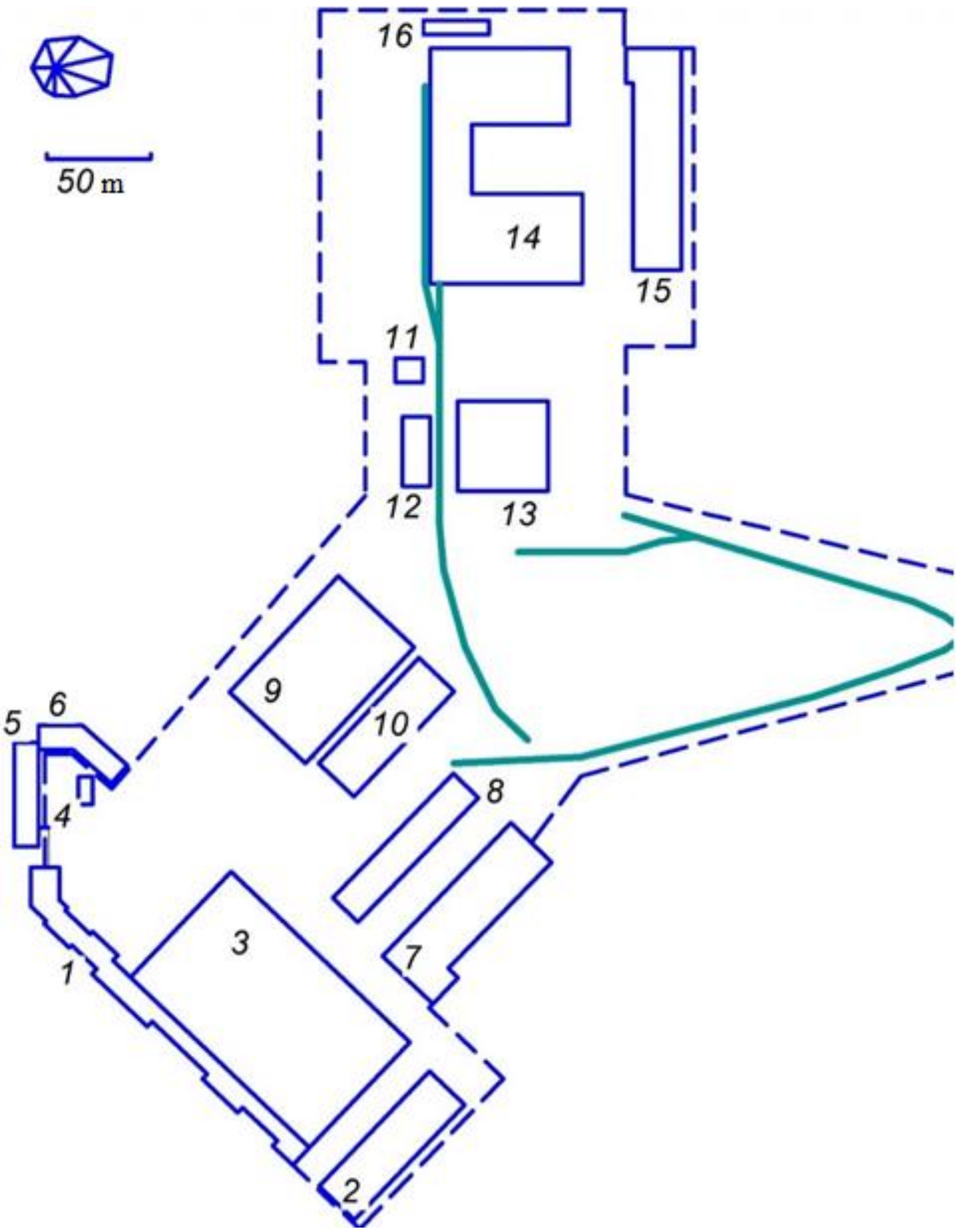
Table 7 – Electrical loads data of enterprise

No	Name	Number of shifts	Reliability category	Environment	Installed power P, kW
1	Administration shop	2	III	Normal	680
2	Instrumental building	2	III	Normal	1250
3	Main building	2	II	Fire hazardous	4500
4	Clearing water station	3	II	Moist	640
5	CC «Motor»	3	III	Normal	550
6	Administration building	3	III	Normal	350
7	Building of ancillary services	3	III	Normal	300
8	Warehouse	3	III	Normal	185
9	Mechanical shop	3	III	Normal	228
10	Garage complex	2	III	Normal	210
11	Chop shop	3	II	Normal	250
12	Compressor room	3	II	Normal	-
	0,38 kV				180
	10 kV SD 2x630 kV				1260
13	Warehouse №1	2	III	Normal	172
14	Water pump station	3	II	Normal	450
15	Iron-foundry	3	II	Hot	2980
16	Warehouse №2	4	III	Normal	115
Length of the feeding line, km		2,2			

There are loads of II and III category of power supply reliability. The majority of the shops work 2 or 3 shifts by 8 hours. Environment: Normal.



Picture 4 – Scheme of distribution of equipment in Mechanical shop.



Picture 5 – General plan of the enterprise

Railway roads

All drawings are performed in the program “Compas”.

2.2 Calculation of electrical loads in Mechanical shop

For calculation of electrical loads all the equipment is divided into distribution centers (DC) in Mechanical shop.

The maximum number of equipment – 15.

Average active loads for the most loaded shift for each group of equipment is defined by the formula:

$$P_{sh} = K_{op} \cdot P_{nom}, \text{ kW} \quad (1)$$

Average reactive load for the most loaded shift for each group of equipment is defined by the formula:

$$Q_{sh} = P_{sh} \cdot tg\varphi, \text{ kVA} \quad (2)$$

where K_{op} – coefficient of active power use;

P_{nom} – total active power of operating equipment;

tgφ - is accepted by the according value of power factor.

The average coefficient of active power use is determined by a formula:

$$K_{op.av} = \frac{\sum P_{sh}}{\sum P_{nom}} \quad (3)$$

where $\sum P_{sh}$ - total average active load for the most loaded shift,

$\sum P_{nom}$– total rated power of a group of shop equipment.

Effective number of equipment is calculated by formula:

$$n_e = \frac{(\sum P_{nom})^2}{\sum P_{nom}{}^2} \quad (4)$$

Rated active power P_r and reactive power Q_m power of a group:

$$P_r = K_m \cdot \Sigma(K_{op} \cdot P_{nom}) \quad (5)$$

where K_m – coefficient of maximum load

$$Q_m = Q_{sh}, \text{ kVAr when } n_e > 10 \quad (6)$$

$$Q_m = 1{,}1\ Q_{sh}, \text{ kVAr when } n_e < 10 \quad (7)$$

In case when P_r will be less then nominal power of the equipment with the biggest capacity, it is accepted:

$$P_r = P_{n.max} \quad (8)$$

Total rated power is defined by the next formula:

$$S_r = \sqrt{P_r^2 + Q_r^2} \quad (9)$$

Rated current:

$$I_r = \frac{S_r}{\sqrt{3} \cdot U_{nom}} \quad (10)$$

The initial data of the mechanical shop loads is in appendix 1.

Example of calculation for DP 4:

Milling machine LC=40%

$$P_{nom} = P_{ins} \cdot \sqrt{TF} = 4 \cdot \sqrt{0{,}4} = 2{,}53 \text{ kW}$$

$$P_{sh} = K_{op} \cdot P_{nom} = 0{,}3 \cdot 2{,}53 = 0{,}76 \text{ kW}$$

$$Q_{sh} = P_{sh} \cdot tg\varphi = 0{,}76 \cdot 1{,}98 = 1{,}5 \text{ kWAr}$$

Calculations for all equipment and sum values for DP 4 are in the table 8:

Table 8 - Calculation for all equipment and sum values for DP 4

Name	P_{nom}, kW	P_{sh}, kW	Q_{sh}, kVAr
Radial drilling machine (36)	8	1,6	1,87
Universal grinding-machine (37)	5	1	1,17
Universal grinding-machine (38)	5	1	1,17
Face-grinding machine (39)	10	2	2,34
Welding machine LC=40% (46)	2.53	0.76	1.5
Welding machine ат LC=40% (47)	2,53	0.76	1.5
Hardening furnace (48)	12	9	2.97
ΣP_{nom}, kW	45,06		
ΣP_{sh}, kW	16,12		
ΣQ_{sh}, kWAr	11,28		

Operation average factor:

$$К_{op.av} = \frac{\Sigma P_{sh}}{\Sigma P_{nom}} = \frac{16,12}{45,06} = 0,36$$

Effective number of equipment for DP4:

$$n_e = \frac{[\sum_1^n P_{nom}]^2}{\sum_1^n P_{nom}{}^2} = \frac{45,06^2}{8^2 + 5^2 + 5^2 + 5^2 + 10^2 + 2,53^2 + 2,53^2 + 12^2} = 5,48$$

I accepted $n_e = 6$, then $К_m$=1,66.

Rated active load:

$$P_r = К_m \cdot \Sigma P_{sh} = 1,66 \cdot 16,12 = 26,76 \text{ kW}$$

Find rated reactive load: with $n_e < 10$:

$$Q_r = 1,1 \cdot \Sigma Q_{sh} = 1,1 \cdot 11,28 = 12,4 \text{ kVAr}$$

Rated total load:

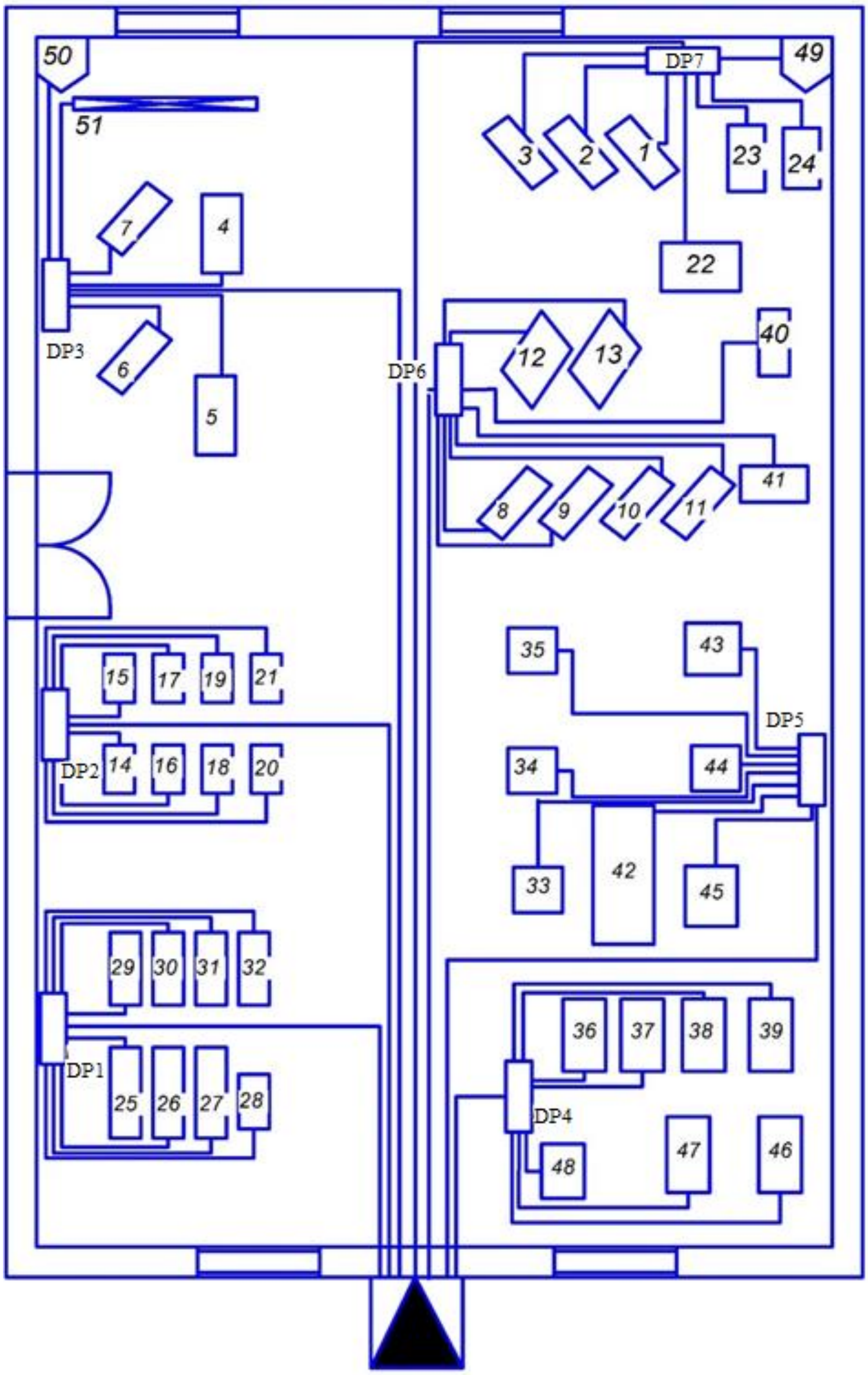
$$S_r = \sqrt{P_r{}^2 + Q_r{}^2} = \sqrt{26,76^2 + 12,4^2} = 29,49 \text{ kVA}$$

Rated current:

$$I_r = \frac{S_r}{\sqrt{3} \cdot U} = \frac{29,49}{\sqrt{3} \cdot 0,38} = 44,81 \text{ A}$$

I did the same calculations for the rest of equipment and put the values into appendix 2.

All the above calculations are performed by [6], [28].



Picture 6 – Scheme of equipment distribution by feeding stations.

2.3 Enterprise total power load calculation

[6], [28] Total equipment power of the enterprise is determined by rated active and reactive shop loads with respect to rated lightning load of shops and the enterprise territory, losses of power in shop substation transformers and MSDS and losses in high voltage lines.

Rated load (active and reactive) of shops are defined from expressions:

$$P_{rat} = K_d \cdot P_{nom} \tag{11}$$

$$Q_{rat} = tg\varphi \quad \cdot P_{rat} \tag{12}$$

where P_{nom}– total equipment power load;

K_d – demand coefficient;

$tg\varphi$ is accepted on the corresponding value of power factor.

Rated active lighting power:

$$P_{rat.l} = K_{d.l} \cdot P_{nom.l} \tag{13}$$

Where $K_{d.l}$ - demand coefficient of lightning load;

$P_{nom.l}$ – nominal power of lightning load.

Rated reactive lighting power:

$$Q_{rat.l} = tg\varphi \quad \cdot P_{nom.l} \tag{14}$$

$$P_{nom.l} = F \cdot P_{sp.l} \tag{15}$$

where F – square of a shop;

$P_{sp.l}$ - specific lightning load density.

Workshop total power, including lightning is defined below:

$$S_{\mathrm{r}} = \sqrt{(P_{\mathrm{rat}} + \mathrm{P}_{\mathrm{rat.l}})^2 + (Q_{\mathrm{rat}} + Q_{\mathrm{rat.l}})^2} \tag{16}$$

For calculation I accepted luminescent lamps.

Example of calculation for the Mechanical shop:

$$P_{rat} = K_d \cdot P_{nom} = 0{,}3 \cdot 331{,}16 = 99{,}35 \text{ kW}$$

$$Q_{rat} = tg\varphi \quad \cdot P_{rat} = 99{,}35 \cdot 0.75 = 74.48 \text{ kVAr}$$

$$P_{nom.l} = F \cdot P_{sp.l} = 12 \cdot 3833{,}5/1000 = 46 \text{ kW}$$

$$P_{rat.l} = K_{d.l} \cdot P_{nom.l} = 46 \cdot 0{,}85 = 39{,}1 \text{ kW}$$

$$Q_{rat.l} = tg\varphi \quad \cdot P_{nom.l} = 46 \cdot 0{,}75 = 34{,}51 \text{ kVAr}$$

$$S_{\mathrm{r}} = \sqrt{(P_{\mathrm{rat}} + \mathrm{P}_{\mathrm{rat.l}})^2 + (Q_{\mathrm{rat}} + Q_{\mathrm{rat.l}})^2} = \sqrt{(99{,}35 + 46)^2 + (74{,}48 + 34{,}51)^2} = 176{,}16 \text{ kVA}$$

The same calculations are performed for other shops.

The obtained results and the results for the other shops are in appendix 3.

2.4 Cartogram and definition of the center of electrical loads

[6], [28] Cartogram of loads presents circles placed on the general plan of the enterprise, that correspond to rated shop loads at a certain scale.

The radiuses of the circles for each workshop are determined by the expression:

$$r_i = \sqrt{\frac{P_{p.i}}{\pi \cdot m}} \tag{17}$$

where: $P\text{p}.i$ - rated the total power of workshop i, with the account of lighting, kWA;

m - The scale for determination of the area of a circle, kVA / mm² (constant for all the shops of the enterprise).

