MINISTRY OF EDUCATION AND SCIENCE, YOUTH AND SPORT OFUKRAINE

VLADIMIR DAHL EAST UKRAINIAN NATIONAL UNIVERSITY

FACULTY OF ELECTRICAL SYSTEMS

Department of electrotechnical system of power consumption

EXPLANATORY NOTE

of master’s thesis on the topic:

INCREASING OF EFFICIENCY OF INDUSTRIAL ENTERPRISES BY REDUCING OF ENERGY LOSSES IN THE POWER EQUIPMENT

PM 101.103.000 EN

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Lugansk 2012

МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ, МОЛОДІ ТА СПОРТУ УКРАЇНИ

СХІДНОУКРАЇНСЬКИЙ НАЦІОНАЛЬНИЙ УНІВЕРСИТЕТ ім. В. ДАЛЯ

Кафедра електротехнічних систем електроспоживання

ПОЯСНЮВАЛЬНА ЗАПИСКА

до магістерської роботи на тему:

ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ПРОМИСЛОВОГО ПІДПРИЄМСТВА ШЛЯХОМ ЗМЕНШЕННЯ ВТРАТ ПОТУЖНОСТІ НА СИЛОВОМУ ОБЛАДНАННІ

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Луганськ 2012

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Task for the master's thesis.

1. **Student** Al-Magidi Sadeq
2. **Group** ET-101m
3. **Topic** Increasing of efficiency of industrial enterprises by reducing of energy losses in the power equipment.
4. **Tasks for the master's thesis.**

   - Calculation and selection of main power supply elements of industry;
   - Analysis of main types, places and methods of reduction of power losses;
   - Analysis of positive effect of implementation of power loss reduction methods.
5. **Contents (the main questions) –** according to plan.
6. **Graph materials.**

1. Plan-scheme of industry power supply.
2. One-line principal scheme of industry.

3. Day load diagrams of workshops.
4. Day load diagrams of industry.
5. Effect of implementation of losses reduction methods
6. Expediency.of cable cross section

7. Consultant.

Chapter	Consultant	Signature
1 – 4	Kuzmenko D.I.	
5. Labor safety	Kas`yanov M.A.	

8. Plan.

Name of the chapter	Date
1. Chapter 1 (PROBLEMS AND TASKS OF THE RESEARCH).	
2. Chapter 2 (CALCULATION OF ELECTRIC LOAD)	
3. Chapter 3 (REDUCING OF POWER LOSS BY SMOOTHING OF DAY LOADS GRAPH)	
4. Chapter 4 (TECHNICAL CALCULATION OF INTERNAL POWER SUPPLY)	
5. Chapter 5 (LABOR SAFETY)	
6. (Execution of the work according to ISO)	

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Date "____" ____________2012

ABSTRACT

For master thesis on theme “Increasing of efficiency of industrial enterprises by reducing of energy losses in the power equipment”.

The work consists of introduction, 6 chapters and conclusions. Full scope of work includes 106 pages, 43 figures, 6 of them on separate sheets and 43 tables. The reference includes 39 items.

The first chapter analyzes the electrical losses: types, appearance places, methods of reduction.

The second chapter shows the calculation of a typical system power supply of enterprise, with a selection of main equipment of medium voltage network of 10 kV.

In the third chapter reviewed graph of daily loading of the enterprise. It also was proposed the smoothed graph of the daily load. Adjusted selection of the supply transformer adjusted selection of the supply transformer, a comparative analysis of power losses in both graphs the load were performed.

In the fourth chapter selection of power supply scheme of the enterprise, preliminary and expedient calculation of cross-section were performed.

The fifth chapter contains a calculation of the lightning protection and grounding of enterprise.

POWER LOSSES, POWER SUPPLY, REDUCING OF LOSSES, TRANSFORMERS, POWER CABLE, LOAD GRAPH, SMOOTHING OF LOAD, SELECTION OF CROSS SECTION.

РЕФЕРАТ

Магістерської роботи з теми «Підвищення ефективності промислового підприємства шляхом зменшення втрат потужності на силовому обладнанні».

Робота складається з вступу, 5 частин та висновків. Повний обсяг робіт включає в себе 106 сторінок, 43 малюнків, 6 з них на окремих аркушах і 43 таблиць. Список літератури включає в себе 39 пунктів.

У першому розділі проведено аналіз електричних втрат: типів, місць виникнення, методів зниження.

У другому розділі показаний розрахунок типової системи електропостачання підприємства, з вибором основного обладнання мережі середньої напруги 10 кВ.

У третьому розділі проаналізовано графік добового завантаження підприємства. Також було запропоновано згладжений графік добової завантаження. Був проведений уточнений вибір живлячих трансформаторів, порівняльний аналіз втрат потужності при обох графіках навантаження.

У четвертому розділі був проведений вибір схеми електропостачання підприємства. Був проведений попередній і доцільний розрахунок перетину кабелю.

У п'ятому розділі міститься розрахунок блискавкозахисту та заземлення підприємства.

ВТРАТИ ПОТУЖНОСТІ, ЕЛЕКТРОПОСТАЧАННЯ, ЗМЕНШЕННЯ ВТРАТ, ТРАНСФОРМАТОР, СИЛОВИЙ КАБЕЛЬ, ГРАФІК НАВАНТАЖЕННЯ, ЗГЛАДЖЕННЯ НАВАНТАЖЕННЯ, ВИБІР ПЕРЕТИНУ.

CONTENTS:

INTRODUCTION

In modern conditions of complete and total economization of all areas, one of the most important tasks of modern power engineering is to minimize losses and, consequently, costs. In connection with the development of market relations in the country the significance of the problem of loss of electricity has increased substantially. Development of methods of calculation, analysis of energy losses and the choice of cost-based measures to reduce them is more than 30 years. Due to the complexity of calculating the losses and the presence of significant errors in the recent emphasis on developing methods of normalization of energy losses.

The simplest and most effective way to reduce losses is to build an effective and competent power supply of industrial enterprises, which can be attributed to the largest loads in the network and, consequently, to the greatest sources of loss. Therefore, the management of industrial enterprises (especially private enterprises) should be interested in activities that reduce the power losses in the equipment.

In power supply to final consumers, losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users. Total losses have two components: technical and non-technical. Technical losses occur naturally and consist mainly of power dissipation in electricity system components such as transmission and distribution lines, transformers, and measurement systems. Non-technical losses are caused by actions external to the power system and consist primarily of electricity theft, non-payment by customers, and errors in accounting and record-keeping. These three categories of losses are respectively sometimes referred to as commercial, non-payment, and administrative losses, although their definitions vary in the literature.

Metering and billing for electricity actually consumed by users is integral to commercial management of an electricity utility. Another critical task is collection of the billed amounts. Effective performance in both functions is critical to ensure the financial viability of the company. From the operational point of view, metering-billing and collection are separate functions and they require specific management approaches.

So, power losses in electrical networks - a key indicator of efficiency of their work, a clear indicator of the state accounting system of electricity, the efficiency of energy sales of power supply companies. This indicator shows the problems that require urgent solutions in development, reconstruction and technical re-equipment of electrical networks, methods and means of improving their operation and management, to improve the precision metering of electricity, the efficiency of collecting money for the electricity supplied to consumers, etc.

Methodology for determining standards of losses has not yet been established. Do not even define the principles of valuation. Views on approach to rationing are a wide range - from the desire to have established a firm standard as a percentage of loss to control the "normal" losses, with the help of calculations carried out continuously by the schemes of networks using appropriate software. According received norms established electricity losses in electricity tariffs. Energy suppliers must justify the level of energy losses, which they consider appropriate to include in the tariff, and the energy commission - to analyze these studies and to accept or adjust them.

Analysis of foreign experience shows that the growth of electricity losses in networks - an objective process for countries with economies in crisis, and reformed energy, a sign of the existing gaps between solvency and consumer rates for electricity, the rate of under-investment in network infrastructure and system metering, lack of full-scale automated information systems for the collection and transfer of useful data on electricity supply, the structure of the flow of electricity on the steps of the voltage, power balances in electric networks.

In countries where these factors occur, the loss of power in networks tends to have high and growing.

The cost of losses - is part of the costs of transmission and distribution of electricity to the grid. The greater the loss, the higher these costs and thus electricity prices for consumers. It is known that some of the losses is a technological power consumption required to overcome the resistance of the network and delivery to consumers of electricity generated by power plants. This technology required energy consumption to be paid by the consumer. It, in essence, is the norm loss.

1. PROBLEMS AND TASKS OF THE RESEARCH

1.1 Problem of power losses in power engineering

The issue of limited resources in today's world is one of the most pressing. The constant increase of production, which is characteristic for the global industry as the intensive and extensive way, in most cases, leads to an increase in power consumption. This creates a shortage of energy resources.

The division of natural resources in inexhaustible and exhaustible is becoming more tentative. Many types of resources are now moving from the first into the second category.

The main type of energy is still mineral fuels - oil, gas and coal. These non-renewable energy sources, and at the present rate of growth of their production, they may be exhausted by 80-140 years. However, the proportion of these sources must be reduced through the development of nuclear energy, based on the use of "heavy" fuel - fissile isotopes of thorium and uranium. However, these non-renewable resources: the scientists' calculations, only enough uranium for several decades. Also, by order of the European Union, the construction of nuclear power is suspended, which increases the need for fossil fuel. Energy shortages, in turn, will significantly increase the cost for exhaustible resources.

At this point, the specific consumption of fuel produced at the 1 kW·h is 200-400 g / kW·h The need for power produced from the power of one million kW·h is 11-13 tons per day.

Thus, the problem of reducing the power loss is becoming increasingly important for both private and state-owned enterprises.

Power losses in electrical networks - a key indicator of efficiency of their work, a clear indicator of the state accounting system of electricity, the efficiency of energy sales of power supply companies.

This indicator is all the clearer indicates the cumulative problems that require urgent solutions in development, reconstruction and technical re-equipment of electrical networks, methods and means of improving their operation and management, to improve the precision metering of electricity, the efficiency of collecting money for the electricity supplied to consumers, etc.

According to international experts, the relative power losses during transmission and distribution in networks of most countries can be considered satisfactory if they do not exceed 4-5%. The loss of electricity at 10% can be considered as acceptable from the standpoint of physics transmission over networks.

It is becoming increasingly clear that the aggravation of the problem of reducing the energy losses in electric networks require an active search for new ways to solve it, new approaches to the selection of appropriate activities, and most importantly, the organization works to reduce losses.

Due to the sharp decline in investment in the development and modernization of power grids in the improvement of their management regimes, measurement equipment, a number of negative trends affecting the level of losses in the networks, such as outdated equipment, physical and moral deterioration of electricity metering discrepancy, the equipment installed transmission capacity.

From the aforementioned it follows that on the background of a changing economic mechanism in the energy sector, the economic crisis in the country the problem of reducing energy losses in electric networks, not only has not lost its relevance, but instead popped into one of the tasks of ensuring the financial stability of power supply companies.