Lighting load is plotted in the form of a circle sector, depicting a load up to 1000 V. The angle of the sector α is determined by the ratio of the total rated Ppi and lighting Ppo loads of the shops:

$$a_1 = \frac{360^0 \cdot P_{p.o}}{P_{p.i}} \tag{18}$$

Coordinate axis are depicted on the general plan of the plant and x_i and y_i values for each shop are determined. Coordinates of the center of electrical loads of the plant are determined by the formulas:

$$X_0 = \frac{\sum P_{p.i} \cdot x_i}{\sum P_{p.i}} \tag{19}$$

$$Y_0 = \frac{\sum P_{p.i} \cdot y_i}{\sum P_{p.i}} \tag{20}$$

Dissipating area of the center of electrical loads represent an ellipse, as a section of a surface of normal distribution. When the probability P = 0.95 of the fact that random point x, y is in ellipse its semi-axis equal:

$$R_x = \frac{\sqrt{3}}{h_x}; \qquad R_y = \frac{\sqrt{3}}{h_y}; \tag{21}$$

Introduce measures the power of random variables:

$$h_x = \frac{1}{\sigma_x \cdot \sqrt{2}}; \quad h_y = \frac{1}{\sigma_y \cdot \sqrt{2}}; \tag{22}$$

The shape of the ellipse depends on the following ratios:

$$\sigma_x^2 = \sum_{i=1}^{n} P_{Xi} \cdot \left(X_i - X_0\right)^2; \qquad \sigma_y^2 = \sum_{i=1}^{n} P_{Yi} \cdot \left(Y_i - Y_0\right)^2 \tag{23}$$

Where: P_{Xi}, P_{Yi}, - empirical probability of occurrence X_i, Y_i in relative units:

$$P_{xi} = P_{yi} = \frac{Pi}{\sum Pi} \tag{24}$$

Example of calculations for the mechanical shop:

Circle radius:

$$r_1 = \sqrt{\frac{P_{\mathrm{p}i}}{\pi \cdot m}} = \sqrt{\frac{138{,}41}{3{,}14 \cdot 3333{,}33}} = 114{,}99\ mm$$

The angle of the sector of the lighting load:

$$\alpha_1 = \frac{360^0 \cdot \mathrm{Pp.o}}{Pp.i} = \frac{360^0 \cdot 39{,}11}{138{,}41} = 101{,}72^0$$

Coordinates of the center of electrical loads of the enterprise:

$$\mathrm{X}_0 = \frac{\sum P\mathrm{p}.i \cdot Xi}{\sum P\mathrm{p}.i} = \frac{1037009}{6184{,}39} = 167{,}43\ m$$

$$Y_0 = \frac{\sum P\mathrm{p}.i \cdot Yi}{\sum P\mathrm{p}.i} = \frac{1854078}{6184{,}39} = 299{,}2\ m$$

Determine parameters of the normal distribution law by the expressions:

$$\sigma_x{}^2 = \sum Pxi \cdot (Xi - Xo)^2 = \sum[0{,}041 \cdot (85 - 167{,}43)^2 + 0{,}059 \cdot (190 - 167{,}43)^2 + .. + 0{,}163 \cdot (230 - 167{,}43)^2] = 4891{,}47$$

$$\sigma_y{}^2 = \sum Pyi \cdot (Yi - Yo)^2 = \sum[0{,}041 \cdot (115 - 299{,}2)^2 + 0{,}059 \cdot (50 - 299{,}2)^2 + .. + 0{,}163 \cdot (600 - 299{,}2)^2] = 31303{,}16$$

Where: P_{Xi}, P_{Yi}, - empirical probability of occurrence X_i, Y_i in relative units:

$$P_{x1} = P_{y1} = \frac{P_{p.1}}{\sum P_{p.1}} = \frac{138{,}41}{7579{,}68} = 0{,}018$$

$$h_x = \frac{1}{\sigma_x \cdot \sqrt{2}} = \frac{1}{69{,}94 \cdot \sqrt{2}} = 0{,}0101$$

$$h_y = \frac{1}{\sigma_y \cdot \sqrt{2}} = \frac{1}{0{,}004 \cdot \sqrt{2}} = 0{,}004$$

Define the semi-axis of scattering ellipse by the formula:

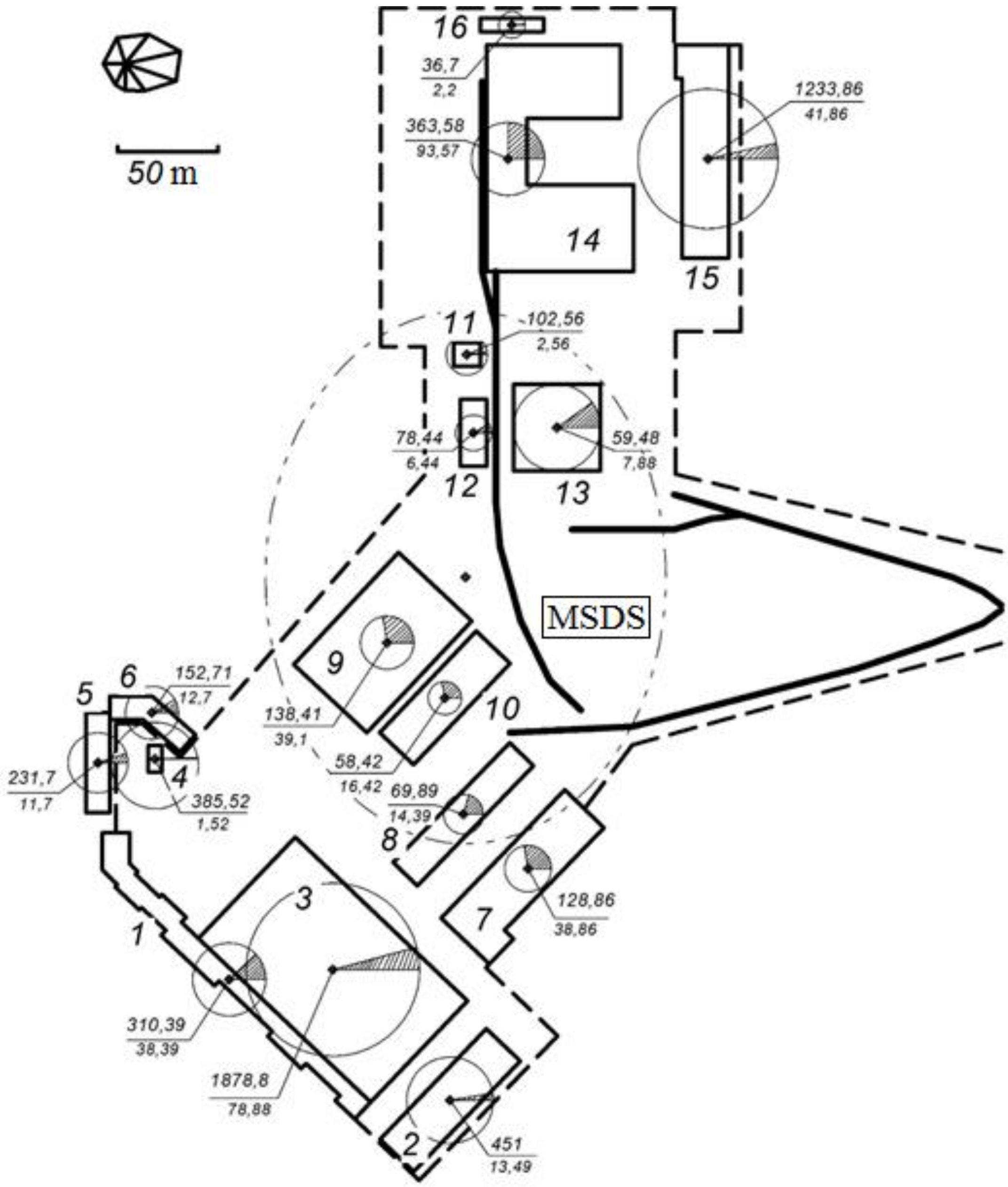
$$R_x = \frac{\sqrt{3}}{h_x} = \frac{\sqrt{3}}{0{,}0101} = 171{,}31$$

$$R_y = \frac{\sqrt{3}}{h_y} = \frac{\sqrt{3}}{0{,}004} = 433{,}38$$

For drawing the scattering zone it is enough to move the axis parallel to themselves to the point X_0, Y_0, and according to x and y axes draw the appropriate R_x, R_y.

Table 9 - Rated values for cartogram of loads

No of a shop	Ppi, kW	Ppo, kW	r, mm	a, deg	Xi, m	Yi, m	Ppi*Xi, kVA*m	Ppi*Yi, kVA*m
	Consumers 0,38 kV							
1	310,39	38,39	172,207	44,53	85	115	26383,49	35695,31
2	450,99	13,49	207,577	10,7679	190	50	85688,1	22549,5
3	1878,8	78,88	423,687	15,1137	120	140	225465,6	263043,2
4	385,52	1,521	191,919	1,42031	50	230	19276,05	88669,83
5	231,7	11,7	148,785	18,1787	25	230	5792,5	53291
6	152,71	12,70	120,788	29,9584	55	255	8398,94	38940,54
7	128,86	38,86	110,958	108,568	230	165	29638,26	21262,23
8	69,892	14,39	81,7166	74,1312	200	190	13978,44	13279,52
9	138,41	39,10	114,994	101,718	165	280	22837,155	38753,96
10	58,422	16,42	74,7109	101,193	195	250	11392,29	14605,5
11	102,56	2,56	98,9885	8,9859	215	445	22050,4	45639,2
12	78,435	6,435	86,5667	29,535	210	400	16471,35	31374
13	59,484	7,884	75,3869	47,718	250	405	14870	24089,4
14	363,575	93,57	186,377	92,655	235	530	85440,125	192694,8
15	1233,86	41,86	343,343	12,213	325	540	401004,5	666284,4
16	36,703	2,203	59,217	0,6428	230	600	8441,736	22021,92
	Consumers 6-10 kV							
12	504	-	-	-	-	-	105840	201600
Total	**6184,4**						**1102968,94**	**1773794**



Picture 7 - General plan of the enterprise with loads cartogram

Legend:

Electrical load up to 1000V, lighting load is dashed

The center of electrical loads

Scattered area of CEL

231,7 / 11,7 Rated shop power / rated lightning power

2.5 The choice of transformers' number and power of shop substations

[6], [28] Nominal power of shop transformers is determined according to the load density, and chosen the same for all transformers. Specific load density is defined by the following formula:

$$\sigma = \frac{S_p^n}{F_{shop}} \tag{25}$$

where: S_p^n- total load for the voltage less then 1000 V, kVA;

F_{shop} - total workshops' square, m^2.

$$\sigma = \frac{S_p^n}{F_{shop}} = \frac{7579{,}7}{28897{,}5} = 0{,}262 \ \frac{kVA}{m^2}$$

For σ=0,2-0,3 $\frac{kVA}{m^2}$ I accepted the recommended transformer $S_{\text{n.tr.}} = 1600$ kVA from [29].

Table 10 – Nominal transformer power

Specific load density, σ, $\frac{kVA}{m^2}$	Recommended nominal power of transformer, $S_{\text{n.tr.}}$, kVA
0,2-0,3	1600

Defining the minimal number of shop transformers $S_{\text{n.tr.}}$=1600 kVA:

$$\sigma = \frac{P_{rat.n}}{\beta_t \cdot S_{n.tr.}} = \frac{5680{,}39}{0{,}7 \cdot 1600} = 5{,}07 = 5 \tag{26}$$

Where β_T – load factor for transformer, we accept 0,7,

$P_{rat.n}$ – rated nominal load of transformer.

Average value of one transformer load is defined by the formula:

$$P_1 = \frac{P_{rat.} + P_{rat.l}}{N_{\min}} \tag{27}$$

Where $P_{rat.}$ – active rated shop load,

$P_{rat.l}$ – lightning shop load.

Active load for one transformer:

$$P_1 = \frac{P_{rat.} + P_{rat.l}}{N_{\min}} = \frac{5680{,}39}{5} = 1136{,}08\, kW$$

Number of transformers in found by the following formula:

$$N_i = \frac{(P_{rat.} + P_{rat.l})_i}{P_i} \tag{28}$$

As example of calculation, the number of transformers for mechanical shop is below:

$$N_9 = \frac{(P_{rat.} + P_{rat.l})_9}{P_1} = \frac{138{,}407}{1136{,}08} = 0{,}122$$

The same calculations are held for other shops and the results are written down in the table 11.

Table 11 – Number of transformers in the shops.

No	Name	Category	$P_{rat.}$+$P_{rat.l}$, kW	Number
1	Administration shop	III	310,39	0,273
2	Instrumental building	III	450,99	0,397
3	Main building	II	1878,88	1,654
4	Clearing water station	II	385,52	0,339
5	CC «Motor»	III	231,7	0,204
6	Administration building	III	152,71	0,134
7	Building of ancillary services	III	128,86	0,113
8	Warehouse	III	69,89	0,062
9	Mechanical shop	III	138,41	0,122
10	Garage complex	III	58,42	0,051
11	Chop shop	II	102,56	0,09
12	Compressor room 0,38 kV	II	78,44	0,069
13	Warehouse №1	III	59,48	0,052
14	Water pump station	II	363,58	0,32
15	Iron-foundry	II	1233,86	1,086
16	Warehouse №2	III	36,7	0,323

This solution does not meet the requirements of shops supply and load transformers. It is necessary to apply the transformers with lower power in order to avoid further difficulties with selection of switchgear, and also for reasons of economic efficiency.

As the active load of the shops 3 and 15 is the main part of the whole enterprise load, I accepted $S_{nom.tr}$ =1600kVA.

Determination the minimal number of transformers for 3 and 15 shops:

$$N_i = \frac{P_8 + P_{15}}{\beta_t \cdot S_{n.tr.}} = \frac{1878{,}88 + 1233{,}86}{0{,}7 \cdot 1600} = 2{,}78 = 3$$

Determination of the average load of one transformer:

$$P_i = \frac{P_8 + P_{15}}{N_{\min}} = \frac{1878{,}88 + 1233{,}86}{3} = 1037{,}58$$

$$N_{\min 3} = \frac{P_3}{P^{'}} = \frac{1878{,}88}{1037{,}58} = 1{,}81 = 2$$

$$N_{\min 15} = \frac{P_{15}}{P^{'}} = \frac{1233{,}86}{1037{,}58} = 1{,}19 = 2$$

For the accepted load it's necessary to take 3 transformers to satisfy the requirements.

The defining of the transformers' minimal number for the shops 1, 2, 4-14, 16 with $S_{nom.tr}$ =630kVA:

$$N_{min} = \frac{\sum P_{rat.+rat.l} - (P_3 + P_{15})}{\beta_t \cdot S_{n.tr.}} = \frac{5680{,}39 - (1878{,}88 + 1233{,}86)}{0{,}9 \cdot 630} = 4{,}53 = 5$$

Find the average load of one transformer:

$$P' = \frac{\sum P_{rat.+rat.l} - (P_3 + P_{15})}{N_{min}} = \frac{5680{,}39 - (1878{,}88 + 1233{,}86)}{5} = 513{,}53\ kW$$

Other data is written in the into the table below.

Table 12 – Number of transformers in shops.

No	Name	$P_{rat.}$+$P_{rat.l}$, kW	Number
1	Administration shop	310,39	0,604
2	Instrumental building	450,99	0,878
3	Main building	1878,88	1,811
4	Clearing water station	385,52	0,751
5	CC «Motor»	231,7	0,451
6	Administration building	152,71	0,297
7	Building of ancillary services	128,86	0,251
8	Warehouse	69,89	0,136
9	Mechanical shop	138,41	0,27
10	Garage complex	58,42	0,114
11	Chop shop	102,56	0,12
12	Compressor room 0,38 kV	78,44	0,153
13	Warehouse №1	59,48	0,116
14	Water pump station	363,58	0,708
15	Iron-foundry	1233,86	1,189
16	Warehouse №2	36,7	0,072

For systematization of calculations, I put the obtained numbers into the table 13.

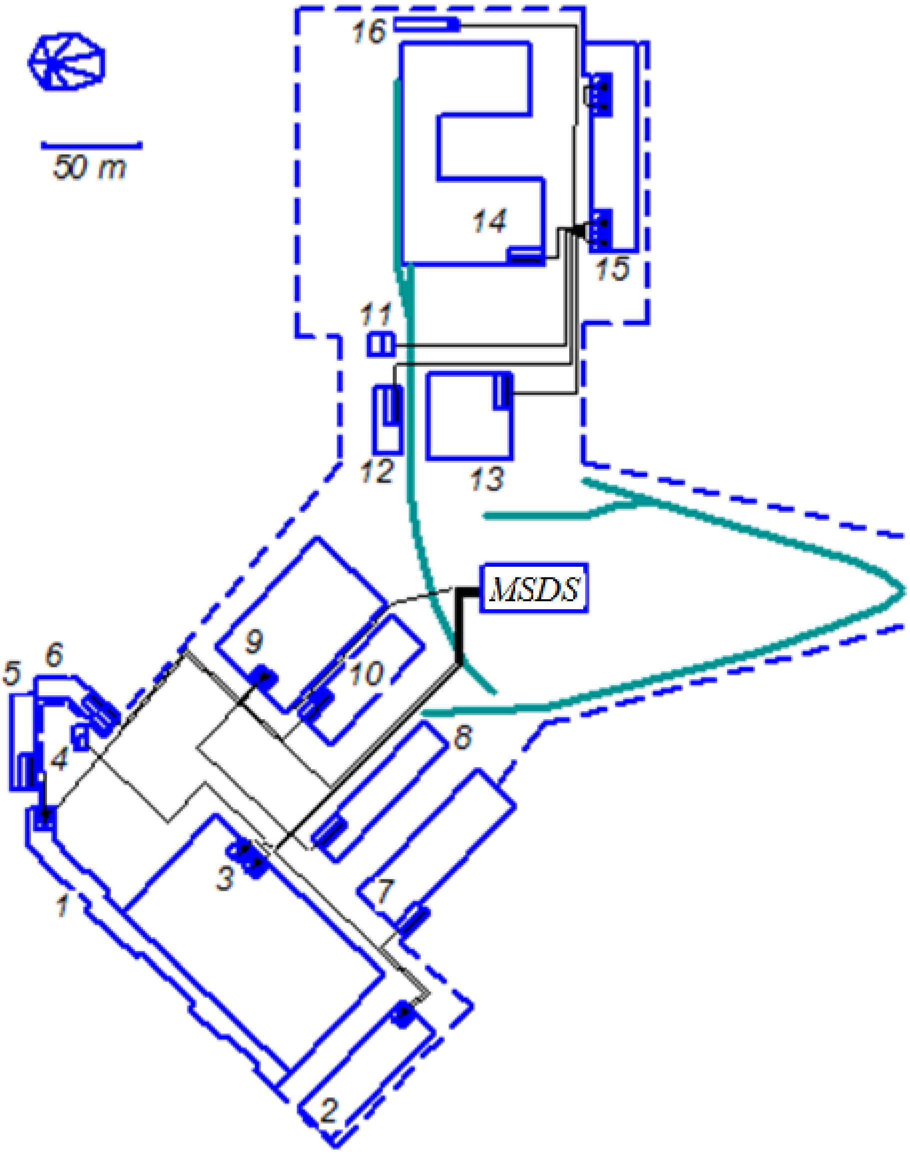
Table 13 – Distribution of electrical loads.

No	Name	Consumers	Place of the shop on the plan	Quantity and capacity of transformers
1	TS-1	Shop 1,5	Shop 1	1x630 кVA
2	TS-2	Shop 3,4	Shop 3	2x1600 кVA
3	TS-3	Shop 2,7	Shop 2	1x630 кVA
4	TS-4	Shop 6,8,9,10	Shop 9	1x630 кVA
5	TS-5	Shop 11,12,13,14,15,16	Shop 14	2x630 кVA
6	TS-6	Shop 15	Shop 15	2x630 кVA

The parameters of the chosen transformers are written into the table 14.

Table 14 – The parameters of the transformers of the TS.

Type of transformer	S_{nom},kVA	U_{nom}, kV		U_{sc},%	P_{sc}, kW	P_{oc}, kW	I_{oc},%
		LV	HV				
TM-1600/10 [29]	1600	6	0,4	5,5	18	3,3	1,3
TM-630/ 10 [30]	630	6,10	0,4	5,5	7,6	1,31	2



Picture 8 – General plan with scheme of feeding substations.

Key map:

 Shop two-transformer substation

 Shop one-transformer substation

Distribution point 1kV

Distribution net 1kV

Railway roads

2.6 Determination of capacitor bank capacity for optimal loss enhancement

Sum rated capacity of capacitor banks is defined as

$$Q_1 = \sum Q_{max.tr} \quad (29)$$

Maximum reactive power:

$$Q_{max.tr} = \sqrt{(n \cdot \beta \cdot S_{n.m})^2 - P_r^2} \quad (30)$$

where n – feasible TS transformers number;

β – normal mode load coefficient;

$S_{n.m}$– TS transformer nominal power;

P_r – rated active LV load.

For TS1 find Q_1:

$$Q_1 = \sqrt{(n \cdot \beta \cdot S_{n.m})^2 - P_r^2} = \sqrt{(1 \cdot 0{,}9 \cdot 630)^2 - 513{,}53^2} = 240{,}37\ kVAr$$

Minimal reactive power of compensating device:

$$Q_{nc1} = Q_r - Q_{max.tr}$$

If Q_{nc1} is possitive, then you should set this capacity for TS1. If it’s negative, then accept Q_{nc1} =0.

$$Q_{nc1} = 473{,}7 - 240{,}37 = 233{,}34\ kVAr$$

I chose for TS1 two capacitor banks UKM 58-04-100-33,3UZ with capacity 100 kVAr and one UKM 58-04-30-10UZ with capacity 30 kVAr.

The further calculations we carry out in the same way. The data is accumulated in appendix 4.

Calculations are performed by [6], [28].

2.7 Selection of transformers' power in the MSDS and cross-section lines, feeding MSDS

Supply voltage is defined by Illarionov:

$$U = \frac{1000}{\sqrt{\frac{500}{L} + \frac{2500}{P}}} = \frac{1000}{\sqrt{\frac{500}{2{,}2} + \frac{2500}{6{,}458}}} = 66{,}28\text{kV} \quad (31)$$

Where L – distance from the voltage source, km; P – transferred capacity, that is equal to rated load of the enterprise, related to basbars of HV MSDS.

I accepted U=35 kV.

Power supply is carried out from electric power system through two transmission lines with voltage of 35 kV. When there is one power source, scheme of external power supply with two radial lines is accepted for redundancy (MSDS with two coupling transformers).

MSDS is located on the territory of the enterprise in accordance with the rated center of electrical loads.

Since MSDS transformers are not selected yet, the power losses in them are defined as follows:

$$\Delta P_{mMSDS} = 0{,}02 \cdot S_{r\Sigma} = 0{,}02 \cdot 8689{,}08 = 173{,}78 \text{ kW} \quad (32)$$

$$\Delta Q_{mMSDS} = 0{,}1 \cdot S_{r\Sigma} = 0{,}1 \cdot 8689{,}08 = 868{,}91 \text{ kVAr} \quad (33)$$

Total rated capacity of the enterprise from HV side is defined as:

$$S_{rMSDS} = \sqrt{(P_{r\Sigma} + \Delta P_{mMSDS})^2 + (Q_{r\Sigma} - Q_{cd} + \Delta Q_{mMSDS})^2} =$$
$$= \sqrt{(6454{,}42 + 173{,}78)^2 + (5817{,}28 - 4268{,}22 + 868{,}91)^2} = 7055{,}46$$

Where Q_{cd} - power of compensating devices; $P_{r\Sigma}$, $Q_{r\Sigma}$ - total rated active and reactive power relatively.

$$Q_{cd} = Q_{r\Sigma} - Q_c = 5817{,}28 - 1549{,}06 = 4268{,}22 \text{ kVA} \quad (34)$$

Power of transformers on MSDS is determined by the formula:

$$S_{n.tr} = \frac{S_{n.tr}}{2 \cdot \beta_{tr}} \quad (35)$$

Where $S_{n.tr}$ - full rated capacity of the plant from the high-voltage side of MSDS transformers;

β_{tr} = 0.7 - the load factor of MSDS transformers;

2 - number of MSDS transformers.

I substituted and obtained:

$$S_{n.tr} = \frac{S_{n.tr}}{2 \cdot \beta_{tr}} = \frac{7055{,}46}{2 \cdot 0{,}7} = 5039{,}62 \text{ kVA}$$

The obtained value is rounded to the nearest standard value, according to this value I accepted the installation of two MSDS transformers of the type TMN-6300/35.

Table 15 - Features of the selected transformer

Type of the transformer	S_{nom}, kVA	U_{nom} of windings,kV		Usc,%	Psc, kW	Poc, kW	Ioc ,%
		HV	LV				
TMN-6300/35 [32]	6300	35	10,5	7,5	4,65	8	0,8

Taking into account that the load factor of MSDS transformers is taken equal to 0.7 in normal mode, in the post-emergency conditions any transformer, taking into account the permissible overload (till 40%) is able to provide the necessary power plant capacity, as:

$$S_{rMSDS} = 7055{,}46 kVA < 1{,}4 \cdot S_{n.tr} = 1{,}4 \cdot 6300 = 8820\, kA$$

Lines, that feed MSDS transformers, are performed by overhead wire AS. Cross-section wire selection is carried out by economic current density

$$I_r = \frac{S_{rMSDS}}{2\sqrt{3} \cdot U_n} = \frac{7055{,}46}{2\sqrt{3} \cdot 35} = 58{,}2 \text{ A}$$

In the emergency mode:

$$I_{r.\max} = \frac{S_{rMSDS}}{\sqrt{3} \cdot U_n} = \frac{7055{,}46}{\sqrt{3} \cdot 35} = 116{,}4 \text{ A}$$

Economic current density accepts j_{ec} = 1,1 A/mm^2 at Tm = 3000 - 5000 hours for aluminum bare wires. The current density value is accepted from the table below:

Table 16 - Economic current density, A/mm^2 [6]

Conductor	With T_{max}, hours		
	1000-3000	3000-5000	>5000
Not insulated wires and bars Copper	2,5	2,1	1,8
Aluminum	1,3	1,1	1
Cables with paper and wires with rubber and polyvinylchloride insulation with cores: Copper	3	3,1	2,7
Aluminum	1,6	1,4	1,2
Cables with rubber and plastic insulation with wires: Copper	3,5	3,1	2,7
Aluminum	1,9	1,7	1,6

Economically feasible cross-section wire equals:

$$F_{ec} = \frac{I_r}{j_{ec}} = \frac{58{,}21}{1{,}1} = 52{,}92 \text{ mm}^2 \quad (36)$$

Where I_r – rated current.

The obtained cross-section is rounded to the nearest standard value and accepted as OPTL of the wire AS - 70/11 from [6]. Admissible continuous current for the selected cross-section is I_{ad} = 265 A.

AS - 70/11: A – Aluminum wire, S – Steel core, 70 – wire cross-section, 11 - core cross-section.

Confirmed cross-section should be checked:

- The cross section should be confirmed by:

$$1{,}3 \cdot I_{ad} > I_{r.max} \quad (37)$$

where 1,3 – ratio of the acceptable overload of the line; $I_{r.max}$-rated maximal current; I_{ad} – admissible continuous current.

$$1{,}3 \cdot I_{ad} = 1{,}3 \cdot 265 = 344{,}5\ A > I_{r.max} = 116{,}43\ A$$

- Acceptable losses of voltage:

$$l_{ad} = l_{\Delta U1\%} \cdot \Delta U_{ad\%} \cdot k_l > l \qquad (38)$$

where $I_{\Delta U1\%}$ - line length at full load of 1% of voltage losses, km;

$\Delta U_{ad\%}$- admissible voltage loss, %, ($\Delta U_{ad\%} = 5\%$, $\Delta U_{ad.aut\%} = 10\%$);

$k_l = \frac{I_{ad}}{I_r}$– adverse coefficient to the line load coefficient;

I_{ad}- admissible line length, km;

l – real line length, km.

Accept $l_{\Delta U1\%}$ = 1,65 km.

Then

$$l_{ad} = l_{\Delta U1\%} \cdot \Delta U_{ad\%} \cdot k_l = 1{,}65 \cdot 5 \cdot \frac{265}{58{,}21} = 37{,}56\ km$$

$$l_{ad} = 37{,}56\ km > l = 2{,}2\ km$$

Therefore, power supply of the enterprise from the substation of the power system with the voltage 35 kV is carried out by the wire AS – 70/11.

All the above calculations are carried out according to [6], [28].

2.8 In-plant power supply system 10kV

High voltage distribution network is carried out with cable lines.

Cross-section selection is performed by means of economic current density. The selected cross-sections were checked for admissible load out of heating conditions at normal operation and admissible overload at emergency operation was also taken into account. The obtained value was round up to proximate standard cross-section.

Economically feasible wire cross-section is defined by the formula:

$$F_{ec} = \frac{I_r}{j_{ec}}$$

where I_r– rated current for one cable, A; j_{ec}– economic current density, A/mm2.

For HV cables with aluminum wire and impregnated-paper insulation $j_{ec} = 1{,}4$ A/mm^2.

Choosing of a cable for line L1 (MSDS – TS1) is carried out below:

Cable lines, that feed shop transformers, are checked for heat by maximum rated current, is defined by the following expression:

$$I_{r.l1} = \frac{n_{tr} \cdot S_{tr.nom} + n_{tr} \cdot \Delta S_{tr}}{n_{lin} \cdot \sqrt{3} \cdot U_n} = \frac{1 \cdot 630 + 1 \cdot 40{,}954}{1 \cdot \sqrt{3} \cdot 10} = 38{,}74\ A \qquad (39)$$

where n_{tr} – number of transformers, feeded by the cable in the normal mode;

n_{lin} – number of feeding lines, in the normal mode it is equal n_{tr};
$S_{tr.nom}$ – nominal capacity of the transformer;
U_n – nominal voltage;
ΔS_{tr} – losses of total capacity in shop transformer.
Cross-section calculations are performed by economic current density:

$$F_{ec} = \frac{I_r}{j_{ec}} = \frac{38{,}74}{1{,}4} = 27{,}67\ mm^2$$

Nearest standard value according to the table of standard cross-sections from [29]:

S = 35 mm^2, I_{ad} = 110 A.

Cross-section check at normal mode:

$$l_{ad} = 110\ A > \ I_{r.l1} = 38{,}74\ A \tag{40}$$

Check of the chosen cross-section at normal and post-emergency mode:

$$I_{ad} \geq \frac{I_{r.l1}}{k_1 \cdot k_2 \cdot k_3} \tag{41}$$

$$k_{ol} \cdot I_{ad} \geq \frac{I_{r.l1}}{k_1 \cdot k_2 \cdot k_3} \tag{42}$$

Where: k_{ol} – overload coefficient;

$k_1 \cdot k_2 \cdot k_3$ – factors, that take into account influence of environment temperature, influence of close laid cable lines, actual resistance of the ground. When laying cables in trenches with six close laid cables laying coefficient is taken into account 0.93. Thus, I obtained the following numbers:

$$k_{ol} \cdot I_{ad} = 1{,}3 \cdot 110 = 130\ A \geq \frac{I_{r.l1}}{0{,}93} = 41{,}66\ A$$

The chosen cross section should be checked:

Cable is checked for voltage loss:

$$\Delta U = 10^{-3} \cdot \sqrt{3} \cdot I \cdot l \cdot (r_0 \cdot\ cos\varphi + x_0 \cdot\ sin\varphi) \tag{43}$$

where I – load current, A; φ – load angle, deg; r_0, x_0 – active and reactive resistance, mOhm/m; l - length, km.

$$\Delta U = 10^{-3} \cdot \sqrt{3} \cdot 38{,}74 \cdot 0{,}2 \cdot (0{,}751 \cdot\ 0{,}109 + 0{,}66 \cdot\ 0{,}868) = 14{,}3\ V$$

Voltage nominal loss:

$$\Delta U = \frac{\Delta U \cdot 100\%}{U_{nom}} = \frac{8{,}8 \cdot 100\%}{10000} = 0{,}14\% \tag{44}$$

Cross-section passes the check on voltage loses.

The cable AAShv - 1 (3x35) is chosen with cross section 35 mm, nominal voltage 10 kV.

The same calculations are performed for choosing the cable for L2 (MSDS – TS-2):

Cable rated current for TS-2:

$$I_{r.l2} = \frac{n_{tr} \cdot S_{tr.nom}}{n_{lin} \cdot \sqrt{3} \cdot U_n} = \frac{2 \cdot 1600}{2 \cdot \sqrt{3} \cdot 10} = 92{,}38\ A$$

Economically feasible wire cross section for the second line:

$$F_{ec} = \frac{I_{r.l2}}{j_{ec}} = \frac{92{,}38}{1{,}4} = 65{,}98\ \text{mm}^2$$

Nearest standard value: S = 95 mm^2, I_{ad} = 110 A.

Cross section check at normal mode:

$$I_{ad} = 110\ A \geq I_{r.l2} = 92{,}38\ A$$

Cross section check at post-emergency mode:

$$I_{ad} \geq \frac{I_{r.l2}}{k_1 \cdot k_2 \cdot k_3}$$

$$k_{ol} \cdot I_{ad} \geq \frac{I_{r.l2}}{k_1 \cdot k_2 \cdot k_3}$$

$$k_{ol} \cdot I_{ad} = 1{,}3 \cdot 110 = 130\ A \geq \frac{I_{r.l2}}{0{,}93} = 99{,}33\ A$$

The chosen cross section meets all the requirements.

Cable check by voltage loss:

$$\Delta U = 10^{-3} \cdot \sqrt{3} \cdot 92{,}38 \cdot 0{,}23 \cdot (0{,}756 \cdot\ 0{,}092 + 0{,}655 \cdot\ 0{,}32) = 10{,}27\ V$$

$$\Delta U = \frac{\Delta U \cdot 100\%}{U_{nom}} = \frac{10{,}27 \cdot 100\%}{10000} = 0{,}1\%$$

The cross section meets the requirements by voltage loss.

The cable AAShv - 2(3x95) is affirmed.

Calculations for the rest lines are in the table 17.

Table 17 – Cable lines

Line	Part of line	Number of lines	I_{rl}, A	F_{ec}, mm^2	Cable	ΔU_{cl}
L1	MSDS - TS1	1	38,74	27,67	AAShv (3x35)	0,009
L2	MSDS - TS2	2	92,37	65,98	AAShv (3x95)	0,01
L3	MSDS - TS3	1	38,74	27,67	AAShv (3x35)	0,01
L4	MSDS - TS4	1	38,74	27,67	AAShv (3x35)	0,006
L5	MSDS - TS5	2	39,79	28,42	AAShv (3x35)	0,008
L6	MSDS – TS6	2	39,79	28,42	AAShv (3x35)	0,01

2.9 High-voltage equipment selection

In order the equipment worked properly under different conditions it is necessary to check switching devices according to the following conditions:

1. By voltage installation: $U_{ins} \leq U_n$;

2. By continuous current: $I_r \leq I_n$;

3. By breaking capacity: $I_{p0} \le I_{n.br}$;

4. By electrodynamic resistance: $I_s \le i_{din}$;

5. By thermal resistance: $B_k \le I^2_{ter}\, t_{ter}$.

where I_{p0} - periodic component of short circuit current; $I_{n.br}$ - nominal breaking current of circuit breaker; I_s - surge short-circuit current; i_{din} –short-time electrodynamic current; B_k - heat pulse; I^2_{ter} - short-time thermal current; t_{ter} - time flow of short-time thermal current. [6]

2.9.1 Selection of switching devices

Table 18 – Selection of switching devices 35 kV

Conditions	Rated values	Catalogue data	
		Disconnector	Circuit breaker
		DTG -35/1000 [33]	CAA-35A-40/2000 [34]
$U_{ins} \le U_n$, kV	U_{ins} = 35 kV	U_{nom} = 35 kV	U_{nom} = 35 kV
$I_{max} \le I_{nom}$ A	I_{max}=116,46 A	I_{nom} =1000 A	I_{nom} =2000 A
$I_{p0} \le I_{n.br}$ kA	I_{p0} = 22,54k A	-	$I_{br\cdot nom}$ = 40 kA
$I_s \le i_{din}$ kA	I_s = 12,507 kA	i_{din} = 63 kA	i_{din} = 102 kA
$B_k \le I^2_{ter}\, t_{ter}$ kA^2 c	B_k =186,83	$25^2 \cdot 4$=2500 kA^2 s	$40^2 \cdot 3$=4800 kA^{2}s

Where DTG -35/1000 - P - Disconnector; T - two-column; G - ground conductor. CAA-35A-40/2000 – C - Circuit breaker; A - air; A - amplified voltage recovery rate.

Vacuum circuit breaker VCE-10-20 / 630U2 suits for installation on the side of 10 kV MSDS.

Table 19 - Parameters of the circuit breaker for the protection of MSDS transformers and outgoing CL.

Rated values	Catalogue data
	Circuit breaker VCE-10-20 / 630U2 [35]
U_{ins} = 10 kV	U_n =10 kV
$I_{r.max.}$ = 181,87 A	I_n = 630 A
$I_{n/a}$ = 363,73 A	I_n = 630 A
I_{p0} = 4,91 kA	$I_{br\cdot nom}$ = 20 kA
I_s = 12,507 kA	i_{din} = 52kA
B_k = 8,93 kA^{2}s	$I^2_{ter}\, t_{ter}$ =1200kA^{2}s

2.9.2 Selection of current transformer

I chose TCB-10-U3 (Cast basbar transformer).
U_{nom}=10 kV, I^1_{nom}=2000 A, I^2_{nom}=5 A.
The transformer was checked by the conditions above.
The same checking is performed for the current transformer TPCO 35 B-1 CL1

Table 20 – Parameters of the current transformer TPCO 35 B-1 CL1

Checking conditions	Rated values	Catalogue data current transformer TPCO 35 B-1 CL1 [36]
$U_{ins} \le U_n$, kV	U_{ins} = 35 kV	U_n = 35 kV
$I_{max} \le I_{nom}$ A	I_{max}=116,46A	I_{nom} =150/5 A
$I_s \le i_{din}$ kA	I_s = 12,507 kA	i_{din} = 31 kA
$B_k \le I^2_{ter}\, t_{ter}$ kA^2 c	B_k =186,83	$7^2 \cdot 3$=147 kA^{2}s
$r_2 = z_2$	$r_2 = z_2$ = 0,46 Ohm	z_2 = 0,46 Ohm

2.9.3 Voltage transformer

For voltage 10 kV I chose GVOC-10. [37]
G-grounded transformer;
V-voltage transformer;
O-one-phase transformer;
C-cast insulation.
U_{nom}=10 kV; U^1_{nom}=10000/$\sqrt{3}$ V; $U_{nom}^{2bas.second}$ =100/$\sqrt{3}$ V.
The voltage transformer satisfies the checking conditions.

For voltage 35 kV I chose voltage transformer GVOC-35. [38]
U_{nom}=35 kV; U^1_{nom}=35000/$\sqrt{3}$ V; $U_{nom}^{2bas.second}$ =100/$\sqrt{3}$ V.
This transformer also satisfies the requirements.

2.9.4 Surge arrestor

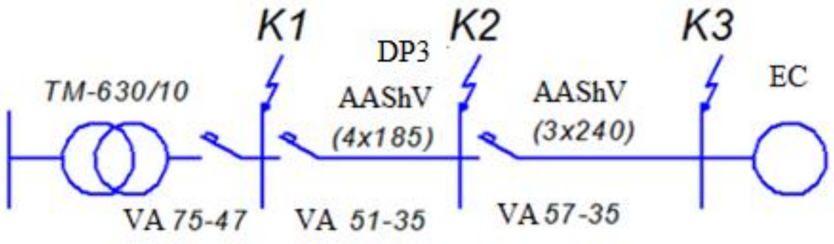
In order to protect the power transformer windings I took a non-linear surge arrester of SA-35 [39] type with the following technical features:
Nominal voltage – 35 kV;
Maximum operating voltage – 40,5 kV;
Discharge voltage at pulse current 1,2/2,5 ms with amplitude 400 A, less then 105 kV.
Discharge voltage at pulse current 8/20 ms with amplitude 5000 A, less then 120 kV.