1.2. Places of power losses

After electric power is generated, it is sent through the transmission linesto the many distribution circuits that the utility operates. The purpose of thedistribution system is to take that power from the transmission system anddeliver it to the consumers to serve their needs. However, a significant portion ofthe power that a utility generates is lost in the distribution process. These lossesoccur in numerous small components in the distribution system, such astransformers and distribution lines. Due to the lower power level of thesecomponents, the losses inherent in each component are lower than those incomparable components of the transmission system. While each of thesecomponents may have relatively small losses, the large number of componentsinvolved makes it important to examine the losses in the distribution system.These losses typically account for approximately four percent of the total systemload.

There are two major sources of losses in power distribution systems.These are the transformers and power lines. Additionally, there are two majortypes of losses that occur in these components. These losses are often referred toas core losses and copper, or I^2Rlosses. Core losses in transformers account forthe majority of losses at low power levels. As load increases, the copper lossesbecome more significant, until they are approximately equal to the core losses atpeak load.

The economic implications of these losses are far reaching. In addition tothe excess fuel cost needed to cover .the lost energy, added generating capacitymay be needed. Also, the power lost in the distribution system must still betransmitted through the transmission system which further adds to the loss in thatsystem. It is very important for electric power suppliers to consider these lossesand reduce them wherever practical.

LossesinDistributionLines:

One of the major sources of losses in the distribution system is the powerlines which connect the substation to the loads. Virtually all real power that islost in the distribution system is due to copper losses. Since these losses are afunction of the square of the current flow through the line, it should be obvioustha the losses in distribution lines are larger at high power levels than they are atlower levels.

Since power loss in the distribution lines can be considered to be entirelydue to copper losses, it can be calculated using formula:

$$P=I^2R \qquad (1.1)$$

From this, it is apparent that anything that changes either current or lineresistance will affect the amount of power lost in the line.

The primary determining factor for the magnitude of line current is theamount of real and reactive power loading at the end of the line. As the powerthat is transmitted along the line increases, the current flow in .the line becomeslarger. Another factor which affects the level of current flow is the operatingvoltage of the line. For a given real and reactive power load level, S, a highvoltage line will have a lower current than a low voltage line. This can be seenfrom formula:

$$S=UI \qquad (1.2)$$

Therefore, for a given power level, the higher voltage line will have lower copperlosses.

Another factor which can result in higher line losses is unbalancedloading. If one of the phases is loaded more heavily than the others, the loss willbe larger than it would have been in the balanced load case. This is due to thesquaring of the current in (1.1). For instance, if one line carries twicethe current of ,the other two and all other factors are kept constant, an increase incopper loss of 12.5% occurs compared to the balanced load case.

While the current level has the biggest effect on line loss, the resistance ofthe line cannot be neglected. The line resistance depends on many factors,including the length of the line, the effective cross-sectional area, and theresistivity of the metal of which the line is made. The resistance is inverselyproportional to the cross-sectional area and directly proportional to both thelength and resistivity. This is shown in 1.3 below, where R is theresistance, ρ is the resistivity, L is the length of the line, and A is the effectivecross-sectional area.

$$R=\rho L/A \tag{1.3}$$

Therefore, a long line will have a higher resistance and larger losses than a shortline with the same current flow. Similarly, a large conductor size results in asmaller resistance and lower losses than a small conductor.

The resistivity is determined by the material of which the line isconstructed and the temperature of the material. A better conducting material willresult in lower resistivity and lower losses. The resistivity of the metal in the linewill be affected by the temperature. As the temperature of the metal increases,the line resistance will also increase, causing higher copper losses in thedistribution line. The resistivity of copper and aluminum can be calculated from

$$\rho_1=\rho_2\frac{T_2-T_0}{T_1-T_0} \tag{1.4}$$

LossesinDistributionTransformers:

While losses in distribution lines are virtually all due to copper losses,transformer losses occur due to both copper and core losses. The core losses aremade up of eddy current and hysteresis losses.The copper losses in transformersare essentially the same as those in the power distribution lines.

The copper losses in a transformer are smaller in magnitude than the corelosses. These losses occur in the form of heat produced by the current, bothprimary and secondary, through the windings of the transformer. Like the copperloss in the distribution line, it is calculated using the $P=I^2R$relationship of 1.1. Any factor which affects either current or winding resistance will alsoaffect the amount of copper loss in the transformer.

An increase in loading, either real or reactive, will result in an increase incurrent flow and a correspondingly greater amount of loss in the transformer.Additionally, an unbalanced system load will increase transformer loss due to thesquared current relationship. The winding resistance also has an effect on theamount of copper loss and is mainly determined by the total length of the wireused, as well as the size of the wire. The temperature of the winding will affectthe resistivity of the wire, therefore affecting the overall resistance and thecopper loss. Since all but the smallest distribution transformers have some typeof cooling system, such as immersion in oil, the temperature effect on losses isusually minimal.

The core loss in a transformer is usually larger in magnitude than thecopper loss. It is made up of eddy current losses, which are due to magneticallyinduced currents in the core, and hysteresis losses, which occur because of theless than perfect permeability of the core material. These losses are relativelyconstant for an energized transformer and can be considered to be independentof the transformer load. Transformer core losses have been modeled in variousways, usually as a resistance in parallel with the transformer's magnetizingreactance.

Since the core loss is relatively independent of loading, the most importantfactor when considering core loss is the manufacture of the core. The physicalconstruction of the core has serious consequences on the amount of core lossoccurring in the transformer. For instance, eddy currents are greatly reduced byusing laminated pieces to construct the core. These thin sheets are oriented alongthe path of travel of the magnetic flux and restrict the amount of induced currentsthat occur.

The hysteresis loss occurs in the transformer core due to the energyrequired to provide the magnetic field in the core as the direction of magneticflux alternates with the alternating current wave form. This energy is transformedinto heat. Hysteresis loss can be reduced by the use of higher quality materials inthe core which have better magnetic permeability. Many advanced core materialshave been developed recently with claims of core loss reductions in the range of50 % and above.

A final aspect of the distribution system that increases losses in thetransformers is the presence of harmonics in the system. The harmonic currentsonly cause a small increase in copper losses throughout the system. However, thehigh frequency harmonic voltages can cause large core losses in the transformer.Frequently, utilities are forced to use an oversized transformer to compensatewhen a large harmonic presence is indicated. The increased skin effect of largerconductors combined with the high frequency harmonics can result in evengreater losses.

Losses due to nonoptimal modes of electrical networks, the errors of measurement equipment deficiencies in the power sales activities, are the direct loss of power supply organizations and, of course, must be reduced.

Therefore normative power losses of industrial enterprises can be divided into quasi-constant and loading.

Quasi-constant losses:

- on the crown;
- in steel of transformers;
- in compensating devices;
- in the accounting system;
- in the valve and surge arresters;
- in the cable insulation;
- from the leakage of overhead insulators;
- own demands of substations;
- melting ice.

Loading losses:

- in line;
- in transformers;
- in current-limiting reactors.

Excessive losses include:

- low level of reactive power compensation;
- nonoptimal operation of networks, due to overload and underload equipment;
- poor technical condition equipment;

- outdated equipment with high power consumption;
- inefficient networking.

1.3. Methods of reducing of power losses

According to international experts, the relative power losses during transmission and distribution in networks of most countries can be considered satisfactory if they do not exceed 4-5%. The loss of electricity at 10% can be considered as acceptable from the standpoint of physics transmission over networks. This is confirmed by the pre-crisis level of energy losses in most of the power of the former Soviet Union, which does not exceed usually 10%. Since today the rates are increased by 1.5-2, and the electric grid for individual companies - even three times, it is obvious that in the context of the economic mechanism of change in energy, economic crisis in the country the problem of reducing energy losses in electric networks not only lost its relevance, and vice versa - has popped into one of the tasks of ensuring the financial stability of organizations.

Technical:

- Optimization of the power networks load due to construction of transmission lines and substations;

- Replacement of overloaded and underloaded power networks equipment;

- Commissioning of electric energy saving equipment.

Organizational:

- Optimization of circuits and modes of supply;

- Reduction of electrical systems repairs;

- Commissioning of unused auto-regulation of load, equalization of asymmetric loads, phase, and so on.

Measures to improve the design of systems and technical accounting of energy:

- Conducting raids to identify unrecorded electricity;

- Improving the system for collecting indications of counters;

- To ensure normal working conditions of metering devices;

- The replacement, modernization, installation of the missing meters.

Compensating of reactive power:

In electrical circuits with a purely resistive load flowing current is not leading and lagging the voltage. Inductive load current lags the voltage, the capacitance leads voltage. At work electric motors, compressors, electromagnets, etc., that the most typical of most consumer load is inductive, and the total power consumption of reactive power is present. In this case, the power factor is reduced and its increasing need to connect a capacitive load, which compensates for the inductive component. The resulting load is closer to a purely active power factor and takes the maximum value. For reactive power compensation condenser units are used in the automatic mode, increasing the power factor and thereby reduce the overall losses of the consumer. In particular, with an increase in the power factor from 0.5 to 0.9 reactive power is reduced by 44%.

The need for energy conservation is becoming increasingly important. This is due to the increasing deficit and increasing energy costs, growth of production and urban infrastructure. The majority of consumers consume, along with active power and reactive power, which is spent on the creation of electromagnetic fields, and is useless. The presence of reactive power supply reduces the quality of electricity leads to an increase in charges for electricity, additional losses and overheating of wires, overloaded substations need to over-capacity power transformers and cable cross-sections, subsidence voltage sources.

The use of condensing units allows to reduce the amount of reactive power consumption and achieve economic benefits in terms of energy savings.

There are several ways to reduce reactive power, but the use for these purposes is condensing units is preferred. Condensing units have low loss, ease of setup and operation, they can be plugged into any power point. They can be used to compensate for almost any amount of reactive power. The payback period condensing units is less than years and in some cases no more than several months.

In the future we should expect a further increase of tariffs on the consumption of reactive power.

Implementation of condensing units will help to avoid subsidence voltage on power lines of remote users will reduce the amount of payment for electricity to ensure power supply cable with a smaller cross-section, increase the service life of electrical equipment due to its lower heat.

What consumers need power factor correction:

Reactive power compensation is particularly important for consumers who have a low coefficient of power. In particular, this applies to customers operated with a large number of induction motors (power factor ~ 0.7), especially in view of underloading (power factor ~ 0.5), lifting and transport mechanisms (power factor ~ 0.5).

In place of the connection distinguish following schemes of reactive power compensation:

total - on input the enterprise;

group - on the power line of the same type of consumers;

Individual - condenser unit is installed in close proximity to the consumer with a low cosine fi.