For the protection of power transformer on 10 kV side I accepted non-linear surge arrester SA-10 [40] with the following technical parameters:
Nominal voltage – 10 kV;
Maximum operating voltage – 12 kV;
Discharge voltage at pulse current 1,2/2,5 ms with amplitude 300 A, less then 28 kV.
Discharge voltage at pulse current 8/20 ms with amplitude 5000 A, less then 35 kV.

The table with all chosen equipment and their lifetime is presented in appendix 5.

2.10 Calculation of short-circuit currents in the network up to 1000 V

Calculation of short-circuit currents is carried out for the section of the shop network from TS1 to the most powerful electric consumer of the shop - Milling machine. The obtained data is plotted on the selective tripping map.



Picture 9 - Circuit diagram of calculation of short-circuit currents up to 1 kV

Calculation of short-circuit currents in the network up to 1000 V has the following features:

1) the power of the system is accepted $S_c = \infty$;
2) 2) when calculating, the active and reactive resistances all elements of the network up to the point of SC are taken into account;
3) The voltage is assumed to be 5% higher than the nominal voltage. I accepted Uc = 400 V.

<u>Calculation of short-circuit currents for point K1:</u>

Active resistance of transformer:

$$R_{tr} = \frac{\Delta P_{sc} \cdot U_c^2}{S^2_{n.tr}} = \frac{7{,}6 \cdot 400^2}{630^2} = 3{,}064 \text{ mOhm}$$

Reactive resistance of transformer:

$$X_{mp} = \frac{U_r\% \cdot U_c^2}{100 \cdot S_{n.tr}} = \frac{5{,}5 \cdot 400^2}{100 \cdot 630} = 13{,}968 \text{ mOhm}$$

Resistance of the maximum current coils of VA 75-47:

$$R_{coil} = 0{,}34 \text{ mOhm}$$

$$X_{coil} = 0{,}42 \text{ mOhm}$$

Contact resistance:

$$R_{cont} = 0{,}55 \text{ mOhm.}$$

Total impedance to the SC point:

$$Z_{k1} = \sqrt{(R_{tr} + R_{coil} + R_{cont})^2 + (X_{tr} + X_{coil})^2} =$$

$$= \sqrt{(3{,}064 + 0{,}34 + 0{,}55)^2 + (13{,}968 + 0{,}42)^2} = 14{,}92 \; mOhm$$

Current value of SC:

$$I_{k1} = \frac{U_c}{\sqrt{3} \cdot Z_{k1}} = \frac{400}{\sqrt{3} \cdot 14{,}92} = 15{,}48 \; kA$$

Surge short-circuit current

$$i_s^{k1} = k_s \cdot \sqrt{2} \cdot I_{s1} = 1{,}2 \cdot \sqrt{2} \cdot 15{,}48 = 26{,}27\ kA$$

where k_s – surge coefficient.

<u>Calculation of SC currents for point K2:</u>

$$R_{cl} = r_0 \cdot L = 0{,}28 \cdot 104 = 29{,}12 \text{ mOhm}$$

$$X_{cl} = x_0 \cdot L = 0{,}06 \cdot 104 = 6{,}24 \text{ mOhm}$$

Resistance of the maximum current coils of VA 51-35:

$$R_{coil} = 0{,}34 \text{ mOhm}$$

$$X_{coil} = 0{,}42 \text{ mOhm}$$

Contact resistance:

$$R_{cont} = 0{,}55 \text{ mOhm}$$

Total impedance to the SC point:

$$Z_{k2} = \sqrt{(R_{cl} + R_{coil} + R_{cont})^2 + (X_{cl} + X_{coil})^2} + Z_{k1} =$$
$$= \sqrt{(29{,}12 + 0{,}34 + 0{,}55)^2 + (6{,}24 + 0{,}42)^2} + 14{,}92 = 45{,}66\ mOhm$$

Current value of SC:

$$I_{k2} = \frac{U_c}{\sqrt{3} \cdot Z_{k2}} = \frac{400}{\sqrt{3} \cdot 45{,}66} = 5{,}06\ kA$$

Surge short-circuit current:

$$i_s^{k2} = k_s \cdot \sqrt{2} \cdot I_{k2} = 1{,}2 \cdot \sqrt{2} \cdot 5{,}06 = 8{,}58\ kA$$

<u>Calculation of SC currents for point K3:</u>

$$R_{cl} = r_0 \cdot L = 0{,}28 \cdot 16 = 4{,}48 \text{ mOhm}$$

$$X_{cl} = x_0 \cdot L = 0{,}06 \cdot 16 = 0{,}96 \text{ mOhm}$$

Resistance of the maximum current coils of VA 57-35:

$$R_{coil} = 2{,}03 \text{ mOhm}$$

$$X_{coil} = 1{,}73 \text{ mOhm}$$

Contact resistance:

$$R_{cont} = 0{,}92 \text{ mOhm}$$

Total impedance to the SC point:

$$Z_{k3} = \sqrt{(R_{cl} + R_{coil} + R_{cont})^2 + (X_{cl} + X_{coil})^2} + Z_{k2} =$$
$$= \sqrt{(4{,}48 + 0{,}92 + 2{,}03)^2 + (0{,}96 + 1{,}73)^2} + 45{,}66 = 53{,}56\ mOhm$$

Current value of SC:

$$I_{sc} = \frac{U_c}{\sqrt{3} \cdot Z_{sc}} = \frac{400}{\sqrt{3} \cdot 53{,}56} = 4{,}31\, kA$$

Surge short-circuit current:

$$i_s^{sc} = k_s \cdot \sqrt{2} \cdot I_{sc} = 1{,}2 \cdot \sqrt{2} \cdot 4{,}31 = 7{,}32\, kA$$

Calculations are performed by [6].

2.11 Construction of selective tripping map of the protective devices for the section of circuit diagram

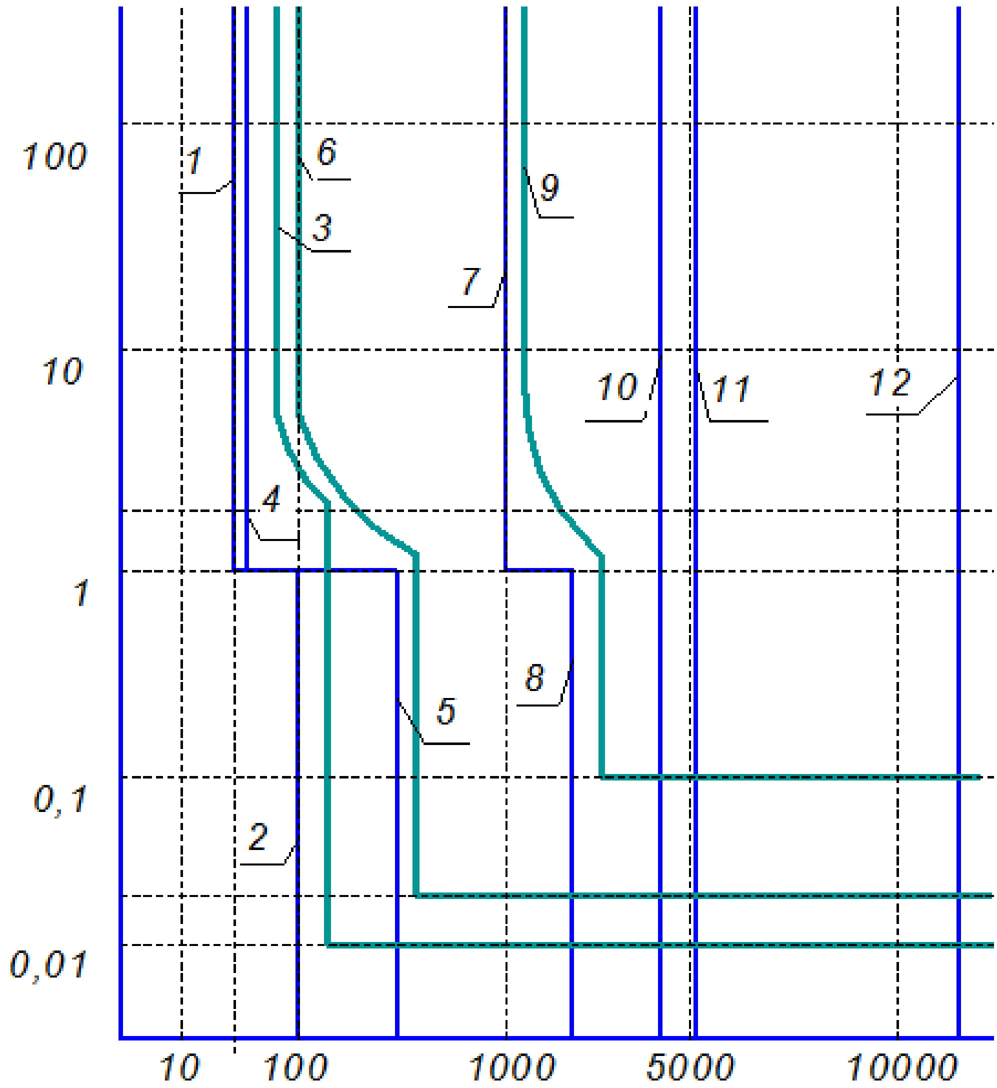
The construction of selective tripping map was done for the section of the circuit diagram from TS-4 substation to the most powerful electric receiver. The data for construction are presented in the table below.

Table 21 - Data for construction of selective tripping map

<table>
<tr><th rowspan="2"></th><th rowspan="2">EC5</th><th rowspan="2">DP3</th><th rowspan="2">TS4</th><th colspan="3">I_{sc} in relative points, kA</th></tr>
<tr><th>K1</th><th>K2</th><th>K3</th></tr>
<tr><td>I_{rat},A</td><td>-</td><td>57,26</td><td>957,19</td><td rowspan="4">15,48</td><td rowspan="4">5,06</td><td rowspan="4">4,31</td></tr>
<tr><td>I_{peak},A</td><td>-</td><td>284,3</td><td>1301,11</td></tr>
<tr><td>I_{nom},A</td><td>47,3</td><td>-</td><td></td></tr>
<tr><td>I_{in},A</td><td>105,1</td><td>-</td><td></td></tr>
</table>

Table 22 - Data for construction of selective tripping map

Name of protective device	Nominal current, A	Nominal current of trip setting in SC zone, A
VA75-47 (TS4)	1000	2000
VA51-35 (DP3)	100	500
VA57-35 (EC5)	80	200



Picture 10 - Selective tripping map of protection in devices.

The following marks were accepted:

1 – Nominal current of EC-5;

2 – In-rush current of EC-5;

3 – Protective characteristics of VA 75-47 for protection of EC-5;

4 – Rated current DP3;

5 – Peak current DP3;

6 – Protective characteristics of VA 51-35 for protection of DP3;

7 – Rated current of TS-4;

8 - Peak current TS-4;

9 Protective characteristics of VA 57-35 for protection of TS-4;

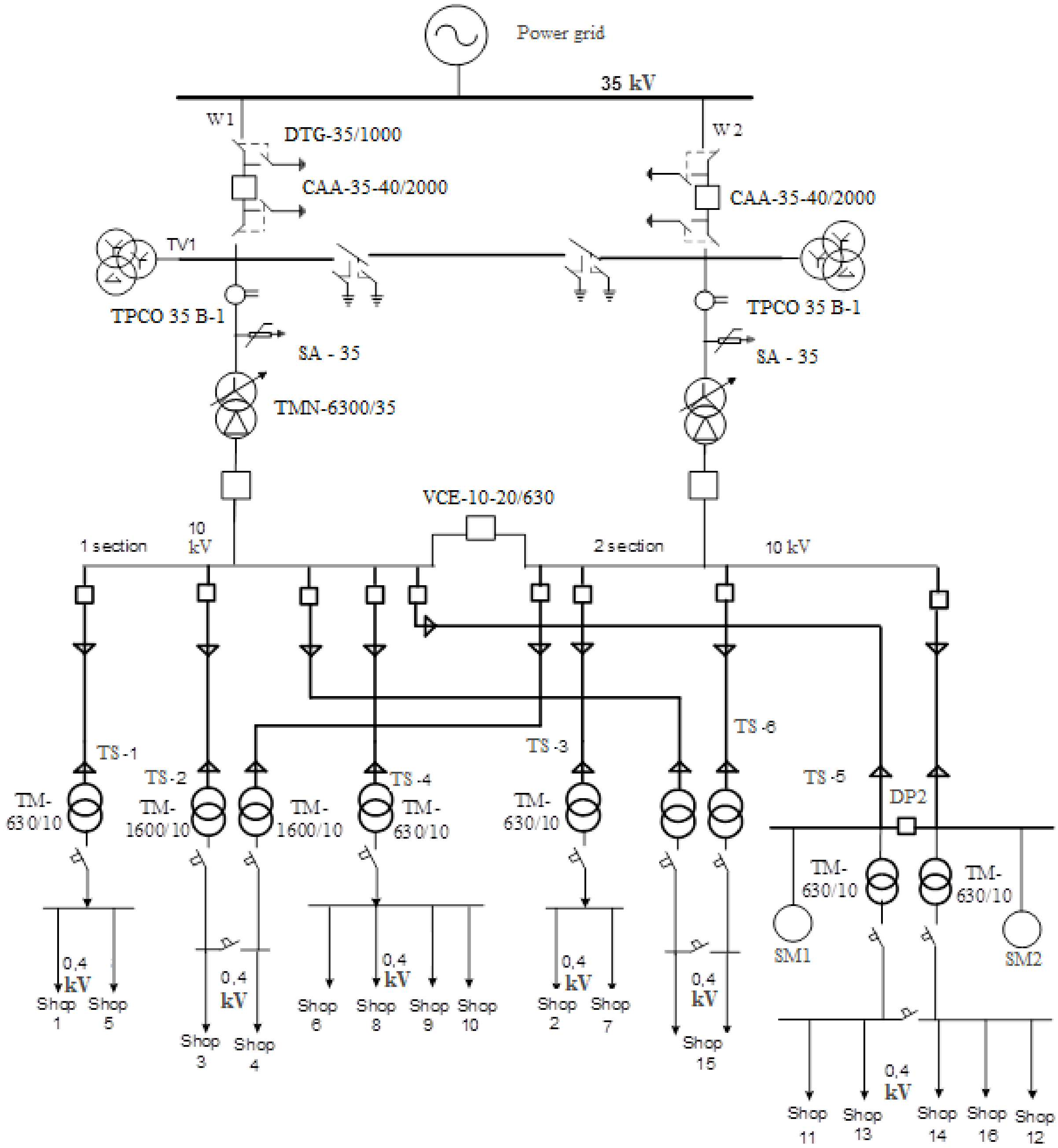
10 – SC current in the point K3;

11 – SC current in the point K2;

12 – SC current in the point K1

3. THE POWER SUPPLY SCHEME RECONSTRUCTION

Having performed the calculations, the following scheme is obtained.



Picture 11 – Power supply system with cables with IPI insulation

The transition of the cables with IPI insulation to XPLE insulation is connected to the growing demands to the reliability and other technical features. For this matter the benefits of XPLE are evident.

Having taken into consideration all the features of the insulation materials, the reconstruction was performed. The result of the work is presented in the picture 7.

The calculations for another scheme is performed bellow.

Economically feasible wire cross-section is defined by the formula:

$$F_{ec} = \frac{I_r}{j_{ec}}$$

where I_r– rated current for one cable, A; j_{ec}– economic current density, A/mm2.

For HV cables with aluminum wire and XPLE insulation $j_{ec} = 1,7$ A/mm^2 from the table 19 [6].

Defining of a cable for line L1 (MSDS – TS1):

Maximum rated current is defined by the following expression:

$$I_{r.l1} = \frac{n_{tr} \cdot S_{tr.nom} + n_{tr} \cdot \Delta S_{tr}}{n_{lin} \cdot \sqrt{3} \cdot U_n} = \frac{1 \cdot 630 + 1 \cdot 40,954}{1 \cdot \sqrt{3} \cdot 10} = 38,74\,A$$

$$F_{ec} = \frac{I_r}{j_{ec}} = \frac{38,74}{1,7} = 22,79\,mm^2$$

Nearest standard value according to the table of standard cross-sections from [41]:

S = 35 mm^2, I_{ad} = 95 A.

Cross-section check at normal mode:

$$l_{ad} = 95\,A > I_{r.l1} = 38,74\,A$$

Check of the chosen cross-section at normal and post-emergency mode:

$$I_{ad} \geq \frac{I_{r.l1}}{k_1 \cdot k_2 \cdot k_3}$$

$$k_{ol} \cdot I_{ad} \geq \frac{I_{r.l1}}{k_1 \cdot k_2 \cdot k_3}$$

$$k_{ol} \cdot I_{ad} = 1,3 \cdot 95 = 123,5\,A \geq \frac{I_{r.l1}}{0,93} = 41,66\,A$$

The chosen cross section is checked.

Checking of the cable for voltage loss:

$$\Delta U = 10^{-3} \cdot \sqrt{3} \cdot I \cdot l \cdot (r_0 \cdot\ cos\varphi + x_0 \cdot\ sin\varphi)$$

$$\Delta U = 10^{-3} \cdot \sqrt{3} \cdot 38,74 \cdot 0,345 \cdot (0,751 \cdot\ 0,109 + 0,66 \cdot\ 0,868) = 15,16\,V$$

Nominal voltage losses:

$$\Delta U = \frac{\Delta U \cdot 100\%}{U_{nom}} = \frac{15,16 \cdot 100\%}{10000} = 0,15\%$$

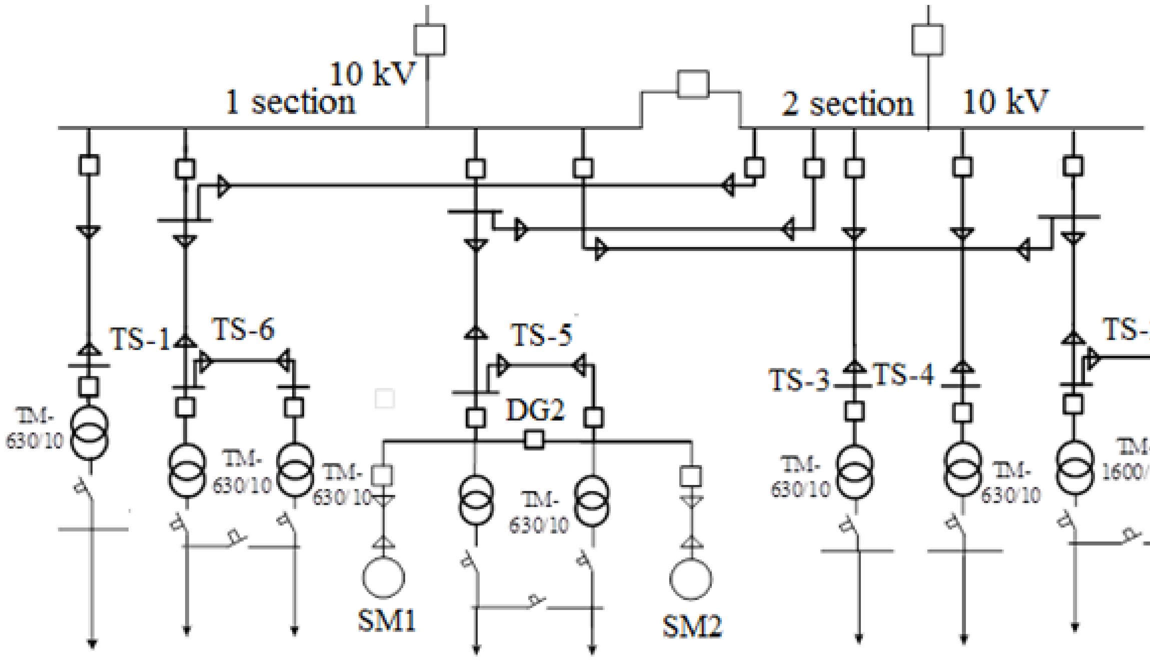
Cross-section passes the check on voltage loses.

The cable APvV - 1(3x35) is chosen with nominal voltage 10 kV.

The same calculations are carried out for other lines. The results are in the table 23.

Table 23 – Cable lines

Line	Part of line	Number of lines	I_{rl}, A	F_{ec}, mm^2	Cable	ΔU
L 1	MSDT - TS1	1	38,74	22,79	APvV (3x35)	15,16
L 2	MSDT - TS2	1	199,53	117,37	APvV (3x120)	20,08
L 3	MSDT - TS3	1	38,74	22,79	APvV (3x35)	13,86
L 4	MSDT - TS4	1	38,74	22,79	APvV (3x35)	8,02
L 5	MSDT - TS5	1	79,58	46,81	APvV (3x50)	14,06
L 6	MSDT – TS6	1	79,58	46,81	APvV (3x50)	19,07



Picture 12 – Reconstructed power supply system with cables with XPLE insulation.

4. ECONOMIC EVALUATION

Economic changes of the last years force the modern business and production to adapt to new conditions - austerity conditions.

The number of lines was decreased thanks to the reconstruction and the reliability also increased. In spite of all the mentioned above technical features of the cables, the final decision on the project is always accepted according to economic evaluation.

The economic calculations are performed to select:

1) The most rational scheme of the shop and the whole enterprise electricity supply,

2) Cross sections of wires of cables depending on a number of technical and economic factors.

The main purpose of technical and economic comparison is to determine the optimal version of the scheme, the parameters of the network and its elements.

The economic evaluation contains consideration of the two possible variants of power supply schemes:

The production plant keeps on functioning with the traditional cables

The reconstruction is held on the production plant and the old-type cable are replaced for the new ones.

I assumed that in both variants the mending work is held.

In the first variant the old cables are out of operation and normal change for the same type of cables is held. In reconstruction case, the switching to a new type is held. So, I took 2017 year as first year of operation for all the cables, and also I calculated the investments' cost for all other necessary equipment for power supply.

4.1 Economic estimation factors

4.1.1 Profit evaluation

The main goal of any organization is to make a profit. Profit is the main indicator of the economic development of organization. The goal of profit management is to maximize its absolute value and stabilize it over time. Profit reflects:

- The result of financial and economic activities of the organization and reward for entrepreneurial risk;
- Management efficiency of the operating, investment and financial activities of organization;
- Is the cheapest source of financing the organization's capital needs.

Economic profit (EP) is defined as the result of the work of capital. In fact, it is the profit, that is left after the subtraction of costs for servicing the entire capital, including the own one. This indicator is a measure of the degree of increase in the value of investments of shareholders. Its calculation is possible for organizations whose shares participate in the listing.

The effectiveness of organization is determined by calculating the following profit indicators, listed below:

1. Gross profit (GP).

2. Operating income before depreciation of fixed assets and amortization of intangible assets (OIBDA). The indicator excludes the impact on non-operating income and expenses and is a reliable indicator of the value of the organization.

OIBDA = Profit from sales + Amortization of intangible assets + Depreciation of fixed assets.

3. Earnings before interest, taxes, depreciation and amortization (EBITDA) shows the financial result of the company, excluding the influence of the capital structure effect (ie interest paid on borrowed funds), tax rates and organization's depreciation policy:

EBITDA = Profit (loss) before taxation + Interest payable + Amortization of fixed assets and intangible assets.

4. Profit before taxes and interest ("operating profit", earnings before interest & tax)

EBIT = Income - Operating expenses.

or

EBIT = Profit (loss) before tax + Interest payable.

5. Profit before tax or balance profit (earnings before tax, EBT).

EBT = Income - Expenditures (not including taxes)

6. Net operating profit less adjusted taxes (NOPLAT):

NOPLAT = EBIT * (1 - t),

where t - income tax rate.

7. Net profit (NP). [42]

Profit before taxation is the platform for determining the company's net profit. In order to do it, the taxable profit should be reduced by the amount of taxes, that should be transferred to the budget. The resulting indicator is the final economic result of the company's activities. [43]

As I don’t consider the revenues of the enterprise, the taxation of operating expenditures helps the whole enterprise to reduce the tax, that was taken from the revenues, and, thus, increase the profit.

4.1.2 Cash flows

The concept of cash flow is widely applied in the quantitative analysis of various economic processes. To the greatest extent, this refers to the definition of the effectiveness of investment projects. [44]

Cash flows are the movement of cash received and spent by the enterprise in cash and non-cash forms. These flows are of two kinds: positive and negative. Positive flows (cash inflow) reflect the flow of money to the enterprise, negative (cash outflows) - spending money by the enterprise. The difference between gross inflows and outflows of money for a certain period of time is called net cash flow. It can be either positive or negative.

For the analysis purposes, the enterprise's cash flows are divided into three groups: operational cash flows, investment and financial activities. The most significant source of cash flows of an enterprise is, as a rule, its main activity (production and sales of products for an industrial enterprise). Inflows from the main (operating) activity are formed in returns from the sale of products (works, services), repayment of receivables, and advance payments received. Outflows from operating activities are due to payment of accounts of suppliers, payment of wages, loan interest payments. Thus, cash flows from operating activities are related to the use of the company's working capital.

The investment activity of the enterprise assumes realization of long-term investments. Cash inflows from investment activities are formed in returns from the sale of fixed assets, returns of long-term loans, the amount of dividends received by the enterprise during the period of ownership of their shareholdings or interest paid by borrowers during long-term borrowings. Cash outflows on investment activity arise in the case of the acquisition of fixed assets, capital investments in the construction of new buildings, purchase of shares of other enterprises.

Financial activity is associated with the capital formation of the enterprise. Cash inflows from financing activities are revenues from issuing shares or bonds, getting short-term and long-term loans. Accordingly, outflows in this area include repayment of loans, redemption of bonds, redemption of own shares, payment of dividends.

The main method for estimating cash flow in investment planning is the discounting method, that allows you to determine the current value of future cash flows (Discounted Cash Flow).

Analysis of cash flows generated during the implementation of the investment project involves:

- selection of the type and duration of the cash flow;
- determination of factors that affect the value of its elements;
- calculation of the discount rate, that lets you to compare the elements of the flow that arise at different times;
- evaluation and accounting of the risk associated with this flow. [45]

In the technical part I calculated the load of the whole enterprise and chose the appropriate equipment. As I compare two schemes of the same enterprise with the difference of the chosen cables, the investments of all equipment and their maintenance will remain the same in both variants. Thus, there’s no need to consider these issues. It won’t affect my results.

In order to estimate the economic feasibility of a definite cable, I compared the investment costs and operational costs of the two cables.

The CF of the project contains the cash inflow and outflow that is connected with cables’ operation. According to the defined groups of cash flows I took into account the following activities:

- Operating activities: interest of the taken loan, maintenance of cables, depreciation;
- Financial activities: loan principle;
- Investment activities: investments of the cables, their installation costs.

4.1.3 Loan

The objective need for the existence of a loan, first of all, is conditioned by the law of market system management, according to which the funds must be in constant turnover. Therefore, the production process at an enterprise initially assumes a constant finding in its capital turnover. At a certain point, some enterprises have temporarily released monetary resources, while others have an objective need for them. In the absence of monetary funds at the enterprise, the production process is frozen, down to a complete stop.

The objective need for the existence of a loan, first of all, is conditioned by the law of the market system of management, according to which the funds must be in constant turnover. Therefore, the production process at the enterprise initially assumes a constant finding in its turnover of money. At some point in time, some enterprises have temporarily released monetary resources, while others have an objective need for them. In the absence of cash funds at the enterprise, the production process is frozen, up to a complete stop.

The arising contradiction is resolved, as a rule, by means of the loan.

The main functions of a loan:

1. Distributive: Distribution of funds on a return basis between loan participants. It is implemented in the process of providing funds to enterprises and organizations under the terms of urgency, repayment and payment ability.
2. Emissive: Issuing of loan funds flow and replacement of cash. It is manifested by creation of funds in the process of lending, that is, along with cash, non-cash money are involving in turnover process.
3. Controlling: It is manifested by the all-round control of the financial and economic activities of the entity that received the loan. This function allows you to timely analyze the status of borrowers and on this basis to implement the appropriate credit policy.

The utilization of loan lets increase the efficiency of the functioning of business entities, as well as to stimulate the introduction of scientific and technological progress in the form of various innovations in the real sector of the economy. [46]

Loan is a kind of borrowing in money form, provided by a lender to a borrower on the terms of repayment, with payment of interest by the borrower for using the loan. [47]

In the Russian Federation, as well as all over the world, two systems of repayment of loans are in most demand: differentiated and annuity.

The most common is the annuity payment system. The sense is in the fact that during the entire loan period you pay the same constant amount of money. The payment consists of the principal amount and a certain part of the loan interest. At the initial stage, the share of interest in this payment prevails, and at the end of repayment period the principal takes the major part of the debt. The advantage of such a system resides in the fact that the debt load can be clearly fixed in the structure of yearly/monthly payments.

With a differentiated payment system, the payment is reduced with each subsequent payment. The amount of the principle in the differential payment remains constant throughout the period, and the interest rate gradually decreases, as they are accrued for the remaining part of the principal debt. The advantage of such a system is that with every payment the load on the paying entity budget is decreasing. [48]

In my work I used the annuity payment system: there is a fixed annual payment, that consists of decreasing with the following payments amount of interest and increasing amount of principle.

4.1.4 Net present value

Among the main methods of investment calculations it is possible to point out the following methods:

- method of net present value;
- method of internal rate of return;
- method of discounted payback period.

The main role among them plays the method of net present value. The remaining methods are either modification of the net present value method, or based on it.

Net present value (NPV) of cash flows is the difference between the market value of a project and the costs of its realization. It represents the amount of cash flows discounted by years for all project implementation periods:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - K$$

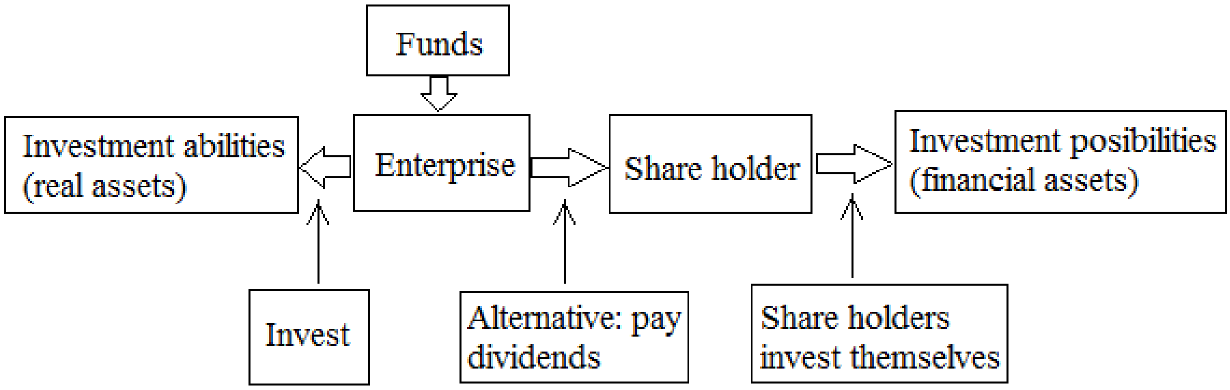
where r – discount rate, that is used for the given project; T – the period of project realization; C_t – net cash flow during t period; K – sum of the initial investments.

The net present value shows the present value of the time diversified results from the implementation of a particular project. In other words, net present value is a measure of the added or newly created value, that is received by financing today the initial costs of the project.

The investment proposal should be considered if the net present value of the project is positive. In the case if the net present value of the project is less than 0, the project must be rejected. From several alternative projects one should choose that one, with other things being equal, that has a higher net present value.

The positive value of the net present value is indicative not only of a full recovery of costs for an investment project with a forecasted level of return on capital, but also of obtaining additional income, i.e. of increasing the assets of the enterprise due to the admission of the project.

One of the most important problems when using the criterion of net present value is the choice of the discount rate. From the theoretical point of view, it represents the cost of the enterprise's capital, i.e. those alternative costs that are associated with investing in this project. The alternative costs of the project are the income that the shareholders could get if they invested their own funds at their own discretion. When we discount the cash flows at the expected rate of return on comparable financial assets, we determine how much investors would be willing to pay for our project. Comparability of assets means that they have the same level` of risk as investments in enterprise projects. Such a theoretical concept is presented in Pic. 13.



Picture 13 – The rate of return as an opportunity cost.

As common methods for determining net present value they are used:

- Capital asset pricing model (CAPM);
- Build-up approach;
- Weighted average cost of capital (WACC) method. [49]

4.1.5 Depreciation

Depreciation refers to the process of systematic compensation of loss in the value of fixed assets by transferring the lost value of the product. When being under operation, equipment is turning into cash form and depreciation charges, included in the cost of production. Consequently, depreciation is a monetary expression of physical and moral depreciation of fixed assets along its lifetime. [50]

Lifetime is considered to be the period of time, when the assets can operate, generate the profit. Depreciation is not used in cash flow, but it helps to reduce the tax. It also reflects the allocation of asset costs.

All the assets are tangible an their lifetime is over 12 months, so I can depreciate them. The assets, that have lifetime lower than 12 months are considered to be inventories and not depreciated.

All my assets are equipment with different lifetime.

There are the following main methods of depreciation based on time:

1. Straight-line method
2. Declining balance method
3. Sum-of-the-years'-digits method:

Straight-line depreciation is the most widely spread and simple method. It can be calculated by the following formulas:

$$\text{Straight line depreciation for the } 1^{st} \text{ year} = \frac{\text{Original cost of asset}}{2 \cdot T - 1}$$

Straight line depreciation for the t year = 2∙Straight line depreciation for the 1^{st} year

Through the economic lifetime the company charges the same amount of money each year until the cost of asset is equal to salvage value.

In order to depreciate the equipment I used linear depreciation according to the lifetime of each unit. The cables are depreciated for 25 years.

4.1.6 Discount rate

Discounting is the determination of the value of cash flows related to future periods (future earnings to the present moment). In order to estimate future revenues properly, it's necessary to know the expected values of revenues, expenditures, investments, residual values of the property, as well as the discount rate, which is used to assess the effectiveness of investments.

Discount rate is the rate of return with the invested capital, required by the investor. In other words, with its help one can determine the amount that the investor will have to pay today for the right to receive the estimated income in the future. Therefore, the adoption of key decisions depends on this value, including when choosing an investment. [51]

There are different ways to calculate discount rate. I my work I used WACC (Weighted average cost of capital).

All companies commonly are financed with debt and equity. As there can be several financing sources, therefore the weighted average is found. If not only own funds are used for financing projects, but also borrowed capital, then the profitability of such project should compensate not only risks, connected to own funds investments, but also expenditures for borrowed money. In order to determine WACC, one should multiply the cost of equity by its relevant weight and add multiplication of cost of debt and its share. The debt is tax obligated so the tax rate is also taken into account.

$$WACC = \frac{E}{V} \cdot R_e + \frac{D}{V} \cdot R_d \cdot (1 - T)$$

where E - market value of the company's equity, D - market value of the company's debt, V – total market value of the company (E + D), R_e – cost of equity, R_d – cost of debt, T – tax rate. [52], [53]

CAMP value is used as R_e and bank interest rate is used as R_d.

4.1.7 CAMP

Capital asset pricing model helps to determine the fair income of a security based on its risk.

Capital asset pricing model was developed by Harry Markovitz in the 1950s. The sense of this model is to demonstrate close relationship between the rate of return and the risk of a financial instrument.

It is known that, the greater the risk is, the greater the profitability. Therefore, if I know the potential risk of a security, I can predict the rate of return. Conversely, if I know the profitability, then I can calculate the risk. All calculations of a kind with respect to profitability and risk are carried out using the capital asset pricing model.

As any share has its own level of risk, this risk must be covered by profitability, so that the instrument remained attractive. According to CAPM model, the rate of return of any financial instrument consists of two parts:

- Risk-free return
- Premium return

In other words, any profit from stocks includes risk-free profit (often calculated by the rates of government bonds) and risky profit, which (ideally) corresponds to the level of risk of this paper. If the profitability indicators exceed the risk indicators, then the instrument generates more profit than it is required by its level of risk. Conversely, if the risk indicators turned out to be higher than the profit, then we do not need such an instrument.

The relationship between risk and return according to CAPM is described as follows:

$$r_a = r_{rf} + \beta\ (r_m - r_{rf})$$

where r_a – expected rate of return, r_{rf} – risk-free rate of return, r_m – expected rate of return of the market, β – beta of asset, $r_m - r_{rf}$ – premium for market risk.

Expected rate of return is a return that you or other investor are waiting for from financial instrument. The expected rate of return can also describe your need, not expectations. When you need a certain rate of return (the reasons can be different), then this certain rate of return will be your expected rate of return. In a nut shell, the expected rate of return is a profit from the instrument.

Risk-free rate of return is the part of return that is in all investment instruments. Risk-free rate of return is measured, as a rule, by the rates of state bonds with expiration date more than 30 years, as they have little or no risk.

Expected rate of return of the market is the rate of return of the index of this market. In Russia it's RTS index.

Premium for market risk is a value by which the average market rates of return on the stock market exceeded the rate of return on risk-free securities for a long time. It is calculated on the basis of statistical data on market premiums over a long period.

Beta is a special coefficient that measures the riskiness of the instrument.

Beta levered is calculated by the formula:

$$\beta_L = \beta_U \cdot \frac{D}{E} \cdot (1 - T) + 1$$

Where β_L – beta coefficient with respect to the level of debt, β_U - beta coefficient without including debt, T – tax rate, $\frac{D}{E}$ - ratio of debt to equity at market value. [54]

Beta coefficient shows the sensitivity of stocks to market volatility. If the coefficient is less than 1 – the share is stable, if it is more than 1 – not stable. Therefore, the purchase of small value of the coefficient is preferable.

Unlevered beta has the same meaning, the difference is that it doesn’t takes into account the impact of debt part. The bigger debt the company has, the more risk it contains. [55]

4.1.8 Balance sheet

Equity and Liability values, that are necessary for discount rate calculations, are taken from Balance sheet of the enterprise.

The balance sheet is a reporting document that characterizes the financial condition of the whole organization. It consists of 2 parts - assets and liabilities. Accounting data in monetary terms is reflected on the balance sheet in the relevant sections.