Individual compensation scheme is most preferred. It allows you to compensate the reactive power in the place of its occurrence, without causing overflow of reactive power in power lines and in the case of the immutability of the power factor the consumer to fully compensate the reactive power by using a constant capacitance of the capacitor unit.

However, an individual compensation scheme is not always applicable. As a rule at the enterprise operated a lot of electrical power with low and provide them with all the individual capacitor banks is not possible. Also, the persistent power factor in life are rare, most often the level of reactive power depends on the mode of operation of electrical and varies during the day.

Therefore, a mixed use scheme of compensation, when the reactive power of the largest consumers partially offset by individual capacitor bank fixed capacitors and variable balance of reactive power and reactive power is compensated by smaller customers with automated capacitor bank connected on input of the enterprise.

Types of condenser units:

As a switching element in the condenser units can be used contactors or thyristors. Contactor capacitor banks were the most widely used because of easier implementation and lower cost compared to the thyristor (static) condenser units. However, if the load is quick-changing character, for reactive power compensation applied thyristor capacitor banks, as they have the highest speed. And the fact that the thyristor switched capacitors in the capacitor units occurs at zero current, greatly extends the life of a capacitor bank, and the entire installation.

In addition, there are specific installation of reactive power compensation, not containing capacitors in which the phase shift between current and voltage compensated with current generators, built on the non-linear elements of either synchronous generators, but they have not achieved widespread use because of the complexity and the technical realization of their high cost .

Voltage capacitor banks are divided into low voltage (0.4 kV) and high (6.3, 10 kV or more).

The influence of higher harmonics on life of condensing units:

In today's networks due to the nonlinearity of the electrical load (for example, in pulsed operation of stabilizers and power converters) having the higher current harmonics, which in magnitude are often commensurate with the fundamental harmonic. Cosine capacitors for reactive power compensation systems in conjunction with the inductance of the load can form a tuned circuit, close to the resonance frequency to the frequency of one of the higher harmonics. This leads to a significant increase in power capacitors, and significantly shortens their life span. Overvoltages occurring at resonance on the elements of the capacitor bank and the load can lead to breakdown of insulation. To address these issues during site survey before the introduction of condensing units for reactive power compensation is necessary to analyze the spectrum of current consumption. To suppress the used filter-plugs, tuned to the frequency of the most significant harmonics.

In developing the balance of power in the electrical network must be compiled balance the active and reactive power of network to their consumption, including losses in the network was provided by the generation of the active and reactive power on the power system, the transfer of power from neighboring and other sources of reactive power. At the same time should be provided with a reserve in case of disaster or in a repair mode.

In assessing the consumption of reactive power used the power factor

cos φ = P / S,

where P, S - respectively the values of the active and apparent power.

The power factor isinsufficient characteristic of reactive power consumption, since the values of cos φ, close to 1, the power consumption of the reactive power is still quite high. For example, at high value of cos φ = 0,95 reactive power load consumption is 33% consumed by active power (Table 1). At cos φ = 0,7 the value of consumption reactive power is almost equal to the active power.

The most successful indicator of the amount of consumption of the reactive power, is the ratio of

tg φ = Q/P,

where Q, P - respectively the values of reactive power and active power.

The transfer of the reactive power to the consumer and its consumption in the network lead to additional losses in the active power power distribution networks. In Table.1,6 shows an example of calculating the consumer utility of active power transmission over the network constant active power (P = 100%) at different cos φ, and condition that the transfer of this amount of power loss in the active power of network when cos φ = 1 are equal to ΔP = 10%. Loss of AM in the electrical network:

$$\Delta P = \frac{P^2+Q^2}{U^2}R = \frac{P^2(1+tg^2\varphi)}{U^2}R = \frac{P^2R}{U^2}\cdot\frac{1}{cos^2\varphi} \quad (1.5)$$

where, where P, Q, U -, respectively, the active power, reactive power, and the supply voltage;

R - the equivalent resistance of the network;

tg φ - reactive power coefficient of the network;

cos φ - power factor in the network.

From the expression it follows that at constant parameters of the transmitted power (P), voltage (U) and the resistance of the network (R) value of the losses of network active power is inversely proportional to the square of the power factor of transmitted, or

$$\Delta P = f \cdot \frac{1}{cos^2\varphi} \tag{1.6}$$

Using this relationship, in table. 1.6 determined the values of the active losses in the network at different cos. and unchanged AM, transferred over the network. From the calculations in table. 1.6 shows that the loss of active power in the electrical network are growing rapidly with decreasing of cos φ. If cos φ = 0,5 they reach 40%, and at cos φ = 0,316 entire active power, transmitted over the network, is spent on losing it. The value of reactive power is almost 3 times higher than of active power.

In the electricity supply network RSK RAO "UES of Russia" in 2007 amounted to 742.5 billion kilowatt-hours Of this amount of electricity through the network 10 (6) -0.4 kV released 50% of electricity, or 370 billion kWh Electricity losses in networks of 10 (6) -0.4 kV RAC assessment in 2007 was 11.6%:

$$\Delta W_{fact}^{10(6)-0.4} = 370 \cdot 0.116 \approx 43 \cdot 10^9 kW \cdot h$$

We assume that due to the measures to optimize the balance of the reactive power of network cos φ is increased by 0.01. Then, the projected loss of power reduced to a value of:

$$\Delta W_{forecast}^{10(6)-0.4} = 43 \cdot 10^9 \frac{0.85^2}{0.86^2} \approx 42 \cdot 10^9 kW \cdot h$$

Consequently, we can tentatively assume that the increase in the overall power factor in electric networks 10 (6) -0.4 kV RAC 0.01 (1.2%) will save 1 billion kWh of electricity, at an average cost of a kWh at the wholesale electricity market in Russia in 2007 at a rate of 0.68 rubles. will make annual savings of 680 million rubles. or more than

28 million U.S. dollars per year. This does not exhaust the economic importance of improving the power factor.

Increasing the power factor of 0.01 in the networks of 10 (6) -0.4 kV SSC releases power generators to power about 150 thousand kW. If we consider that for the production of 1.1 billion kWh of electricity should be about 0.370 million tons of standard fuel, which must be obtained from the bowels of the earth, to spend a great work on the production and delivery to the plant, providing electricity generation, we can provide all the economic benefits in the economy from reduced consumption of reactive power .Increased consumption of reactive power from the network at low values of cos φ calls for increased cross-sections of wires and cables in power networks in order to reduce losses. If cos φ 0,7 overruns caused by non-ferrous metals (copper and aluminum) will be more than 50% .

Low cos φ leads to excessive load of reactive power transmission in step-down substations, so needs of increasing the power of transformers or their number. Increased network load reactive current causes a drop voltage, and sharp fluctuations in the value of the reactive power - fluctuations in voltage and, consequently, the deterioration of the quality of electricity allocated by consumers.

Table 1.1

Value of reactive power in dependence on cos φ

(in percentage of active power)

cosφ	1,0	0.99	0.97	0.95	0.94	0.92	0.9	0.87	0.85	0.8	0.7	0.5	0.316
tgφ	0	0.14	0.25	0.33	0.36	0.43	0.484	0.55	0.6	0.75	1.02	1.73	3.016
Q,%	0	14	25	33	36	43	48.4	55	60	75	102	173	301.6

Table 1.2

Value of active losses with different cos φ and constant active power, transferred in the network

cosφ	tgφ	Power		Active losses, $\Delta P\%=10\%:\cos^2\varphi$	Useful active power of user (P- ΔP) in % of P
		Reactive, Q=P tgφ	Total, S=P/cosφ		
1	0	0	100	10	90
0.9	0.484	48.4	111.1	12.3	87.7

0.8	0.75	75	125	15.6	84.4
0.7	1.02	102	142.9	20.4	79.6
0.5	1.73	173.2	200	40	60
0.316	3.016	301.6	316.5	-100	0

At present, the nature of public utilities load has changed dramatically as a result of the wide spread of new types of power consumers (microwave ovens, air conditioners, freezers, fluorescent lamps, washing machines and dishwashers, personal computers, etc.), consuming from the feed network, along with active power also a significant reactive power. As early as 1987 the Ministry of Energy and Electrification of the USSR [9] established the extent of compensation of reactive power in the amount of cos φ = 0,858 (tg φ = 0,6). At the same time on different expert estimates, the power factor in distribution networks has a value of about 0,8-0,85 (tg φ = 0,75-0,62).

In 2007 in Russia requirement for the minimum value of the coefficient of the reactive power for the consumer connection points to the power supply 10 (6) -0.4 kV was considerably stiffened and set cos φ = 0,944 (tg φ = 0,35) for network 0,4 kV and cos φ = 0,93 (tg φ = 0,4) for a network of 6-20 kV.

As is known, the use of compensation can significantly improve the technical and economic performance of power distribution networks with a voltage of 10 (6) -0.4 kV due to:

1) reducing the loss of active power;

2) increasing the capacity of step-down transformer 10 (6) / 0.4 kV;

To estimate the degree of reduction of losses of active power, assume that N transformer substations 10 (6) / 0.4 kV (TS) with the rated capacity of S_n (kW) powered by a radial scheme from the power supply unit (FS). The transformers are equally loaded with capacity S with the power factor cos φ. Cable (air) line at full compensation on the side of 0.4 kV the AM loss of Ts in the distribution network will be equal (neglecting losses of reactive power in transformers, 10 (6) / 0,4 kV):

$$\Delta P_l' = N \cdot (P^2 \cdot R_{0av} \cdot L_{mid} \cdot 10^{-3})/U_n^2, \text{ kW} \quad (1.7)$$

Losses of active power during the actual loading S (in the absence of compensation):

$$\Delta P_l = N \cdot (S^2 \cdot R_{0av} \cdot L_{mid} \cdot 10^{-3})/U_n^2, \text{ kW} \quad (1.8)$$

where Roav - the average value of specific resistance of supply lines from the FS to the TS, Ohm / km; Lav - the average length of supply lines from the FS to the TS, km; Un-rated voltage of the electrical network, kV.

The ratio values of these losses can be characterized by the appropriate factor:

$$K_c = \frac{\Delta P_l}{\Delta P_l'} = \frac{S^2}{P^2} = \frac{1}{cos^2 \varphi} \quad (1.9)$$

The lower the value of the previous power factor, the higher the efficiency of compensation.

Considering that the actual power factor in power distribution networks, 10(6) - 0.4 kV is about 0.8-0.85, it is easy to see that the loss of active power in the distribution network after installing condenser units can be reduced to 1,38-1,56 times, or 27-36%.

Table 1.3

Dependence of compensation on power factor in cable and overhead lines

cos φ	0.8	0.85	0.9	0.95	1.0
K_c	1.563	1.384	1.235	1.108	1.0

Losses in transformers AM are characterized by a complex dependence compared to the power lines:

$$\Delta P_{tr} = N \cdot (\Delta P_{nl} + \beta^2 \cdot \Delta P_{sc}) \quad (1.10)$$

whereP_{nl} is no-load losses, kW; ΔP_{sc} is short circuit losses, kW; $\beta = S/S_n$ is ratio of loading of transformer by total power.

With full compensation on 0.4 kV losses of active power will reduce and would be equal

$$\Delta P'_{tr} = N \cdot (\Delta P_{nl} + \alpha^2 \cdot \Delta P_{sc}), \quad (1.11)$$

where α= P/S_n is ratio of loading of transformer by active power.

The ratio values of these losses can be calculated from following formula:

$$K_c = \frac{N \cdot (\Delta P_{nl} + \beta^2 \cdot \Delta P_{sc})}{N \cdot (\Delta P_{nl} + \alpha^2 \cdot \Delta P_{sc})} = \frac{(1 + \beta^2 \cdot \Delta P_{sc}/\Delta P_{nl})}{1 + \alpha^2 \cdot \Delta P_{sc}/\Delta P_{nl}} \quad (1.12)$$

In the particular case with load of transformer on nominal capacity will have: β=1, $\alpha = P/S_n = \cos\varphi$. Then the last expression can be put in the form:

$$K_c = \frac{(1+K_r)}{(1+K_r \cdot cos^2\varphi)} \quad (1.13)$$

where $K_r = \frac{\Delta P_{sc}}{\Delta P_{nl}} = 6.0$ is the coefficient characterizing the ratio of losses of short circuit to the losses of no-load in transformers with capacity of 400-1000 kVA.

Analysis of the data presented in Table. 4, shows that due to no-load losses, which do not depend on the load, the degree of reduction of losses in transformers AM when installing BC will be somewhat less than in the cable or overhead lines. Thus, the loss of AM in the step-down transformer 10 (6) / 0.4 kV after installing BC can be reduced to 1,31-1,44 times, or 24-31%.

Table 1.4

Dependence of compensation on power factor in step-down transformers

cos φ	0.8	0.85	0.9	0.95	1.0
K_c	1.446	1.312	1.195	1.091	1.0

The calculations show that the main effect in reducing the technical losses of electricity can be produced by modernization, renovation, improving throughput and reliability of electrical networks, a balance of modes, ie, through the introduction of capital-intensive activities.

The priority actions to reduce technical losses in electricity distribution networks 0,4-35 kV are:

- the use of 10 kV as the primary voltage distribution network;
- increase in the proportion of networks with a voltage of 35 kV;
- reduction in range and construction of overhead lines (0.4 kV) in the three-phase over the entire length;
- the use of self-supporting insulated and protected wires for voltage 0.4-10 kV overhead line;

- using the maximum allowable cross section wires in the electrical voltage of 0.4-10 kV networks in order to adapt their carrying capacity to increase load during the entire period of service;
- development and introduction of new, more cost-effective, electrical equipment, such as distribution transformers with reduced active and reactive losses, idling, and embedded in the CTS and ITS capacitor banks;
- the use of low power transformers pillar (6-10/0, 4 kV) to reduce the length of the network voltage of 0.4 kV and the energy losses in them;
- greater use of the automatic voltage regulation under load, booster transformers, voltage regulation of the local to improve power quality and reduce its losses;
- complex automation and telemechanization electrical networks, the use of switching devices of new generation of remote fault location in networks to reduce the duration of nonoptimal repair and post-emergency modes, search, and emergency response;
- improving the reliability of measurements in networks using new information technologies, automation, processing telemetry data.

1.4. Task of the research:

- Calculation and selection of main power supply elements of industry;
- Analysis of main types, places and methods of reduction of power losses;
- Analysis of positive effect of implementation of power loss reduction methods.

2. CALCULATION OF ELECTRIC LOAD

The first stage of system design is the definition of electric power loads. Electrical equipment of the electrical power supply system is selected and checked by the value of electrical loads, the power and electricity loss are determined by the value of electrical loads too. The capital spending of the power supply system, operating costs, reliability of electrical equipment depends on a correct estimation of expected loads.

Calculation of electrical loads in the workshop and a group of workshops is being organized by the method of ordered diagrams.This method is currently the major in the development of technical and working projects of electricity supply.

2.1. Calculation of electric load plant № 1 without illumination

For determinationof the electrical loads you should make the consolidated statement of prescribed, estimated and total estimated capacity of the shop. All receivers are divided into groups according to the principle of technology (machines, fans, pumps, etc.). The value of use factors $k_{вик}$, cosφ for all types of electrical consumers (EC) is accepted from the tabl.A1.

According to the task all consumers are divided into groups and presented in tabl.2.1

Table2.1

Equipment characteristic	Name of equipment										
	Single-spindle machine	Lathe	Screw lathe	Screw lathe	Vertical drilling machine	Radial drilling machine	Thread rolling machine	Horizontal - milling machine	Compound-table milling machine	Welding transformer	Overhead crane
Rated capacity , P_r , kW	2.4	7	4.5	11.15	4.5	10	5.2	10	20	28	4.85
Duty rating , DR,%	-	-	-	-	-	-	-	-	-	25	40
Number of equipment, n, pcs.	6	8	12	9	10	10	12	8	8	12	4

Use factor k_{use}	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.5	0.1
$\cos\varphi$	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,65	0,5	0,5
$tg\varphi$	1,73	1,73	1,73	1,73	1,73	1,73	1,73	1,73	1,17	1,73	1,73

Use factor k_{use} characterizes the use of active power by receiver and is the ratio of the average active power consumed by the receiver for the most loaded shift $P_{зм}$ to the nominal load capacity ($P_н$, ($k_{use} = P_{çì} \; / P_{í}$).).

Total nominal capacity for group of electrical consumers is (for example on turning lathes of plant number 1), kW:

$$P_{\Sigma í} = \sum_{1}^{n} P_{í\,.i} \,, \qquad (2.1)$$

where $P_{í\,.i}$ is the power of i-th electrical consumer (turning lathe), kW;

n is the number of electrical consumers of one typical category.

For lathes, kW:

$$P_{\Sigma í\,.ò} = \sum_{1}^{n} P_{í\,.i} = P_{í\,.ñò} \cdot n = 2.4 \cdot 6 = 14.4$$

One typical category includes electrical consumers who have the same technological purpose, and the same value of use factor $k_{вик}$and tgφ.

For electrical consumers of one mode group wedetermine the average active power load for the most loaded shift, kW:

$$P_{sh} = k_{вик} \cdot P_{n} \,, \qquad (2.2)$$

where $P_н$ is the rated power of electrical consumers group, kW;

$k_{вик}$ is the use factor for the group of EC(electrical consumers).

For lathes, kW:

$P_{с.т} = k_{вик.т} \cdot P_{\Sigma н.т}$ =0,16·14.4=2.3;

for welding transformers, kW:

$P_{с.зв} = k_{вик.зв} \cdot P_{\Sigma н.зв} \cdot DR_{зв}$ =0,3·28·12·(25/100)^{0,5}=84.

Estimated active power of the plant number 1 we determine according to the formula:

$P_{p1} = \Sigma P_c$,

where ΣP_c is the sum of all secondary active powers of electrical consumers.

For electrical consumers of one mode group we determine the average reactive power load for the most loaded shift, kVAr:

$$Q_c = P_c \cdot tg\varphi , \qquad (2.3)$$

where P_c is the average active power load for the most loaded shift, kW;

$tg\varphi$ is the reactive power factor.

For lathes, kVAr:

$Q_{c.m} = P_{c.m} \cdot tg\varphi_m$=2.3·1,73=3,98

$Q_{p1} = \Sigma Q_c$

where ΣQ_c is the sum of all secondary reactive powers of electrical consumers.

We determine the group use factor for all electrical consumers of the workshop number 1:

$$\kappa_{вик.ц.1} = \frac{\sum P_c}{\sum P_{ном}} \qquad (2.4)$$

where ΣP_c is the sum of average active powers of load of workshop receivers for the most loaded shift, KW;

$\Sigma P_{ном}$ is the nominal amount of active powers of load receivers shop kW.

We determine the equivalent number of electrical consumers of the workshop number 1:

$$n_э = \frac{\left(\sum P_н\right)^2}{\sum P_н^2} , \qquad (2.5)$$

where$n_э$ is the efficient (compatible) number of electrical consumers - it is such a number of receivers in the same capacity on homogeneous mode, which causes the same computational load asreceivers data, which differ in rated power and operation.

$\sum P_н$ =2.4·6+7·8+4.5·12+11.15·9+4.5·10+10·10+5.2·12+10·8+

+20·8+28·12·(25/100)^{0,5}+4.85·4·(40/100)^{0,5}=821.4

$\sum P_н^2$ = (2.4·6)^2+(7·8)^2+(4.5·12)^2+(11.15·9)^2+(4.5·10)^2+(10·10)^2+

+(5.2·12)^2+(10·8)^2+(20·8)^2+(28·12·(25/100)^{0,5})^2+(4.85·4·(40/100)^{0,5})^2=92622.78

$n_э$ =(821.4)^2/92622.78=2.08

Estimated load of the workshop number 1is presented in the table. 2.2.

Table 2.2

Equipment characteristic	Name of equipment										
	Single-spindle machine	Lathe	Screw lathe	Screw lathe	Vertical drilling machine	Radial drilling machine	Thread rolling machine	Horizontal - milling machine	Compound-table milling machine	Welding transformer	Overhead crane
Total capacity of the group, $P_{\Sigma í}$, kW	14.4	56	54	100. 4	45	100	62.4	80	160	336	19.4
Average active power of the group, $P_{\tilde{n}}$, kW	2.3	8.9	8.6	16.1	7.2	16	9.9	12.8	27.2	84	1.22
Average reactive powerof the group, $Q_{\tilde{n}}$,kVAr	3,98	15,4	14,9	27,9	12,4 6	27,6 8	17,1 3	22,1 4	31,8 2	145, 32	2,11
Calculated active power of the workshop №1, P_{p1},kW	194,22										
Calculated reactive power of the workshop №1, Q_{p1}, kVAr	320,77										
Use factor for all electrical consumers	0.19										
Equivalent number of workshop electrical consumers	2.08										

2.2. Calculation of electrical loads for workshops' group

Calculated electrical loads for the workshops №2 - № 8 are given in thetask.

We calculate squares of workshops $F_i$andenterprises (which are needed for the calculation of illumination) according to the sizes of site plan in the task and they are presentedin tabl.2.3.

Table2.3

Name	Length, m,	Width, m	Square, m^2
Workshop №1	240	120	28800
Workshop №2	300	90	27000
Workshop №3	240 60	135 75	36900
Workshop №4	240 240 90	90 45 75	39150
Workshop №5	150 90	150 75	29250
Workshop №6	270	90	24300
Workshop №7	75 90	225 75	23625
Workshop №8	315	225	70875
Workshop №9	225	60	13500
Workshop №10	165	165	27225
Territory of the enterprise	1875	975	1828125

High pressure lamps of DRL type are installed for illumination in all workshops and at the territory of enterprise. Illumination demand factor $K_{n.o}$ is taken in the range from 0.8 to 1. Lighting power consumption $P_{num.o}$ is taken in the range from 9 to 14 W/m^2, for the outdoor illumination $P_{num.з.o}$ 0.2 W/m^2. We accept:

illumination demand factor $K_{n.o}$ = 0,9

powerconsumptionfor the indoor illumination $P_{num.o}$ = 10 W/m^2;

powerconsumptionfor the outdoor illumination $P_{num.з.o}$ = 0,2 W/m^2.