The document is based on the equality between the existing assets and liabilities of the organization. The assets include all the property and resources of the economic entity. The liabilities part of the report reflects the sources of its formation - liabilities to third parties and own capital (equity).

The balance sheet data provide information about the current state of the organization. For example, the security of obligations with assets shows how much the own property and other assets cover the amount of available debt.

The relative equation is the following:

$$\text{Assets} = \text{Equity} + \text{Liability}$$

Accounting of assets and liabilities

Assets and liabilities are the main components of the balance sheet, the movement of which occurs, as a rule, during the reporting period.

The assets of the balance is divided into current and non-current. Current assets are characterized as the most liquid, have the ability to turn into monetary resources in a shorter period than non-current assets. Current assets are represented by the following items:

- Cash and cash equivalents;
- Materials, stocks, involved in the production process;
- Short-term debt of debtors;
- Unrecorded VAT in the reporting period;
- financial investments;
- Other current assets.

As non-current assets it is accepted to consider resources, the which using duration exceeds the reporting period. This category includes fixed assets, intangible assets, long-term financial investments and others.

As for obligations, it is common to understand the debt of the enterprise, which is divided into the following categories:

- Long-term debt is an organization's debt that has existed for a long time (estimated liabilities, long-term loans and others).
- Short-term debt is an actively changing amount of debt during the tax period. This is the debt to suppliers, staff, budget, as well as other liabilities that are short-term.

Equity

In addition to liabilities, there is another section in the passive balance -shareholders' equity. Often the equity is calculated as net assets, that is the difference between other assets and liabilities of the enterprise. Formed capital is a set of contributions of the founders and the economic result of the work of the enterprise. It consists of the following items:

- The authorized share capital is formed at the beginning of the activity, and can changed during the working time;
- Additional capital - part of own funds that affect the amount of net assets;

- Reserve capital is used to repay potential losses;
- Revaluation of current assets - a financial instrument that increases the investment attractiveness of the firm and affects the amount of net assets;
- Own shares;
- Undistributed profit as a financial result based on the results of operations.

Each of the indicators of financial statements - assets, liabilities, equity - characterize the company's activities. For financial analysis and economic evaluation, it is necessary to know the real value of each component. [56],[57]

4.1.9 Operational cost

In order to calculate the maintenance and repair of the project I used consolidated index for all kinds of equipment, that is necessary for supplying the production plant from [41].

Annual operational cost in power supply schemes is determined by the following expenditures:

1) Losses of electrical energy
2) Maintenance and repair
3) Amortization

Therefore, comparative annual operational cost of compared variants is found by the equation:

$$C_{op} = C_{los} + C_r + C_a$$

Amortization is 5% from investments for cable lines, for circuit breakers, transformers – 6,7%. The operational cost for repair and maintenance – 2,3% of capital investments for cable lines, and 5,9% - for circuit breakers and transformers.

Table 24 - Maintenance and repair coefficients of cables.

Cost	Coefficients
Cost for maintenance	2 %
Cost for repair	0,3 %
Total cost	2,3 %

Table 25- Amortization coefficients

Name of the element	Amortization coefficients
Transformers, circuit breakers, disconnectors	6,7%
Cables	5%

All the coefficients are the percentages from the investments. [41]

4.1.10 Capital investments

The calculations of losses in cables are presented lower.

Total sum of capital investments is defined by summing cost of equipment (K_{eq}), construction and assembly operations CMP (K_{cmp}) and other cost (K_{oth}).

$$K = K_{eq} + K_{cmp} + K_{oth} \quad (45)$$

According to the chosen power supply scheme the total capital investment are calculated. According to [41]:

Table 26 - Cost coefficients

Cost	Cost coefficients
K_{cmp}	1,5 %
K_{oth}	1,15 %

All the coefficients are the percentages from the investments.

4.1.11 Losses in cable lines

The cost of losses in cable lines are calculated be the next formula:

$$C_{los} = n \cdot L \cdot \Delta P \cdot k_{load}^2 \cdot \tau_{max} \cdot \Delta C_e$$

where n – number of lines; ΔW– specific losses in lines with nominal load; τ_{max} – time of maximum losses; ΔC_e- price of 1 kWh of electrical energy, rub/ kWh (1,12 rub/kWh [58]), L – length of the line, m;

$$\tau_{max} = (0,2 \cdot \frac{T_m}{8760} + 0,8 \cdot (\frac{T_m}{8760})^2) \cdot 8760$$

Where Tm - duration of use of the maximum load, T_m=5000 hours for three-shift enterprise. [6]

$$\Delta P = 3 \cdot I_{rat}^2 \cdot R$$

Where: I_{rat}^2- rated current; R- resistance of a line with a type of a cable, accepted in the calculations.

$$R = \frac{R_0 \cdot L}{S}$$

Where R_0 – resistance for a specific cross-section, Ohm/km; L – length, km; S – cross-section of a cable, mm^2.

$$k_{load} = \frac{I_{rat}}{I_{ad}}$$

4.1.12 Sensitivity analysis

After having performed calculations of all economic parameters, one shouldn't hurry with making conclusion. Before taking decision on a project, it is necessary to evaluate weight and influence on NPV of the parameters.

Sensitivity analysis is a method of assessing the impact of the main parameters of a financial model on the resultant criteria (NPV). It is assumed that uncertainty of the final value is mainly connected with some definite parameter. And if this parameter is the most significant, one should give the most attention to it.

When performing the sensitivity analysis, all project parameters are fixed at the level of the projected values, except for one, the effect of which is investigated. And then the NPV dependence on this parameter is constructed.

The value of the parameter at which NPV = 0 is called the pivot point. Its influence is estimated by how much the projected and critical value of the investigated parameter differ. The difference (absolute, relative) between the critical and projected values determines the "safety factor" of the project. Subjectively, it is estimated how much it is achievable in the context of the assumptions, from which this value is derived. [59]

Sometimes the resulting criterion (NPV) is dependent not only on one but directly on two parameters.

If the sensitivity analysis is not held, then all the values are constant within the project assumption and their relation to market changes, economic situation in the country, etc. is not reflected, therefore we can’t fully evaluate the risks.

The sensitivity analysis shows the cost of your mistake and a project stability.

Steps of performing sensitivity analysis:

During sensitivity analysis of the investment project, first the initial parameters are determined, by which the sensitivity of the investment project is calculated. Then change of each selected index is made. Only one of the variables changes its value to the predicted number of percentages (usually 1%, 5% or 10%), and on this base a new value of a criterion (for example, NPV or IRR) is recalculated.

Further, the relative change in the criterion with respect to the base case is evaluated and the sensitivity index is calculated.

The sensitivity index is the ratio of the percentage change of the criterion to the change of the variable by the predicted percent number (the elasticity of the change of the indicator). Similarly, the sensitivity indicators for the other selected variables are calculated.

On the next stage, the results of the performed calculations are used, then ranking of the parameters in terms of their importance is held (for example, very high, medium and low) and carry out an expert assessment of the predictability of the values of the indicators.

To analyze the sensitivity of an investment project, the main thing is to assess the degree of influence of the each initial parameters change (or their combination) in order to foresee the worst possible development of the situation in the investment project.

The results of the sensitivity analysis are taken into account when comparing interchangeable and non-interchangeable, with a constrain on the maximum budget, investment projects.

Under other factors being equal, an investment project that is least sensitive to the change of input parameters is chosen. The sensitivity analysis shows not reduction of the investment risk, but the consequences of incorrect estimation of certain quantities.

And it is also important to know that the sensitivity analysis does not change the risk factors. [60]

4.2 Economic evaluation of the projects

In the technical part I calculated the load of the whole enterprise and chose the appropriate equipment. As I compare two schemes of the same enterprise with the difference of the chosen cables, the investments of all equipment and their operation cost will remain the same in both variants. Thus, there's no need to consider these issues. It won't affect my results.

In order to estimate the economic feasibility of a definite cable, I compared the investment costs and operational costs of the two cables.

The project doesn't generate any income. I considered from investment point: operation, installation and replacement of the equipment, that are changed during lifetime of the project. NPV will be negative in both variants. The project with the bigger NPV will be considered as the most preferable, according to this method.

4.2.1 Power supply system with oil-impregnated cables AAShV

Capital investment

Cable investments are the variable part in this project. In order to obtain them, I had to calculate the length of the cables according to the scale in the picture 6 and multiply it by the price per meter. Thus, the sum of all cables costs will give me the investments costs.

The obtained results are in the table below:

Table 27 – Cable investments

	Cable length, m	*Price per meter*	*Number of lines*	*Investment cost, Rub*
TS1	349,65	263,45	1	92 115
TS2	306,36	393,13	2	240 879
TS3	233,1	263,45	1	61 410
TS4	349,65	263,45	1	92 115
TS5	592,74	263,45	2	312 315
TS6	233,1	263,45	2	122 820
			Total	**921 655**

In order to get the total investments' costs, I have to calculate construction and assembly operations CMP (K_{cmp}) and other costs (K_{oth}):

$$K_{cmp} = 1{,}5\% \cdot 921\ 655 = 13\ 825\ Rub$$

$$K_{oth} = 1{,}15\% \cdot 921\ 655 = 10\ 599\ Rub$$

The total capital investments are obtained as summing investments and costs for installation:

$$K = K_{cmp} + K_{oth} + K_{eq} = 13\ 825 + 10\ 599 + 921\ 655 = 946\ 079\ Rub$$

Operational annual cost

In order to obtain operational cost, I should calculate its items of the sum.

The costs of losses in AAShV cable.

$$C_{los} = n \cdot L \cdot \Delta P \cdot k_{load}^2 \cdot \tau_{max} \cdot \Delta C_e$$

For the cross section 3x35, TS1:

$$C_{los} = 1 \cdot 0{,}35 \cdot 13{,}01 \cdot 0{,}34 \cdot 3283{,}11 \cdot 1{,}12 = 5\ 635\ Rub$$

Where time of maximum losses τ_{max}:

$$\tau_{max} = (0{,}2 \cdot \frac{T_m}{8760} + 0{,}8 \cdot (\frac{T_m}{8760})^2) \cdot 8760 =$$

$$= (0{,}2 \cdot \frac{5000}{8760} + 0{,}8 \cdot (\frac{5000}{8760})^2) \cdot 8760 = 3\ 283{,}11\ hours$$

Load Coefficient:

$$k_{load}^2 = (\frac{I_{rat}}{I_{ad}})^2 = (\frac{38{,}74}{110})^2 = 0{,}34$$

Specific losses in lines with nominal load ΔP:

$$\Delta P = 3 \cdot I_{rat}^2 \cdot \mathrm{R} = 3 \cdot 38{,}74^2 \cdot 0{,}0029 = 13{,}01\ kW$$

Where: I_{rat}^2- rated current, A; R- resistance of a line with a type of a cable, accepted in the calculations, Ohm.

$$R = \frac{R_0 \cdot \mathrm{L} \cdot n}{\mathrm{S}} = \frac{0{,}868 \cdot 0.35}{3 \cdot 35} = 0{,}0029 \quad Ohm$$

Where R_0 – 0,868 Ohm/km for a cable with the cross-section 35 mm^2 [6]; L – length, km; S – cross-section of a cable, mm^2, n – number of lines.

The results are in the table below:

Table 28 – Losses cost.

AAShV cross section	***n, number of lines***	***L, km***	***ΔP, kW***	***C_{los}, Rub***
3x35	1	0,34965	13,01	5 635
3x95	2	0,30636	10,27	22 523
3x35	1	0,2331	8,67	2 505
3x35	1	0,34965	13,01	5 635
3x35	2	0,59274	23,27	70 205
3x35	2	0,2331	9,15	10 857
			Total	**117 360**

Cables' repair coefficient for one year:

$$C_r = 2{,}3\% \cdot 921\ 655 = 21\ 198\ Rub$$

Cables' amortization coefficient for one year:

$$C_a = 5\% \cdot 921\ 655 = 46\ 083\ Rub$$

Having obtained all the containing values, I can calculate annual operational of cables:

$$C_{op} = C_{los} + C_r + C_a = 117\ 360 + 21\ 198 + 46\ 083 = 184\ 641\ Rub$$

The operational cost is escalated on the inflation rate 4% [60] every year.

Loan

I considered the project with loan. According to [62], the loan for entity on reconstruction purpose is taken from Sberbank. The payback period is 14 years. The interest rate is 10,72%. By the conditions of the bank, the own funds should be at least 20% of the project.

The payment of the loan is calculated by the following formula:

$$PMT = \frac{PV \cdot R}{1 - (1 + R)^{-n}}$$

Where PV – present value of loan, R – interest rate of the loan, n – payback period. [63]

The payment is carried out once a year at the end of the year.

$$PMT = \frac{756\,863 \cdot 0{,}1072}{1 - (1 + 0{,}1072)^{-14}} = 106\,806\ Rub$$

where $PV = K \cdot 80\% = 94\,6079 \cdot 80\% = 756\,863\ Rub$

Interest and principle of the loan are accounted in a different way.

I used annuity payment system. The annual payment is fixed. It consists of decreasing from payment to payment amount of interest and increasing principal.

In the 1^{st} year principle and interest amounts are calculated as followed:

Interest amount = I_1 = PV · r = 756 863 · 0,1072 = 81 136 Rub
Principal amount = P_1 = PMT – I = 106 806 - 81136 = 25 670 Rub
The remaining balance = RB_1 = PV – P = 756 863 - 25670 = 731 193 Rub

For the second year:

Interest amount = I_2 = RB_1 · r = 731 193 · 0,1072 = 78 384 Rub
Principal amount = P_2 = PMT – I_2 = 106 806 – 78 384 = 28 422 Rub
The remaining balance = RB_2 = RB_1 – P_2 = 731 193 – 28 422 = 702 771 Rub

According to this principal, the rest payments of the repayment period are calculated. The results are in the table below:

Table 29 – Interest and Principal repayment table

Repayment Period	Starting balance, Rub	Interest, Rub	Principal, Rub	Remaining balance, Rub
1	756 863	81 136	25 670	731 193
2	731 193	78 384	28 422	702 771
3	702 771	75 337	31 469	671 302
4	671 302	71 964	34 843	636 459
5	636 459	68 228	38 578	597 882
6	597 882	64 093	42 713	555 169
7	555 169	59 514	47 292	507 877
8	507 877	54 444	52 362	455 515
9	455 515	48 831	57 975	397 540
10	397 540	42 616	64 190	333 351
11	333 351	35 735	71 071	262 280
12	262 280	28 116	78 690	183 590
13	183 590	19 681	87 125	96 465
14	96 465	10 341	96 465	0

Only interest obligated by tax. Principle is subtracted in CF, and it is not obligated by tax as it represents the account payable. And the interest is the expense.

Discount rate

According to the annual report from [64], short balance sheet of the enterprise is reflected as follows:

Table 30 – Balance sheet of the enterprise.

Assets		**Equity**	
Current assets	171 817	Equity	212 587
Non-current assets	682 968	**Liabilities**	
		Long-term liabilities	68 600
		Short-term liabilities	573 598
TOTAL	**854 785**	**TOTAL**	**854 785**

From the report I can see that Equity = 212 587, Debt = 642 198
Equity + Debt = 854 785.

These numbers I used when calculating discount rate.

WACC:

$$WACC = \frac{E}{V} \cdot R_e + \frac{D}{V} \cdot R_d \cdot (1 - T) =$$
$$= \frac{212\ 587}{854\ 785} \cdot 0{,}1156 + \frac{642\ 198}{854\ 785} \cdot 0{,}1072 \cdot (1 - 0{,}2) = 0{,}086$$

where E - market value of the company's equity, D - market value of the company's debt, V – total market value of the company (E + D), R_e – cost of equity, R_d – cost of debt (loan interest), T – tax rate. [52], [53]

As cost of equity R_e is calculated through CAPM model.

$$r_a = r_{rf} + \beta_L \cdot \left(r_m - r_{rf}\right) = 0{,}93 + 2{,}6 \cdot (0{,}1017 - 0{,}093) = 0{,}1156$$

where r_a – expected rate of return, r_{rf} – risk-free rate of return [64] , r_m – expected rate of return of the market [65], β – beta of asset, $r_m - r_{rf}$ – premium for market risk.

Beta levered:

$$\beta_L = \beta_U \cdot (\frac{D}{E} \cdot (1 - T) + 1) = 0{,}76 \cdot (\frac{642198}{212587} \cdot (1 - 0{,}2) + 1) = 2{,}6$$

β_U – beta unlevered [66].

Cash flow

In 0 year the investments are done. The investments include the cost of the cables and the amount of money that is required for its installation and other additional expenditures. In CF I took into the own funds, as it is the actual cash outflow.

CF_0 = - Own funds = -189 216 Rub

The rest of the investment is covered by loan.

Since the first year the cables are started being depreciated, the loan payment is withdrawn and the annual operation of the cables is also taken into account.

The lifetime of the project is 30 years. The CF is always negative, as I don't consider the profit of the company.

$$CF_1 = - \text{Principle} - \text{Interest} - \text{Operation} + \text{Tax shield}_1 = - 25\,610 – 81\,136 – 184\,641 + 56\,917 =$$
$$= -234\,530 \text{ Rub}$$

$$\text{Tax shield}_1 = \text{Tax} \cdot (\text{Depreciation} + \text{Operation} + \text{Interest}) =$$
$$= 0,2 \cdot (18\,809 + 81\,136 + 184\,641) = 56\,917 \text{ Rub}$$
$$DCF_1 = CF \cdot (1 + \text{Discount rate})^{-t} = -234\,530 \cdot (1 + 0,086)^{-1} = -215\,899 \text{ Rub}$$
$$CDCF_1 = CDCF_0 + DCF_1 = -189\,216 -215\,899 = -405\,114 \text{ Rub}$$

In the 14th year the payment of the loan is completed and since the 15th it is not in the CF. In the 25th year the cables are depreciated.

The same calculations are performed for the rest years. The results are in the table in appendix 6.

Thus I obtained NPV = -3 197 767 Rub

4.2.2 Power supply system with cross-linked polyethylene cables APVV

Capital investment

Cable investments are in the table below:

Table 31 – Cable investments

	Cable length, m	*Price per meter, Rub*	*Number of lines*	*Investment costs, Rub*
TS1	349,65	405	1	141 608
TS2	306,36	732	1	224 256
TS3	233,1	405	1	94 406
TS4	349,65	405	1	141 608
TS5	592,74	489	1	289 850
TS6	233,1	489	1	113 986
			Total	**1 005 713**

$$K_{cmp} = 1,5\% \cdot 1\,005\,713 = 15\,086\ Rub$$
$$K_{oth} = 1,15\% \cdot 1\,005\,713 = 11\,566\ Rub$$
$$K = K_{cmp} + K_{oth} + K_{eq} = 15\,086 + 11\,566 + 1\,005\,713 = 798\,831\ Rub$$

Operational annual costs

The costs of losses in APVV cables for the cross-section 3x120, TS2, is calculated as follows.

$$C_{los} = n \cdot L \cdot \Delta P \cdot k_{load}^2 \cdot \tau_{max} \cdot \Delta C_e =$$
$$= 1 \cdot 0,306 \cdot 25,71 \cdot 0,68 \cdot 3283,12 \cdot 1,12 = 19\,593\ Rub$$

$$k_{load}^2 = (\frac{I_{rat}}{I_{ad}})^2 = (\frac{199,53}{295})^2 = 0,68$$

$$\Delta P = 3 \cdot I_{rat}^2 \cdot \mathrm{R} = 3 \cdot 199,53^2 \cdot 0,00022 = 25,71\ kW$$

The results for all lines are in the table below.