For the workshops №1:

The calculation of illuminating power is satisfied by the formula, kW:

$$P_{р.о1} = K_{п.о1} \cdot P_{пит.о1} \cdot F_1 \cdot 10^{-3} = 0,9 \cdot 10 \cdot 28800 \cdot 10^{-3} = 259.2, \quad (2.6)$$

where $K_{n.o1}$ is theillumination demand factor, [1];

$P_{num.o1}$ is the powerconsumption of illumination, W/m^2, [1];

F_1 is the workshop'ssquare, m^2.

Reactive illumination power, kVAr:

$$Q_{p.o.1} = P_{p.o.1} \cdot tg\,\varphi_0 = 259.2 \cdot 0,48 = 124.4, \quad (2.7)$$

where $tg\,\varphi_0 = 0,48$ for the DRL type [1].

Total square of the territorytaking into account squares of workshops from the table. 1.3:

$F_{під}$ =1828125m^2.

Square of group of workshops:

$\Sigma F_{ö}$ = 28800+27000+36900+39150+29250+24300+23625+70875+ +13500+27225=320825m^2,

$$F_т = F_{під} - \Sigma F_ц = 1828125 - 320825 = 1507500 m^2. \quad (2.8)$$

The calculation of power of outdoor illuminating is satisfied by the formula, kW:

$$P_{p.o.n} = K_{n.o.n} \cdot P_{num.o} \cdot F_m \cdot 10^{-3} = 0,9 \cdot 0,2 \cdot 1507500 \cdot 10^{-3} = 271.35,$$

where $\hat{E}_{ï.î.ï}$ is the illumination demand factor, [1];

$P_{num.o}$ is the powerconsumption of illumination, W/m^2, [1];

F_m is the square of the outdoor illumination territory, m^2.

The illumination demand factor is taken in the range from 0.8 to 1. The powerconsumption of illumination is accepted for outdoor illumination 0.2 W/m^2.

Reactive illumination power for the territory of outdoor illumination of the enterprise, kVAr, is:

$$Q_{р.о.п} = P_{р.о.п} \cdot tg\,\varphi_0 = 271.35 \cdot 0,48 = 130.25$$

The results of calculations of electric loads of other shops including illumination power are given in the table. 2.4.

Table 2.4

Characteristics of workshop's load	Name of workshops									
	№1	№2	№3	№4	№5	№6	№7	№8	№9	№10
Calculated active power, P_p,kW	194,22	261	1863	2432	938	313	2345	3127	1214	1715
Calculated reactive power, Q_p, kVAr	320,77	216,27	1445,85	1697,55	703,5	226,61	2005,35	2591,12	878,92	1686,38
Square, m^2, (table 1.3)	28800	27000	36900	39150	29250	24300	23625	70875	13500	27225
Calculated illumination active power, P_{poi}, kW	259,2	243	332,1	352,35	263,25	218,7	212,625	637,875	121,5	245,025
Calculated illumination reactive power, Q_{poi}, kVAr	124,42	116,64	159,41	169,13	126,36	104,98	102,06	306,18	58,32	117,61
Calculated total illumination power, S_{poi}, kVAr	287,51	269,54	368,38	390,84	292,01	242,59	235,85	707,55	134,77	271,79
Active load of the workshop with illumination, $P_{pззо}$, kW	453,42	504	2195,1	2784,35	1201,25	531,7	2557,63	3764,88	1335,5	1960,03
Reactive load of the workshop withillumination, $Q_{pззо}$, kVAr	445,19	332,91	1605,26	1866,68	829,86	331,59	2107,42	2897,3	937,24	1803,99
Total load of the workshop withillumination, $S_{pçoi}$, kVAr	635,44	604,03	2719,43	3352,18	1460,02	626,62	3314,01	4750,65	1631,56	2663,85
$tg\varphi_i = \frac{Q_{pзoi}}{P_{pзoi}}$	0,98	0,66	0,73	0,67	0,69	0,62	0,82	0,77	0,7	0,92

2.3. Selection of compensating devices

Calculated load on the buses of low voltage transformers for transformer substations TS-1 of workshop№1 is (from table. 1.4):

$P_{рзз}$ = 453,42kW; $Q_{рзз}$ =445,19kVAr.

Required power of compensating devices from the low voltage transformer TS-1:

$$Q_{кп} = P_{рзо}(tg\varphi_1 - tg\varphi_н) = 453,42(0.98\text{-}0,33)=18 \text{ kVAr} \quad (2.9)$$

where $tg\varphi_í$ = meets the standard value $cos\,\varphi_í$, equal to 0,95.

We choose compensating devices from the table A2, and present the results of calculation in the table 2.5.

Table2.5

Number of workshop	Reactive load of the workshop with illumination, $Q_{рзо}$, kVAr	Required power of compensating devices, $Q_{кп}$, kVAr	Type of compensating device	Nominal rating power of compensating device, $Q_í$, kVAr	Nominal voltage, Unom, V	Number of compensating devices, $n_{кп}$, pieces	Total power of compensating devices, $Q_{кпц}$
1	445,19	294,72	УКМ 58-0,4-100	100	400	2	200
2	332,91	166,32	УКМ 58-0,4-100	100	400	2	200
3	1605,26	878,04	УКМ 58-0,4-400	402	400	2	804
4	1866,68	946,68	УКМ 58-0,4-100	100	400	10	1000
5	829,86	432,45	УКМ 58-0,4-200	200	400	2	400
6	331,59	154,19	УКМ 58-0,4-200	100	400	2	200
7	2107,42	1253,24	УКМ 58-0,4-200	200	400	6	1200
8	2897,3	1656,55	УКМ 58-0,4-402	402	400	4	1608
9	937,24	494,14	УКМ 58-0,4-268	268	400	2	536
10	1803,99	1156,41	УКМ 58-0,4-200	200	400	6	1200

Total power of compensating devices for the workshop number 1, kVAr:

$$Q_{кпц} = n_{кп} \cdot Q_н = 1\cdot100=200, \quad (2.10)$$

where $n_{êï}$ is the number of compensating devices, kVAr.;

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$Q_{í}$ is the nominalrated power of compensating devices, kVAr.

Then decompensated reactive power on the side of low voltage transformers TP-1 will be:

$Q_{рк} = Q_{рзз} - Q_{кпц}$ = 445.19-200=245.19kVAr.(2.11)

Full calculated power taking into account a compensation is determined by:

$$S_{рк} = \sqrt{P_{рзз}^2 + Q_{рк}^2} = (453{,}42^2+245.19^2)^{0{,}5} = 515.47 \text{ kVA}. \quad (2.12)$$

Using the formula find the effect of the compensation as a percentage of saved power.

$$\Delta S_{cds} = \frac{S_{il} - S_{pk}}{S_{il}} \cdot 100\% = \frac{635.44 - 515.47}{635.44} \cdot 100\% = 18.88\%$$

Results are in table 2.6

Table 2.6

Number of workshop	Total power before compensation, S_{il}	Total power after compensation, S_{pk}	Effect of compensation, ΔS_{cds}
1	635,44	515,47	18,88
2	604,03	521,23	13,71
3	2719,43	2336,77	14,07
4	3352,18	2916,12	13,01
5	1460,02	1275,85	12,61
6	626,62	547,74	12,59
7	3314,01	2713,83	18,11
8	4750,65	3979,52	16,23
9	1631,56	1394,47	14,53
10	2663,85	2050,98	23,01
Σ	21757,79	18251,98	16,11

Rated power of transformer at the substation according to [1] is determined, MVA:

$$S_{нтр} = (0{,}65...0{,}7)S_{рк} = 0{,}7 \cdot 515{,}47 = 360{,}83. \quad (2.13)$$

Calculatedpower of transformers, obtained by the formula 1.13, is rounded to the nearest standard power $S_{нтр}$ on the scale of GOST 11920-85, GOST 12965-85, kVA:

25, 40, 63 100, 160, 250, 400; 630, 1000, 1600.

We select two transformers for TS-1 of workshop №1 the power of which is $S_{нтр}$ =400kVA.

In normal mode transformers will work with loadfactor:

$$K_{зн} = \frac{S_{рк}}{2 \cdot S_{нт}} = 515.47/(2 \cdot 400) = 0,64 < 0,7. \quad (2.14)$$

Transformers utilizationin post-emergency conditions (in case of failure of one of the working transformers):

$$K_{зав} = \frac{S_{рк}}{S_{нт}} = 515.47/250 = 1,29 < 1,4 \quad (2.15)$$

Preview selection of transformers' number and power ofothers workshopTS aresimilar and presented in the table form 2.6.

Table 2.6

Substation number	Consumers of electricity	Calculated load			Number of transformers	Required power of transformers, kVA	Nominal rating power oftransformers, $S_{нтр}$, kVA	Transformers utilization in nominal conditions, $K_{зн}$	Transformers utilization in post-emergency conditions, $K_{зав}$
		$P_{рзо}$, kW	$Q_{рк}$, kVAr	$S_{рк}$, kVA					
TS-1	Workshop№1	453,42	245,19	515,47	2	360,829	400	0,64	1,29
TS-2	Workshop№2	504	132,91	521,23	2	364,861	400	0,65	1,3
TS-3	Workshop№3	2195,1	801,26	2336,77	3	1635,739	1600	0,49	0,73
TS-4	Workshop№4	2784,35	866,68	2916,12	3	2041,284	1600	0,61	0,91
TS-5	Workshop№5	1201,25	429,86	1275,85	2	893,095	1000	0,64	1,28
TS-6	Workshop№6	531,7	131,59	547,74	2	383,418	400	0,68	1,37
TS-7	Workshop№7	2557,625	907,41	2713,83	3	1899,681	1600	0,57	0,85
TS-8	Workshop№8	3764,875	1289,3	3979,52	4	2785,664	1600	0,62	0,83

TS-9	Workshop№9	1335,5	401,24	1394,47	2	976,129	1000	0,7	0,7
TS-10	Workshop№10	1960,025	603,99	2050,98	2	1435,686	1600	0,64	0,64

We perform the calculation of power losses in transformers of TS-1 of workshop №1, and transferred power taking into account these losses.

We selecttransformers from the table A3, passport data present in the table. 1.7.

We accept:

for high-voltage side $U_{âí}$ = 10 kV;

for low-voltage side $U_{íí}$ = 0,4 kV.