Table 32 – Losses cost

APVV cross section	***n, number of lines***	***L, km***	***ΔP, kW***	***C_{los}, Rub***
3x35	1	0,34965	13,01	6 822
3x120	1	0,30636	25,71	19 593
3x35	1	0,2331	8,67	3 032
3x35	1	0,34965	13,01	6 822
3x50	1	0,59274	46,63	46 214
3x50	1	0,2331	18,93	7 377
			Total	**89 859**

$$\mathrm{C}_r = 2,3\% \cdot 1\ 005\ 713 = 23\ 131\ Rub$$

$$\mathrm{C}_a = 5\% \cdot 1\ 005\ 713 = 50\ 286\ Rub$$

$$\mathrm{C}_{op} = \mathrm{C}_{los} + \mathrm{C}_r + \mathrm{C}_a = 89\ 859 + 23\ 131 + 50\ 286 = 163\ 276\ Rub$$

Loan

$$PMT = \frac{PV \cdot R}{1-(1+R)^{-n}} = \frac{825\ 892 \cdot 0,1072}{1-(1+0,1072)^{-14}} = 116\ 547\ Rub$$

where $PV = K \cdot 80\% = 1\ 005\ 713 \cdot 80\% = 825\ 892\ Rub$

Discount rate

Discount rate is accepted as calculated previously

$$WACC = 0,0863\%$$

Cash flow

Cash flow is calculated as previously:

The CF table is in appendix 7.

In the reconstruction part I obtained NPV = -3 007 974 Rub

4.2.3 Comparative analysis

All the obtained results I put into the following table

Table 34 – Economic evaluation parameters of the projects

	IPI cables	XPLE cables
Discount rate	8,63%	
Interest rate	10,72%	
Project lifetime	30 years	
Cables lifetime	30 years	
NPV	-3 197 767	-3 007 974
Investments	946 079	1 032 365
Annual operation cost	184 641	163 276
Amount of loan	756 863	825 892
Own funds	189 216	206 473

From the results you can see that in the case of application of cables with paper insulation the investment cost is higher, but the maintenance cost is lower. The increased maintenance cost is caused by the losses in cables. After the reconstruction part, 6 lines to transformer substations are changed for lines, thus the cross-section increases, that decreases the resistance. That lets the resulting value (NPV) to be higher than in the first case. Though, the difference is not high.

The lifetime of both cables is equal.

From the economic point of view, the second case is more profitable.

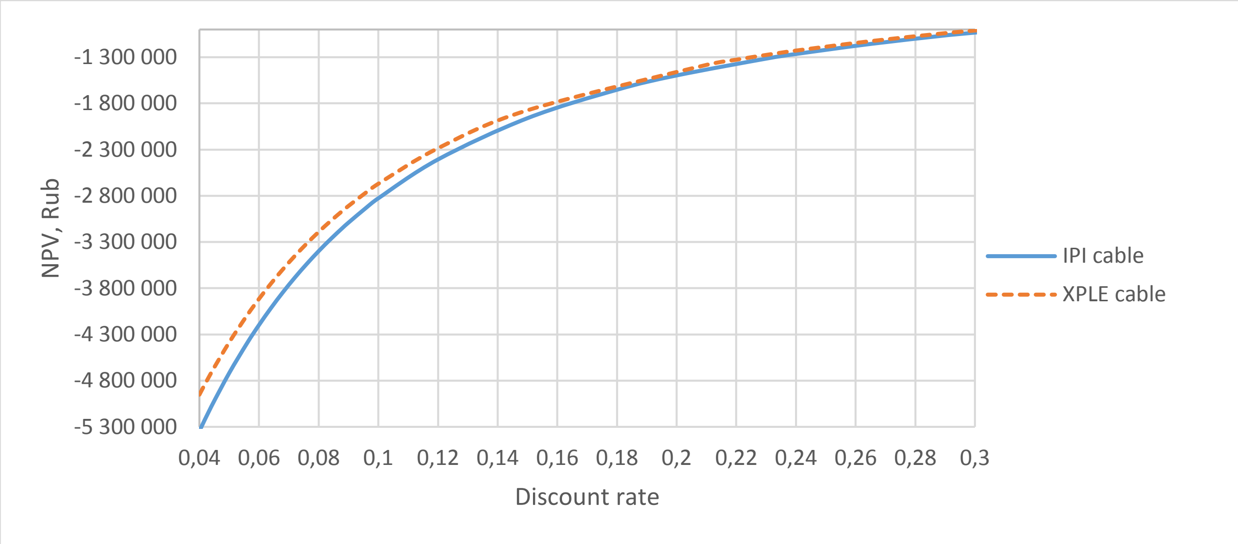
4.3 Sensitivity analysis

In order to obtain the full results it is necessary to perform the sensitivity analysis. Sensitivity analysis shows the price of a mistake or changes in the market.

The sensitivity analysis is made upon the dependence of the following economic parameters:

4) NPV and discount rate
5) NPV and interest rate
6) NPV and inflation rate
7) NPV and maintenance rate
8) NPV and loan share

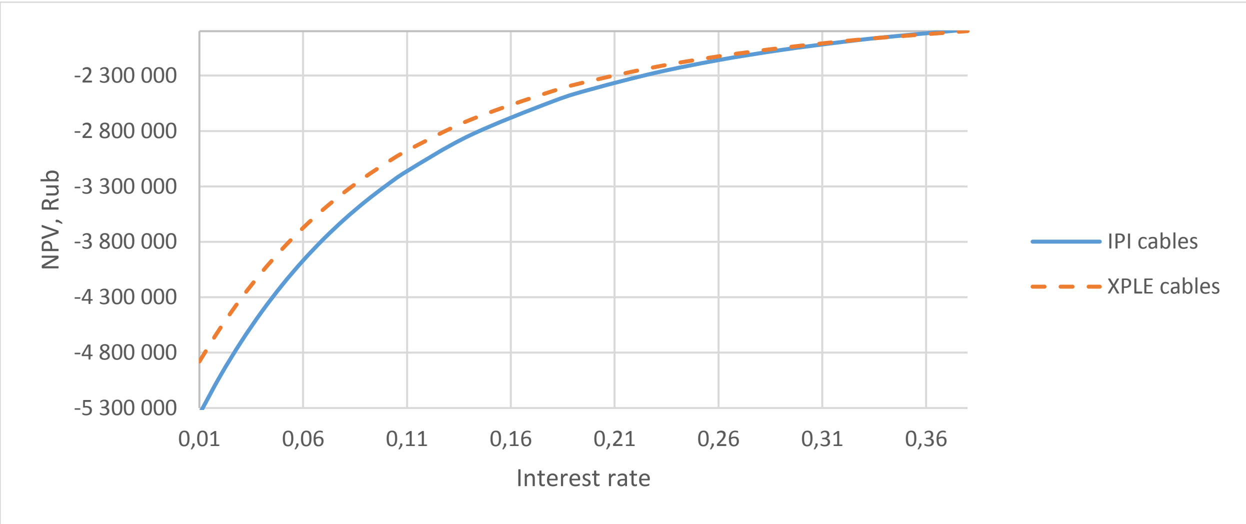
1. NPV and discount rate



Picture 12 – Dependence of NPV and discount rate

The sensitivity of NPV with the change of discount rate is reflected in the graph. It is possible to see that the project is sensitive to the discount rate and influences its resulting value a lot. The graphs do not intersect with each other, it means that the project with XPLE cables will be more profitable with all possible values of the rate.

2. NPV and interest rate



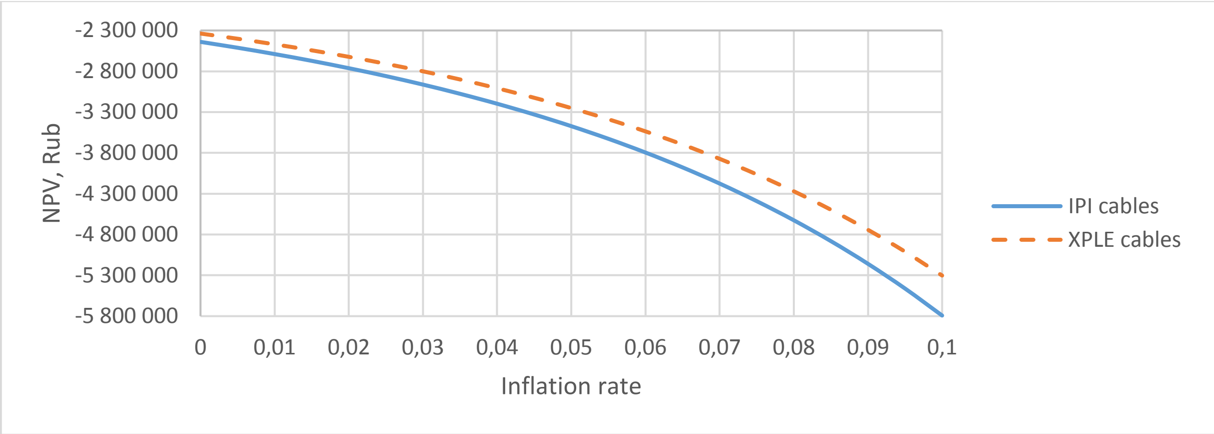
Picture 13 – Dependence of NPV and interest rate

In the point where interest rate = 34%, the NPV values are equal (NPV = 1 954 750 Rub). After this crossing, the project with XPLE cables is not efficient.

The amount of loan is 80% from the investments, thus the project very is dependent on the interest rate. The existing interest rate is 10,72%.

The interest rate 34% is theoretical, in practice such rate is hardly possible, thus, I can admit that reconstruction will be more feasible with possible interest rate changing.

3. NPV and inflation rate



Picture 14 – Dependence of NPV and inflation rate

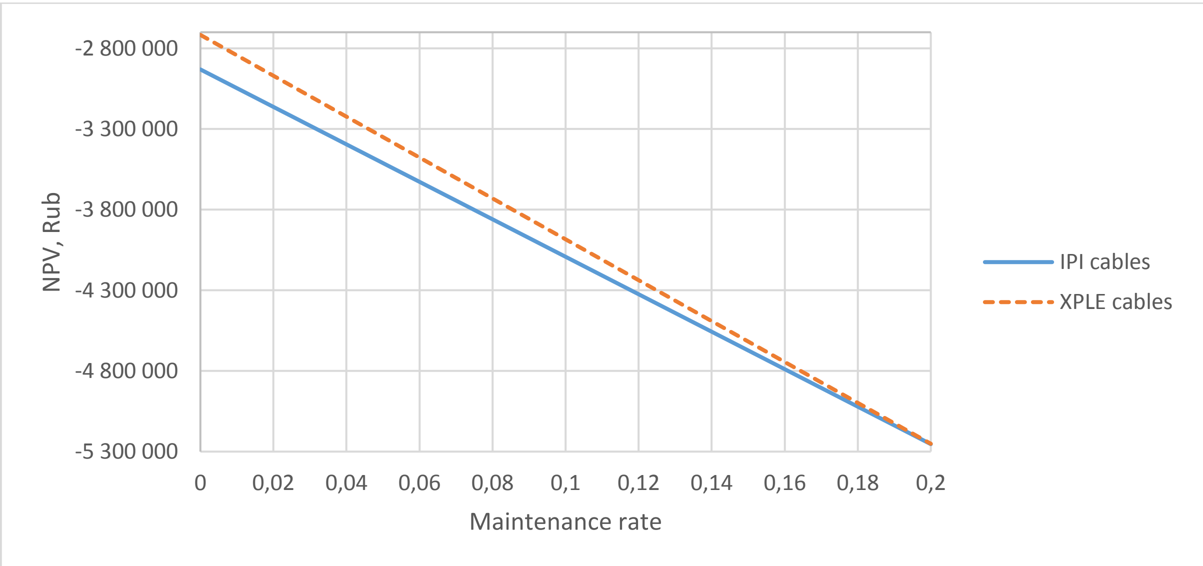
In this graph the dependence of NPV with inflation rate changing is shown.

With increasing of inflation rate, the profitability and feasibility of the reconstruction to be held is increasing. It is explained by the difference in the maintenance cost.

Since the annual maintenance, expenditures for the IPI cable operations are higher, with the increasing inflation rate they are becoming even more higher and the difference in operating cost is increasing rapidly. The less the inflation rate, the less the operating value.

The average inflation rate in Russia is 4%.

4. NPV and maintenance rate



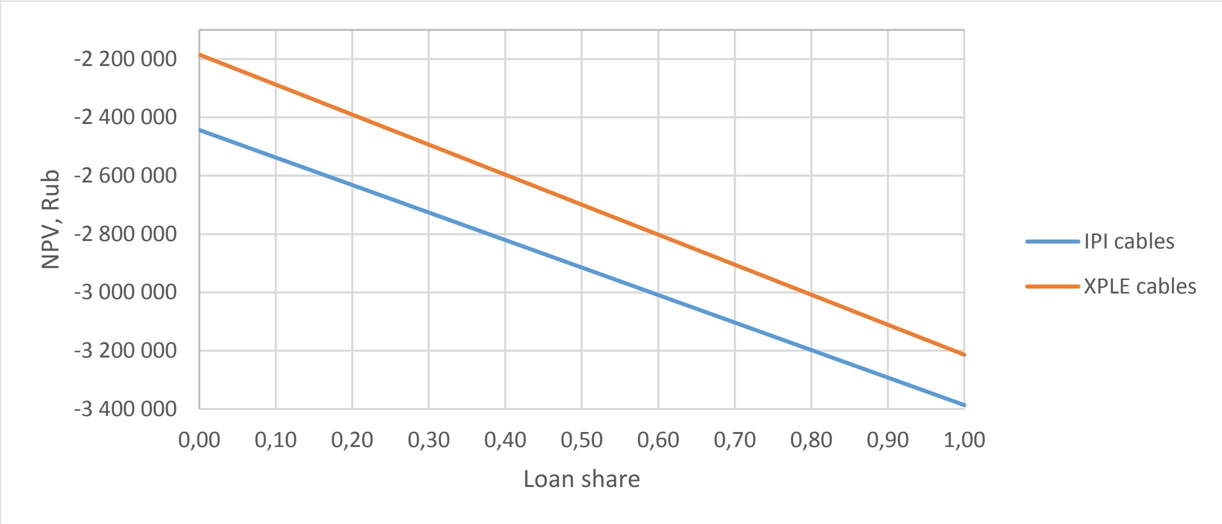
Picture 15 – Dependence of NPV and maintenance rate

The sensitivity of NPV value is measured on the maintenance rate change up to 20%. This value is too high, but it is measured to this point to show the dependence better. In the graph we can see that the crossing happens at the end.

It can be explained by the fact, that the XPLE cables are profitable investments since they demand less expenditures when being under operation, as the investments are higher. The crossing point shows the maximum possible maintenance rate for the reconstruction to be feasible.

The actual value is 2,3%. 20% is very high number and impossible in life. Constant development of technologies decreases the operational costs. Thus, with time the maintenance rate won't gel rapidly higher. Consequently, the application of XPLE cables is feasible with possible maintenance rate.

5. NPV and loan share



Picture 16 – Dependence of NPV and loan share

In the graph we can see that the more the loan share is, the more expensive the projects become. Thus, if there are available own funds, in the long run it is more profitable to invest them.

The case with the own funds to be 100% of the investments is the most feasible in both cases. It is also recognizable that the reconstruction case is a bit less sensitive to the loan share.

I accepted 80% loan share, 20% own funds.

5. CONCLUSION

In my thesis I performed the calculations of power supply network of the mechanical shop of mechanical engineering plant.

As a result of the calculations, the following issues were determined:

• the total load of the mechanical shop;

• the total capacity of the enterprise.

Based on the load calculation results, a cartogram of loads for 10 kV consumers was made in the enterprise's shops, the load center, the GPP installation was determined.

The number (N = 9 units) and power (S = 1600 kVA, S = 630 kVA) of the shop power transformers are determined and their distribution is held throughout the plant's shops.

The power supply of the plant is carried out from the power system substation, which is located at a distance of 2.2 km from the enterprise. Power supply of the enterprise is carried out through overhead line with voltage 35 kV. In order to ensure the reliability of power supply two transformers TMN-6300/35 were installed In MSDS. The feeding of the transformer substation is carried out through cables lines with impregnated-paper insulation for 10 kV voltage. This part of the system was under consideration on the issue of reconstruction for the cables with XPLE insulation.

If to compare only the investments cost, the advantages of XLPE cables in comparison with paper-insulated cables are not obvious. A completely different picture is observed if to take into account the technical characteristics of these cables. They let not only to reduce operating cost, but also to critically look at the traditionally applied power supply schemes for consumers, to perform simplification of the scheme, which will significantly improve the efficiency of using cables with cross-linked polyethylene.

With regard to annual operating cost, in addition to the cost of electricity losses and maintenance and repair cost, it should include possible damage in case of accidents in cable lines. The data for performing calculation of the damage rate can be obtained through practical use. There are no such open data available, so I didn't take this parameter into account in my work. But, if I had access to such data, the reconstruction would be even more feasible, as according to theoretical sources the damage rate of IPI cables should be higher.

The power losses in the newly proposed scheme are lower than in the traditional one due to the smaller total cross-section of the cable lines.

The resulting NPV value shows that the reconstruction is economically feasible. Though, the difference is not high. But the sensitivity of the project to the discount, inflation and maintenance rates should be taken into account.

The amount of the loan share also influences on the project. With regard to its sensitivity to interest rate, if there are available own funds, it would be reasonable to use them as investments.

The calculations are performed within the lifetime of the cables. According to their technical features, the lifetime of the cables is equal.

It should also mentioned that the maintenance rate for all cables is the same, according to the literature for power supply design. It is a percentage of investment cost. The actual rate can be obtained through practical use.

From all that has been said I can concluded, that the cables with XLPE insulation meet the highest requirements for electrical, mechanical and thermal performance. The high capacity and low damage rate of the cables let to apply them for power supply of objects with increased requirements to reliability. The minimum operating costs, the capability of high power transmission and the high reliability of XLPE cables let me speak not only about the technical feasibility of using the latter, but also about their economic attractiveness.