Table2.7

Type	Nominal power, kV ·A	Nominal voltage of windings, kV		Losses, кВт		Short-circuit voltage $U_к$, %	No-load current I_x in %
		HV	LV	No-load ΔP_x	short circuit $\Delta P_к$		
TM-400	400	10	0,4	0.95	5,5	4,5	2,1
TM-400	400	10	0,4	0.95	5,5	4,5	2,1
TC3-1600	1600	10	0,4	2.9	14	6	1
TC3-1600	1600	10	0,4	2.9	14	6	1
TM-1000	1000	10	0,4	2.1	10	6	1
TM-400	400	10	0,4	0.95	5,5	4,5	2,1
TC3-1600	1600	10	0,4	2.9	14	6	1
TC3-1600	1600	10	0,4	2.9	14	6	1
TM-1000	1000	10	0,4	2.1	10	6	1
TC3-1600	1600	10	0,4	2.9	14	6	1

Active power losses, kW:

$$\Delta P_{тр1} = (\Delta P_{к1} \cdot K_{з1}^2 + \Delta P_{х1}) \cdot n_1 = (5{,}5 \cdot 0.64^2 + 0.95) \cdot 2 = 6.41 \qquad (2.16)$$

where $ï$ is the number of transformers in TS (transformer substation);

$\Delta Đ_ê$ and ΔP_x are power losses in transformers in the short-circuit conditions and non-working stroke, respectively;

$K_з$ is the transformer load factor in normal conditions.

Reactive power losses, kVAr:

$$\Delta Q_{тр1} = (\frac{I_{x1}}{100} \cdot S_{нт1} + K_{з1}^2 \cdot \frac{U_{к1}}{100} \cdot S_{нт1}) \cdot n_1 =$$

$$=(2.1/100 \cdot 400+0.64^2 \cdot 4,5/100 \cdot 400) \cdot 2=31.55 \quad (2.17)$$

Imparted active powertaking into account losses in transformers, kW:

$$P_{ц1} = P_{рк1} + \Delta P_{тр1} =453.42+6.41=459,83 \quad (2.18)$$

Imparted reactive power taking into account losses in transformers, kVAr:

$$Q_{ц1} = Q_{рк1} + \Delta Q_{тр1} =245,19+31.55=276,74 \quad (2.19)$$

Imparted total power taking into account losses in transformers, kVA:

$$S_{ц1} = S_{рк1} + \Delta S_{тр1} = \sqrt{P_{ц1}^2 + Q_{ц1}^2} =(335.94^2+49.3^2)^{0,5}=339.5 \quad (2.20)$$

Calculation of powers taking into account losses in transformers of others workshop's TS is the same and presented in the table 1.8.

Table 2.8

Number of substation	Active power losses, $\Delta P_{тр}$, kW	Reactive power losses, $\Delta Q_{тр}$, kVAr	Imparted active power, $P_ц$, kW	Imparted reactive power, $Q_ц$, kVAr	Imparted total power, $S_ц$, kVA
TS-1	6,41	31,55	459,83	276,74	536,677
TS-2	6,55	32,01	510,55	164,92	536,5234
TS-3	18,78	117,15	2213,88	918,41	2396,822
TS-4	24,33	155,16	2808,68	1021,84	2988,786
TS-5	12,39	69,15	1213,64	499,01	1312,227
TS-6	6,99	33,45	538,69	165,04	563,4004
TS-7	22,35	141,57	2579,97	1048,98	2785,069
TS-8	33,13	211,61	3798,00	1500,91	4083,815
TS-9	14	78,8	1349,50	480,04	1432,337
TS-10	17,27	110,64	1977,29	714,63	2102,473
Total:			17450,03	6790,52	18724,709

*Annotation.

$$S_з = \Sigma S_{цi} = \sqrt{\Sigma P_{цi}^2 + \Sigma Q_{цi}^2} = (17450{,}03^2 + 6790{,}52^2)^{0{,}5} = 18724{,}709 \text{ kVA}. \quad (2.21)$$

For further calculations day load diagram should be formed. For the typical ferrous industry day loads are divided into three types, depended on the power of workshops. For the powers that are given in the initial data day load graphs would be following.

1) Below 1500 KVA (workshops 1,2,5,6,9)

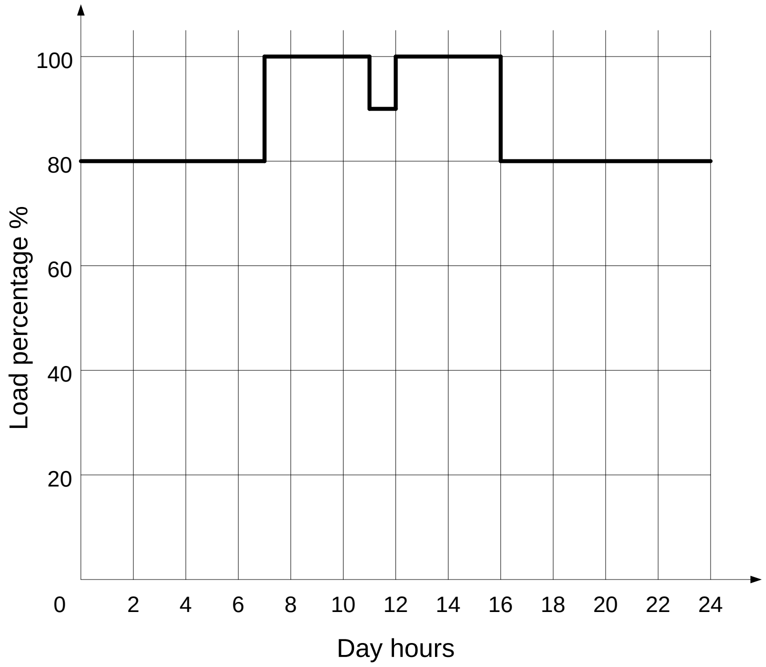

Fig 2.1 Day load graph for workshops with power less than 1500 KVA

with following step diagram

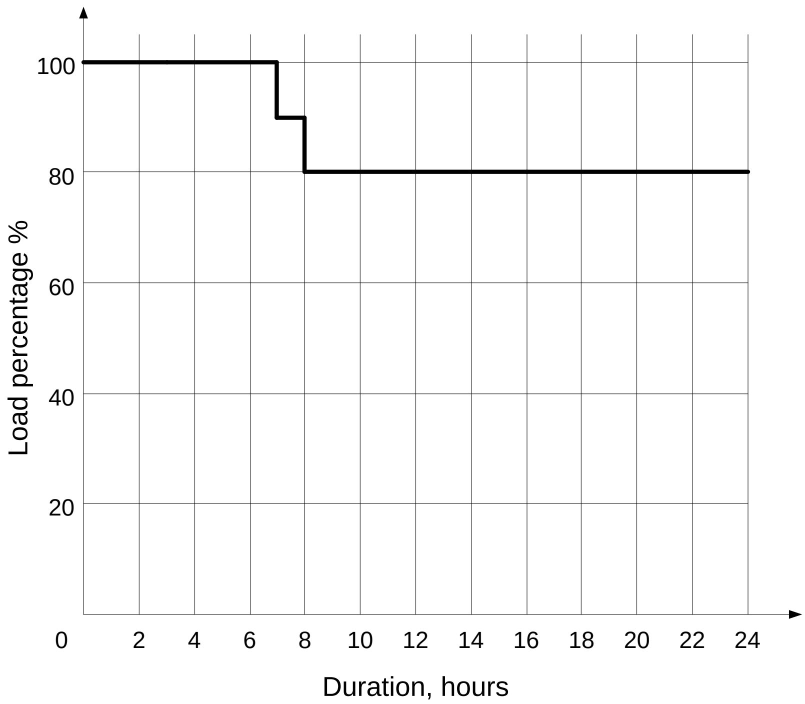

Fig2.2Step load graph for workshops with power less than 1500 KVA

2) Below 2500 KVA (workshops 3,10)

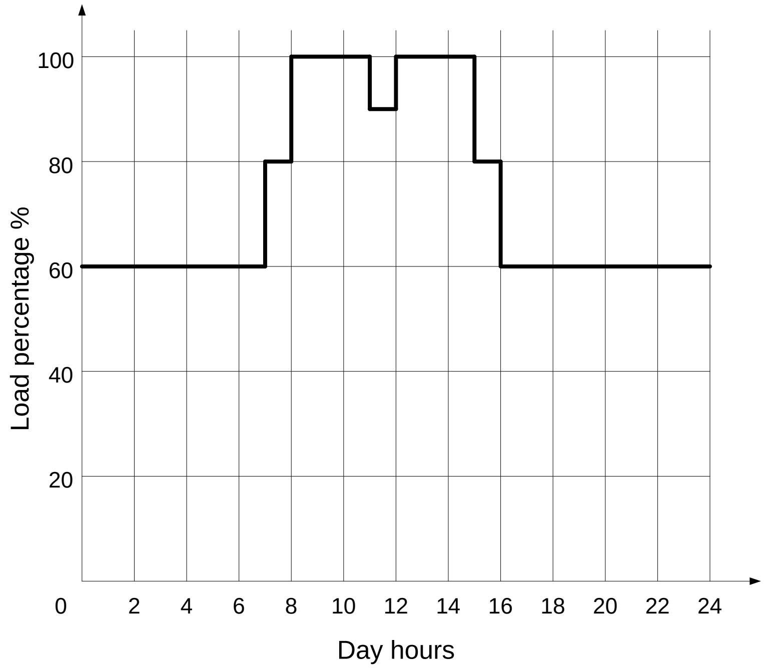

Fig 2.3 Day load graph for workshops with power less than 2500 KVA

with following step diagram

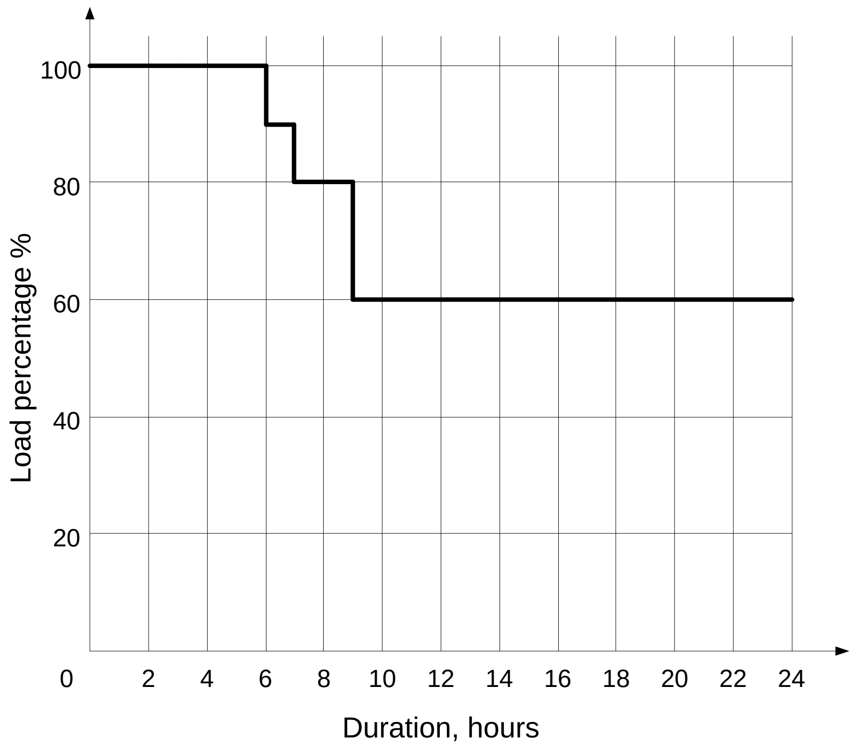

Fig 2.4Step load graph for workshops with power less than 2500 KVA

3) More than 2500 KVA (workshops 4,7,8)

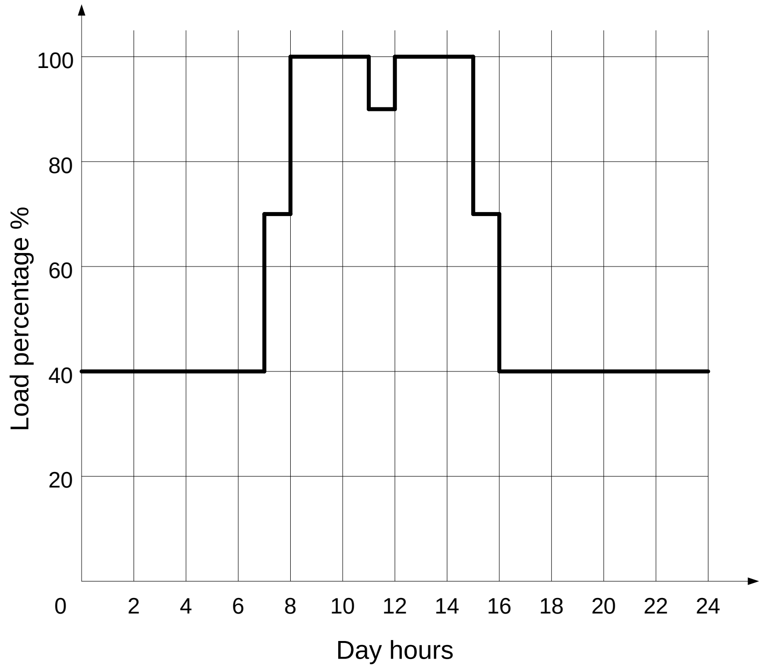

Fig 2.5 Day load graph for workshops with power more than 2500 KVA

with following step diagram

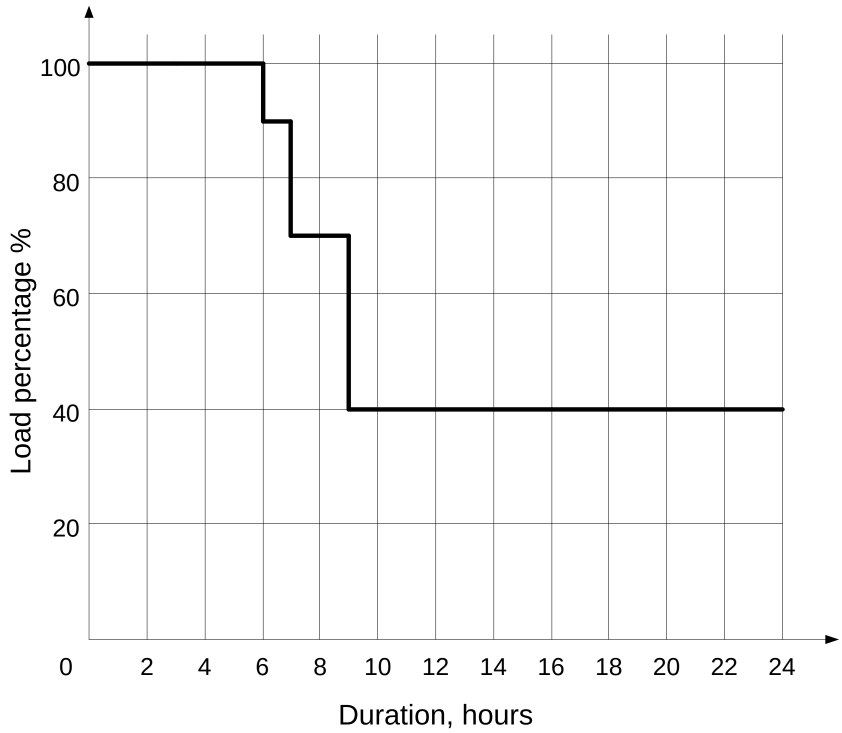

Fig 2.6Step load graph for workshops with power more than 2500 KVA

Using this diagrams, tables of the workshops` loads could be calculated

Table 2.9

Day load of workshop 1:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$,MW·hours	$P_{is} \cdot t_i$,MW·hours
0-1	80	362,74	253,92	412,38	288,66	362,74	253,92
1-2	80	362,74	253,92	412,38	288,66	362,74	253,92
2-3	80	362,74	253,92	412,38	288,66	362,74	253,92
3-4	80	362,74	253,92	412,38	288,66	362,74	253,92
4-5	80	362,74	253,92	412,38	288,66	362,74	253,92
5-6	80	362,74	253,92	412,38	288,66	362,74	253,92
6-7	80	362,74	253,92	412,38	288,66	362,74	253,92
7-8	100	453,42	317,39	515,47	360,83	453,42	317,39
8-9	100	453,42	317,39	515,47	360,83	453,42	317,39
9-10	100	453,42	317,39	515,47	360,83	453,42	317,39
10-11	100	453,42	317,39	515,47	360,83	453,42	317,39
11-12	90	408,08	285,65	463,92	324,75	408,08	285,65
12-13	100	453,42	317,39	515,47	360,83	453,42	317,39
13-14	100	453,42	317,39	515,47	360,83	453,42	317,39
14-15	100	453,42	317,39	515,47	360,83	453,42	317,39
15-16	100	453,42	317,39	515,47	360,83	453,42	317,39
16-17	80	362,74	253,92	412,38	288,66	362,74	253,92
17-18	80	362,74	253,92	412,38	288,66	362,74	253,92
18-19	80	362,74	253,92	412,38	288,66	362,74	253,92
19-20	80	362,74	253,92	412,38	288,66	362,74	253,92
20-21	80	362,74	253,92	412,38	288,66	362,74	253,92
21-22	80	362,74	253,92	412,38	288,66	362,74	253,92
22-23	80	362,74	253,92	412,38	288,66	362,74	253,92
23-24	80	362,74	253,92	412,38	288,66	362,74	253,92
Σ	–	–	–	–	–	9476,48	6633,53

Table 2.10

Day load of workshop 2:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, P_{iw}, KW	Power on the i-stage of the summer daily-load diagram, P_{is}, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$, MW·hours	$P_{is} \cdot t_i$, MW·hours
0-1	80	403,20	282,24	416,98	291,89	403,20	282,24
1-2	80	403,20	282,24	416,98	291,89	403,20	282,24
2-3	80	403,20	282,24	416,98	291,89	403,20	282,24
3-4	80	403,20	282,24	416,98	291,89	403,20	282,24
4-5	80	403,20	282,24	416,98	291,89	403,20	282,24
5-6	80	403,20	282,24	416,98	291,89	403,20	282,24
6-7	80	403,20	282,24	416,98	291,89	403,20	282,24
7-8	100	504,00	352,80	521,23	364,86	504,00	352,80
8-9	100	504,00	352,80	521,23	364,86	504,00	352,80
9-10	100	504,00	352,80	521,23	364,86	504,00	352,80
10-11	100	504,00	352,80	521,23	364,86	504,00	352,80
11-12	90	453,60	317,52	469,11	328,37	453,60	317,52
12-13	100	504,00	352,80	521,23	364,86	504,00	352,80
13-14	100	504,00	352,80	521,23	364,86	504,00	352,80
14-15	100	504,00	352,80	521,23	364,86	504,00	352,80
15-16	100	504,00	352,80	521,23	364,86	504,00	352,80
16-17	80	403,20	282,24	416,98	291,89	403,20	282,24
17-18	80	403,20	282,24	416,98	291,89	403,20	282,24
18-19	80	403,20	282,24	416,98	291,89	403,20	282,24
19-20	80	403,20	282,24	416,98	291,89	403,20	282,24
20-21	80	403,20	282,24	416,98	291,89	403,20	282,24
21-22	80	403,20	282,24	416,98	291,89	403,20	282,24
22-23	80	403,20	282,24	416,98	291,89	403,20	282,24
23-24	80	403,20	282,24	416,98	291,89	403,20	282,24
Σ	–	–	–	–	–	10533,60	7373,52

Table 2.11

Day load of workshop 3:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$, MW·hours	$P_{is} \cdot t_i$, MW·hours
0-1	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
1-2	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
2-3	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
3-4	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
4-5	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
5-6	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
6-7	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
7-8	80	1756,08	1229,26	1869,42	1308,59	1756,08	1229,26
8-9	100	2195,10	1536,57	2336,77	1635,74	2195,10	1536,57
9-10	100	2195,10	1536,57	2336,77	1635,74	2195,10	1536,57
10-11	100	2195,10	1536,57	2336,77	1635,74	2195,10	1536,57
11-12	90	1975,59	1382,91	2103,09	1472,17	1975,59	1382,91
12-13	100	2195,10	1536,57	2336,77	1635,74	2195,10	1536,57
13-14	100	2195,10	1536,57	2336,77	1635,74	2195,10	1536,57
14-15	100	2195,10	1536,57	2336,77	1635,74	2195,10	1536,57
15-16	80	1756,08	1229,26	1869,42	1308,59	1756,08	1229,26
16-17	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
17-18	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
18-19	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
19-20	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
20-21	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
21-22	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
22-23	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
23-24	60	1317,06	921,94	1402,06	981,44	1317,06	921,94
Σ	–	–	–	–	–	38414,25	26889,98

Table 2.12

Day load of workshop 4:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$, MW·hours	$P_{is} \cdot t_i$, MW·hours
0-1	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
1-2	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
2-3	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
3-4	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
4-5	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
5-6	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
6-7	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
7-8	70	1949,05	1364,33	2041,28	1428,90	1949,05	1364,33
8-9	100	2784,35	1949,05	2916,12	2041,28	2784,35	1949,05
9-10	100	2784,35	1949,05	2916,12	2041,28	2784,35	1949,05
10-11	100	2784,35	1949,05	2916,12	2041,28	2784,35	1949,05
11-12	90	2505,92	1754,14	2624,51	1837,16	2505,92	1754,14
12-13	100	2784,35	1949,05	2916,12	2041,28	2784,35	1949,05
13-14	100	2784,35	1949,05	2916,12	2041,28	2784,35	1949,05
14-15	100	2784,35	1949,05	2916,12	2041,28	2784,35	1949,05
15-16	70	1949,05	1364,33	2041,28	1428,90	1949,05	1364,33
16-17	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
17-18	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
18-19	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
19-20	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
20-21	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
21-22	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
22-23	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
23-24	40	1113,74	779,62	1166,45	816,51	1113,74	779,62
Σ	–	–	–	–	–	39816,21	27871,34