LIST OF APPENDIXES

APPENDIXES

Appendix 1

Data of electrical loads of the Mechanical shop

No	Name	Pins, kW	Кор	Cosφ	tgφ	η	K_{in}	I_{nom}, A	I_{in}, A
1	Vertical milling machine	8,0	0,20	0,65	1,17	0,89	5	21,0	105,1
2	Vertical milling machine	8,0	0,20	0,65	1,17	0,89	5	21,0	105,1
3	Vertical milling machine	8,0	0,20	0,65	1,17	0,89	5	21,0	105,1
4	Milling machine	18,0	0,20	0,65	1,17	0,89	5	47,3	236,4
5	Milling machine	18,0	0,20	0,65	1,17	0,89	5	47,3	236,4
6	Universal milling machine	12,0	0,20	0,65	1,17	0,89	5	31,5	157,6
7	Universal milling machine	12,0	0,20	0,65	1,17	0,89	5	31,5	157,6
8	Turn-milling machine	6,0	0,20	0,65	1,17	0,89	5	15,8	78,8
9	Turn-milling machine	6,0	0,20	0,65	1,17	0,89	5	15,8	78,8
10	Turn-milling machine	6,0	0,20	0,65	1,17	0,89	5	15,8	78,8
	Turn-milling machine	6,0	0,20	0,65	1,17	0,89	5	15,8	78,8
12	Turn-milling machine	12,0	0,20	0,65	1,17	0,89	5	31,5	157,6
13	Turn-milling machine	12,0	0,20	0,65	1,17	0,89	5	31,5	157,6
14	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
15	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
16	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
17	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
18	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
19	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
20	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
21	Bench drilling machine	4,5	0,20	0,65	1,17	0,89	5	11,8	59,1
22	Thread-cutting machine	6,0	0,20	0,65	1,17	0,89	5	15,8	78,8
23	Thread-cutting machine	6,0	0,20	0,65	1,17	0,89	5	15,8	78,8
24	Thread-cutting machine	6,0	0,20	0,65	1,17	0,89	5	15,8	78,8
25	Grinding machine	4,4	0,20	0,65	1,17	0,89	5	11,6	57,8
26	Grinding machine	4,4	0,20	0,65	1,17	0,89	5	11,6	57,8
27	Plate-bending machine	15,0	0,20	0,65	1,17	0,89	5	39,4	197,0
28	Rough grinding machine	3,0	0,20	0,65	1,17	0,89	5	7,9	39,4
29	Rough grinding machine	3,0	0,20	0,65	1,17	0,89	5	7,9	39,4
30	Rough grinding machine	3,0	0,20	0,65	1,17	0,89	5	7,9	39,4
31	Rough grinding machine	3,0	0,20	0,65	1,17	0,89	5	7,9	39,4
32	Rough grinding machine	2,0	0,20	0,65	1,17	0,89	5	5,3	26,3
33	Rough grinding machine	4,0	0,20	0,65	1,17	0,89	5	10,5	52,5
34	Rough grinding machine	4,0	0,20	0,65	1,17	0,89	5	10,5	52,5
35	Radial drilling machine	8,0	0,20	0,65	1,17	0,89	5	21,0	105,1
36	Radial drilling machine	8,0	0,20	0,65	1,17	0,89	5	21,0	105,1
37	Universal grinding-machine	5,0	0,20	0,65	1,17	0,89	5	13,1	65,7
38	Universal grinding-machine	5,0	0,20	0,65	1,17	0,89	5	13,1	65,7

39	Face-grinding machine	10,0	0,20	0,65	1,17	0,89	5	26,3	131,3
40	Face-grinding machine	8,0	0,20	0,65	1,17	0,89	5	21,0	105,1
41	Face-grinding machine	8,0	0,20	0,65	1,17	0,89	5	21,0	105,1
42	Welding machine	5,0	0,30	0,45	1,98	0,95	3	17,8	53,3
43	Welding machine LC =40%	4,0	0,30	0,45	1,98	0,95	3	14,2	42,6
44	Welding machine LC =40%	4,0	0,30	0,45	1,98	0,95	3	14,2	42,6
45	Welding machine LC =40%	4,0	0,30	0,45	1,98	0,95	3	14,2	42,6
46	Welding machine LC =40%	4,0	0,30	0,45	1,98	0,95	3	14,2	42,6
47	Welding machine LC =40%	4,0	0,30	0,45	1,98	0,95	3	14,2	42,6
48	Hardening furnace	12,0	0,75	0,95	0,33	0,98	-	19,6	-
49	Ventilator	8,0	0,70	0,80	0,75	0,89	5	17,1	85,4
50	Ventilator	10,0	0,70	0,80	0,75	0,89	5	21,3	106,7
51	Overhead crane LC =25%	10,0	0,06	0,45	1,98	0,89	5	37,9	189,7

Appendix 2

Rated loads of mechanical shop

No	Name	*n*	Rated power		$m=P_{nom.max}/P_{nom.min}$	K_{op}	Cosφ/tgφ	Average load for the most loaded shift		n_e	K_m	Maximum load			$I_m/I_п$
			P_{nom}, kW	ΣP_{nom}, kW				$P_{sh}=K_{op}\cdot P_{sh}$, kW	$Qsh=Psh\cdot tg\varphi$, kVAr			$P_m=K_m\cdot P_{sh}$, kW	$Q_m=Q_{sh}$ at $n_e>10$ $Q_m=1,1\cdot Q_{sh}$ at $n_e\leq 10$, kVA	$S_m=\sqrt{P_м^2+Q_м^2}$, kVA	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mechanical shop															
	DP1														
	Group A														
1	Grinding machine	2	4,4	8,8		0,2	0,65/1,17	1,76	2,06						
2	Plate-bending machine	1	15	15		0,2	0,65/1,17	3	3,51						
3	Rough grinding machine	4	3	12		0,2	0,65/1,17	2,4	2,8						
4	Rough grinding machine	1	2	2		0,2	0,65/1,17	0,4	0,47						
	Total DP1	**9**	**2-15**	**37,8**	**>3**			**7,56**	**8,85**	**5**	**2,42**	**18,3**	**9,73**	**20,72**	**31,48**
	DP 2														
	Group A														
1	Bench drilling machine	8	4,5	36		0,2	0,65/1,17	7,2	8,42						
	Total DP2	**8**	**4.5**	**36**	**<3**			**7,2**	**8,42**	**8**	**1,99**	**14,33**	**9,27**	**17,06**	**25,93**
	DP 3														
	Group A														
1	Milling machine	2	18	36		0,2	0,65/1,17	7,2	8,42						
2	Universal milling machine	2	12	24		0,2	0,65/1,17	4,8	5,62						

3	Overhead crane LC=25%	1	2,5	2,5		0,06	0,45/1,98	7	5,25						
	Total A		**2,5-18**	**62,5**	>3			**19**	**19,29**	**4,2**	**2,14**	**33,98**	**16,3**		
	Group B														
1	Ventilator	1	10	10		0,7	0,8/ 0,75	0,15	0,3						
	Total B		**10**	**10**				**0,15**	**0,3**			**4,38**	**5,25**		
	Total DP3		**2,5-18**	**72,5**				**19,15**	**19,59**	**5**	**2**	**38,3**	**21,55**	**43,94**	**66,77**
	DP 4														
	Group A														
1	Radial drilling machine	1	8	8		0,2	0,65/1,17	1,6	1,87						
2	Universal grinding-machine	2	5	10		0,2	0,65/1,17	2	2,34						
3	Face-grinding machine	1	10	10		0,2	0,65/1,17	2	2,34						
4	Welding machine LC=40%	2	2,53	5,06		0,3	0,45/1,98	1,52	3						
	Total A		**2,53-10**		>3			**7,12**	**8,31**	**5**	**2,42**	**17,23**	**8,3**		
	Group B														
1	Hardening furnace	1	12	12		0,75	0,95/0,33	9	2,97						
	Total B	**1**	**12**	**12**				**9**	**2,97**			**9,53**	**4,1**		
	Total DP4		**2,53-12**	**45,06**				**16,12**	**11,28**	**6**	**1,66**	**26,76**	**12,4**	**29,49**	**44,81**
	DP 5														
	Group A														
1	Vertical milling machine	2	4	8		0,2	0,65/1,17	1,6	1,88						
2	Radial drilling machine	1	8	8		0,2	0,65/1,17	3,2	1,87						
3	Milling machine	1	0,4	0,4		0,3	0,45/1,98	3	2,97						
4	Welding machine LC=40%	3	1,6	4.8		0,3	0,45/1,98	0,96	2,94						
	Total DP5	**9**	**0,4-8**	**25,8**	>3			**6,14**	**9,57**	**5,17**	**2,42**	**14,86**	**10,52**	**18,21**	**27,66**
	DP 6														
	Group A														

1	Turn-milling machine	4	6	24		0,2	0,65/1,17	4,8	5,6						
2	Turn-milling machine	2	12	24		0,2	0,65/1,17	4,8	4,2						
3	Face-grinding machine	2	8	16		0,2	0,65/1,17	3,2	3,74						
	Total DP6	**9**	**6-12**	**64**	**<3**			**12,8**	**14,98**	**7**	**2,1**	**26,88**	**16,47**	**31,53**	**47,9**
	DP 7														
	Group A														
1	Vertical milling machine	3	8	24		0,2	0,65/1,17	4,8	5,61						
2	Thread-cutting machine	3	6	18		0,2	0,65/1,17	3,6	4,2						
3	Ventilator	1	8	8		0,2	0,8/ 0,75	5,6	4,2						
	Total DP7	**9**	6-8	**50**	**<3**			**14**	**14,03**	**7**	**1,8**	**25,2**	**15,43**	**29,55**	**44,9**
	Total load in the shop	51	2-18	331.16				82,97	86,72			164,6	95,37	190,5	
	Electrical lightning			46		0,85		39,11				39,11			
	Total	**51**		**377,16**				**122,1**	**86,72**			**203,7**	**95,37**	**224,9**	

Appendix 3

Enterprise total power load calculation

No on the plan	Name	Power load				
		P_{nom}, kW	K_d	Cosφ/tgφ	P_{rat},kW	Q_{rat}, kVar
1	2	3	4	5	6	7
	Consumption 0,38 kV:					
1	Administration shop	680	0,4	0,8/0,75	272	204
2	Instrumental building	1250	0,35	0,7/1,02	437,5	446,3
3	Main building	4500	0,4	0,75/0,88	1800	1587,5
4	Clearing water station	640	0,6	0,8/0,75	384	288
5	CC «Motor»	550	0,4	0,7/1,02	220	224,4
6	Administration building	350	0,4	0,8/0,75	140	105
7	Building of ancillary services	300	0,3	0,7/1,02	90	91,8
8	Warehouse	185	0,3	0,8/0,75	55,5	41,6
9	Mechanical shop	331	0,3	0,8/0,75	99,3	74,5
10	Garage complex	210	0,2	0,7/1,02	42	42,9
11	Chop shop	250	0,4	0,75/0,88	100	88,2
12	Compressor room 0,38 kV	180	0,4	0,75/0,88	72	63,5
13	Warehouse №1	172	0,3	0,8/0,75	51,6	38,7
14	Water pump station	450	0,6	0,8/0,75	270	202,5
15	Iron-foundry	2980	0,4	0,75/0,88	1192	1051,3
16	Warehouse №2	115	0,3	0,8/0,75	34,5	25,9
	Total for 0,38 kV	**13143**			**5260,4**	**4576**
	Consumption 6-10 kV:					
12	Compressor room 10 kV SM 2x630 kW	1260	0,4	0,75/0,88	504	444,5
	Total for 6-10 kV	**1260**			**504**	**444,5**

Enterprise lightning load calculation

No on the plan	Name	F, m^2	$P_{sp.l}$, W/ м^2	$P_{n.l}$, kW	$K_{d.l}$	$P_{rat.l}$, kW	$P_{rat} + P_{rat.l}$, kW	Q_{rat}, kW	S_{rat}, kVA
1	2	3	4	5	6	7	8	9	10
	Consumption 0,38 kV:								
1	Administration shop	2133	20	42,66	0,9	38,39	310,39	204	389,92
2	Instrumential building	1058	15	15,87	0,85	13,49	450,99	446,3	646,01
3	Main building	4640	20	92,8	0,85	78,88	1878,88	1587,5	2513,31
4	Clearing water station	84,5	18	1,521	1	1,52	385,52	288	481,9
5	CC «Motor»	650	20	13	0,9	11,7	231,7	224,4	331,9484
6	Administration building	706	20	14,12	0,9	12,71	152,71	105	191,52
7	Building of ancillary servicis	2450	18	45,72	0,85	38,86	128,86	91,8	189,15
8	Warehouse	1411	17	23,99	0,6	14,39	69,89	41,6	91,86
9	Mechanical shop	3834	12	46,01	0,85	39,11	138,41	74,5	176,16
10	Garage complex	1610	17	27,37	0,6	16,422	58,42	42,9	91,77
11	Chop shop	160	16	2,56	1	2,56	102,56	88,2	136,75
12	Compressor room 0,38 kV	429	15	6,44	1	6,44	78,44	63,5	104,58
13	Warehouse №1	730	18	13,14	0,6	7,88	59,48	38,7	76,79
14	Water pump station	6116	18	110,09	0,85	93,57	363,58	202,5	462,01
15	Iron-foudry	2592	19	49,25	0,85	41,86	1233,86	1051,3	1649,46
16	Warehouse №2	204	18	3,67	0,6	2,2	36,7	25,9	46,55
	Total for 0,38 kV	**28897,5**		**508,12**		**419,99**	**5680,39**	**4576**	**7579,69**
	Consumption 6-10 kV:								
12	Compressor room 10 kV SM 2x630 kW		15	-	-	-	504	444,5	672
	Total for 6-10 kV		**-**	**6,44**	**-**	**6,44**	**504**	**444,5**	**672**

Appendix 4

Choice of compensating devices 0,4 kV

TS	ΣQ, kVar	Q_{max}, kVar	Q_{nc1}, kVar	Mark of CB	Quantity and capacity of CB, kVar	Actual capacity of CB, kVar	Q_r after compensation, kVar
TS1	240,37	473,7	233,34	UKM 58-04-100-33,3UZ UKM 58-04-30-10UZ	2x100 1x30	100 30	470,37
TS2	1985,2	1958,43	0	-	-	-	1985,2
TS3	240,37	600,99	360,66	UKM 58-04-100-33,3UZ UKM 58-04-67-33,3UZ	3x100 1x67	100 67	607,37
TS4	240,37	354,96	114,59	UKM 58-04-100-33,3UZ UKM 58-04-20-10UZ	1x100 1x20	100 20	320,37
TS5	1495,27	1616,55	121,28	UKM 58-04-100-33,3UZ UKM 58-04-20-10UZ	1x100 1x20	100 20	1615,27
Total	4201,57	5004,64	829,84		837	1357	5011,8

Appendix 5

Capital investment

Type of equipment	Name of equipment	Quantity	Lifetime, years
Capacitor bank	UKM 58-04-100-33,3UZ	7	5
	UKM 58-04-30-10UZ	1	
	UKM 58-04-67-33,3UZ	1	
	UKM 58-04-20-10UZ	2	
Transformer	TMN-6300/35	2	30
	TM-1600/10	2	25
	TM-630/ 10	7	25
Cables from MSDS to TS (1-6)	AS - 70/11	2,2 km	45
	AAShv (3x35)	1	30
	AAShv (3x95)	2	
	AAShv (3x35)	1	
	AAShv (3x35)	1	
	AAShv (3x35)	2	
	AAShv (3x35)	2	
Circuit breaker	CAA-35A-40/2000	2	10
Disconnector	DTG -35/1000	2	10
Circuit breaker	VCE-10-20 / 630U2	13	10
Current transformer	TCB-10-U3	2	30
	TPCO 35 B-1 CL1	9	25
Voltage transformer	GVOC.10.	9	30
	GVOC-35	2	30
Surge arrester	SA-35	2	25
	SA-10	9	30
	Mechanical shop		
Circuit breaker	BA57-35	51	25
Circuit breaker	BA 75-47	7	20
Circuit breaker	BA 51-35	7	10
Distributing point	DP8503-21U3	7	20
Cables from TS to DP	AAShv 4x120	1	30
	AAShv 4x25	1	
	AAShv 4x185	1	
	AAShv 3x35	1	
	AAShv 3x35	1	
	AAShv 4x120	1	
	AAShv 3x35	1	
Cables from DP to Equipment	AAShv 4x70	8	30
	AAShv 3x240	2	
	AAShv 4x120	6	
	AAShv 4x35	8	
	AAShv 4x25	12	
	AAShv 4x185	2	
	AAShv 4x16	12	

Appendix 6

CF of the project with IPI cables

Years	CF, Rub	DCF, Rub	CDCF, Rub
0	-189 216	-189 216	-189 216
1	-234 530	-215 899	-405 114
2	-237 227	-201 033	-606 147
3	-243 981	-190 332	-796 479
4	-251 046	-180 285	-976 764
5	-258 440	-170 851	-1 147 615
6	-266 179	-161 988	-1 309 603
7	-274 283	-153 660	-1 463 263
8	-282 773	-145 832	-1 609 095
9	-291 671	-138 471	-1 747 566
10	-301 000	-131 548	-1 879 113
11	-310 786	-125 034	-2 004 148
12	-321 056	-118 905	-2 123 053
13	-331 839	-113 135	-2 236 188
14	-343 167	-107 703	-2 343 891
15	-248 267	-71 729	-2 415 620
16	-258 499	-68 752	-2 484 372
17	-269 140	-65 895	-2 550 267
18	-280 206	-63 155	-2 613 422
19	-291 715	-60 526	-2 673 948
20	-303 685	-58 004	-2 731 952
21	-316 133	-55 585	-2 787 536
22	-329 080	-53 264	-2 840 801
23	-342 544	-51 039	-2 891 840
24	-356 546	-48 905	-2 940 745
25	-371 109	-46 859	-2 987 604
26	-393 778	-45 771	-3 033 375
27	-409 529	-43 821	-3 077 196
28	-425 910	-41 953	-3 119 149
29	-442 947	-40 165	-3 159 314
30	-460 665	-38 453	-3 197 767

Appendix 7

CF of the project with IPI cables

Years	CF, Rub	DCF, Rub	CDCF, Rub
0	-206 473	-206 473	-206 473
1	-225 356	-207 453	-413 926
2	-227 076	-192 431	-606 357
3	-233 175	-181 902	-788 259
4	-239 563	-172 038	-960 298
5	-246 255	-162 796	-1 123 094
6	-253 270	-154 132	-1 277 226
7	-260 626	-146 009	-1 423 235
8	-268 343	-138 390	-1 561 624
9	-276 444	-131 242	-1 692 866
10	-284 951	-124 534	-1 817 400
11	-293 889	-118 236	-1 935 636
12	-303 286	-112 324	-2 047 960
13	-313 170	-106 771	-2 154 730
14	-323 574	-101 554	-2 256 284
15	-217 983	-62 979	-2 319 263
16	-227 031	-60 383	-2 379 646
17	-236 441	-57 889	-2 437 535
18	-246 227	-55 496	-2 493 032
19	-256 404	-53 199	-2 546 231
20	-266 989	-50 995	-2 597 226
21	-277 997	-48 879	-2 646 105
22	-289 445	-46 849	-2 692 954
23	-301 351	-44 901	-2 737 855
24	-313 734	-43 033	-2 780 888
25	-326 611	-41 240	-2 822 129
26	-348 214	-40 475	-2 862 604
27	-362 143	-38 750	-2 901 354
28	-376 628	-37 099	-2 938 453
29	-391 693	-35 518	-2 973 970
30	-407 361	-34 004	-3 007 974

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