Table 2.13

Day load of workshop 5:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$,MW·hours	$P_{is} \cdot t_i$,MW·hours
0-1	80	961,00	672,70	1020,68	714,48	961,00	672,70
1-2	80	961,00	672,70	1020,68	714,48	961,00	672,70
2-3	80	961,00	672,70	1020,68	714,48	961,00	672,70
3-4	80	961,00	672,70	1020,68	714,48	961,00	672,70
4-5	80	961,00	672,70	1020,68	714,48	961,00	672,70
5-6	80	961,00	672,70	1020,68	714,48	961,00	672,70
6-7	80	961,00	672,70	1020,68	714,48	961,00	672,70
7-8	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
8-9	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
9-10	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
10-11	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
11-12	90	1081,13	756,79	1148,27	803,79	1081,13	756,79
12-13	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
13-14	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
14-15	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
15-16	100	1201,25	840,88	1275,85	893,10	1201,25	840,88
16-17	80	961,00	672,70	1020,68	714,48	961,00	672,70
17-18	80	961,00	672,70	1020,68	714,48	961,00	672,70
18-19	80	961,00	672,70	1020,68	714,48	961,00	672,70
19-20	80	961,00	672,70	1020,68	714,48	961,00	672,70
20-21	80	961,00	672,70	1020,68	714,48	961,00	672,70
21-22	80	961,00	672,70	1020,68	714,48	961,00	672,70
22-23	80	961,00	672,70	1020,68	714,48	961,00	672,70
23-24	80	961,00	672,70	1020,68	714,48	961,00	672,70
Σ	–	–	–	–	–	25106,13	17574,29

Table 2.14

Day load of workshop 6:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$, MW·hours	$P_{is} \cdot t_i$, MW·hours
0-1	80	425,36	297,75	438,19	306,73	425,36	297,75
1-2	80	425,36	297,75	438,19	306,73	425,36	297,75
2-3	80	425,36	297,75	438,19	306,73	425,36	297,75
3-4	80	425,36	297,75	438,19	306,73	425,36	297,75
4-5	80	425,36	297,75	438,19	306,73	425,36	297,75
5-6	80	425,36	297,75	438,19	306,73	425,36	297,75
6-7	80	425,36	297,75	438,19	306,73	425,36	297,75
7-8	100	531,70	372,19	547,74	383,42	531,70	372,19
8-9	100	531,70	372,19	547,74	383,42	531,70	372,19
9-10	100	531,70	372,19	547,74	383,42	531,70	372,19
10-11	100	531,70	372,19	547,74	383,42	531,70	372,19
11-12	90	478,53	334,97	492,97	345,08	478,53	334,97
12-13	100	531,70	372,19	547,74	383,42	531,70	372,19
13-14	100	531,70	372,19	547,74	383,42	531,70	372,19
14-15	100	531,70	372,19	547,74	383,42	531,70	372,19
15-16	100	531,70	372,19	547,74	383,42	531,70	372,19
16-17	80	425,36	297,75	438,19	306,73	425,36	297,75
17-18	80	425,36	297,75	438,19	306,73	425,36	297,75
18-19	80	425,36	297,75	438,19	306,73	425,36	297,75
19-20	80	425,36	297,75	438,19	306,73	425,36	297,75
20-21	80	425,36	297,75	438,19	306,73	425,36	297,75
21-22	80	425,36	297,75	438,19	306,73	425,36	297,75
22-23	80	425,36	297,75	438,19	306,73	425,36	297,75
23-24	80	425,36	297,75	438,19	306,73	425,36	297,75
Σ	–	–	–	–	–	11112,53	7778,77

Table 2.15

Day load of workshop 7:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$, MW·hours	$P_{is} \cdot t_i$, MW·hours
0-1	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
1-2	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
2-3	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
3-4	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
4-5	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
5-6	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
6-7	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
7-8	70	1790,34	1253,24	1899,68	1329,78	1790,34	1253,24
8-9	100	2557,63	1790,34	2713,83	1899,68	2557,63	1790,34
9-10	100	2557,63	1790,34	2713,83	1899,68	2557,63	1790,34
10-11	100	2557,63	1790,34	2713,83	1899,68	2557,63	1790,34
11-12	90	2301,87	1611,31	2442,45	1709,71	2301,87	1611,31
12-13	100	2557,63	1790,34	2713,83	1899,68	2557,63	1790,34
13-14	100	2557,63	1790,34	2713,83	1899,68	2557,63	1790,34
14-15	100	2557,63	1790,34	2713,83	1899,68	2557,63	1790,34
15-16	70	1790,34	1253,24	1899,68	1329,78	1790,34	1253,24
16-17	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
17-18	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
18-19	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
19-20	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
20-21	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
21-22	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
22-23	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
23-24	40	1023,05	716,14	1085,53	759,87	1023,05	716,14
Σ	–	–	–	–	–	36574,11	25601,88

Table 2.16

Day load of workshop 8:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$, MW·hours	$P_{is} \cdot t_i$, MW·hours
0-1	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
1-2	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
2-3	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
3-4	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
4-5	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
5-6	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
6-7	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
7-8	70	2635,40	1844,78	2785,66	1949,96	2635,40	1844,78
8-9	100	3764,86	2635,40	3979,52	2785,66	3764,86	2635,40
9-10	100	3764,86	2635,40	3979,52	2785,66	3764,86	2635,40
10-11	100	3764,86	2635,40	3979,52	2785,66	3764,86	2635,40
11-12	90	3388,37	2371,86	3581,57	2507,10	3388,37	2371,86
12-13	100	3764,86	2635,40	3979,52	2785,66	3764,86	2635,40
13-14	100	3764,86	2635,40	3979,52	2785,66	3764,86	2635,40
14-15	100	3764,86	2635,40	3979,52	2785,66	3764,86	2635,40
15-16	70	2635,40	1844,78	2785,66	1949,96	2635,40	1844,78
16-17	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
17-18	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
18-19	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
19-20	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
20-21	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
21-22	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
22-23	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
23-24	40	1505,94	1054,16	1591,81	1114,27	1505,94	1054,16
Σ	–	–	–	–	–	53837,50	37686,25

Table 2.17

Day load of workshop 9:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$,MW·hours	$P_{is} \cdot t_i$,MW·hours
0-1	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
1-2	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
2-3	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
3-4	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
4-5	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
5-6	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
6-7	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
7-8	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
8-9	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
9-10	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
10-11	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
11-12	90	1201,95	841,37	1255,02	878,52	1201,95	841,37
12-13	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
13-14	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
14-15	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
15-16	100	1335,50	934,85	1394,47	976,13	1335,50	934,85
16-17	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
17-18	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
18-19	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
19-20	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
20-21	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
21-22	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
22-23	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
23-24	80	1068,40	747,88	1115,58	780,90	1068,40	747,88
Σ	–	–	–	–	–	27911,95	19538,37

Table 2.18

Day load of workshop 10:

Time interval, t,hours	Ordinate of daily diagram's respective stage, %	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$, MW·hours	$P_{is} \cdot t_i$, MW·hours
0-1	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
1-2	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
2-3	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
3-4	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
4-5	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
5-6	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
6-7	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
7-8	80	1568,02	1097,62	1640,78	1148,55	1568,02	1097,62
8-9	100	1960,03	1372,02	2050,98	1435,69	1960,03	1372,02
9-10	100	1960,03	1372,02	2050,98	1435,69	1960,03	1372,02
10-11	100	1960,03	1372,02	2050,98	1435,69	1960,03	1372,02
11-12	90	1764,03	1234,82	1845,88	1292,12	1764,03	1234,82
12-13	100	1960,03	1372,02	2050,98	1435,69	1960,03	1372,02
13-14	100	1960,03	1372,02	2050,98	1435,69	1960,03	1372,02
14-15	100	1960,03	1372,02	2050,98	1435,69	1960,03	1372,02
15-16	80	1568,02	1097,62	1640,78	1148,55	1568,02	1097,62
16-17	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
17-18	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
18-19	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
19-20	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
20-21	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
21-22	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
22-23	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
23-24	60	1176,02	823,21	1230,59	861,41	1176,02	823,21
Σ	–	–	–	–	–	34300,53	24010,37

So, the day load of enterprise would be calculated due to following formulas:

$$P_{he} = \sum_{i=1}^{10} P_{hi};\ S_{he} = \sum_{i=1}^{10} S_{hi} \qquad (2.22)$$

Table 2.19

Day load of enterprise:

Time interval, t,hours	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$,MW·hours	$P_{is} \cdot t_i$,MW·hours
0-1	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
1-2	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
2-3	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
3-4	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
4-5	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
5-6	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
6-7	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
7-8	13724,76	9607,33	14491,59	10144,11	13724,76	9607,33
8-9	17287,84	12101,49	18251,98	12776,39	17287,84	12101,49
9-10	17287,84	12101,49	18251,98	12776,39	17287,84	12101,49
10-11	17287,84	12101,49	18251,98	12776,39	17287,84	12101,49
11-12	15559,06	10891,34	16426,78	11498,75	15559,06	10891,34
12-13	17287,84	12101,49	18251,98	12776,39	17287,84	12101,49
13-14	17287,84	12101,49	18251,98	12776,39	17287,84	12101,49
14-15	17287,84	12101,49	18251,98	12776,39	17287,84	12101,49
15-16	13724,76	9607,33	14491,59	10144,11	13724,76	9607,33
16-17	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
17-18	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
18-19	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
19-20	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
20-21	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
21-22	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
22-23	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
23-24	9356,51	6549,56	9880,25	6916,17	9356,51	6549,56
Σ	–	–	–	–	287083,27	200958,29

Percentage of the load could be found by formula:

$$S_{hi\%} = \frac{S_{hi}}{S_{hmax}} \cdot 100\% \qquad (2.23)$$

Table 2.20

Time interval, t,hours	Ordinate of daily diagram's respective stage, %
0-1	54,13
1-2	54,13
2-3	54,13
3-4	54,13
4-5	54,13
5-6	54,13
6-7	54,13
7-8	79
8-9	100
9-10	100
10-11	100
11-12	90
12-13	100
13-14	100
14-15	100
15-16	79,4
16-17	54,13
17-18	54,13
18-19	54,13
19-20	54,13
20-21	54,13
21-22	54,13
22-23	54,13
23-24	54,13

So, day load graph would be:

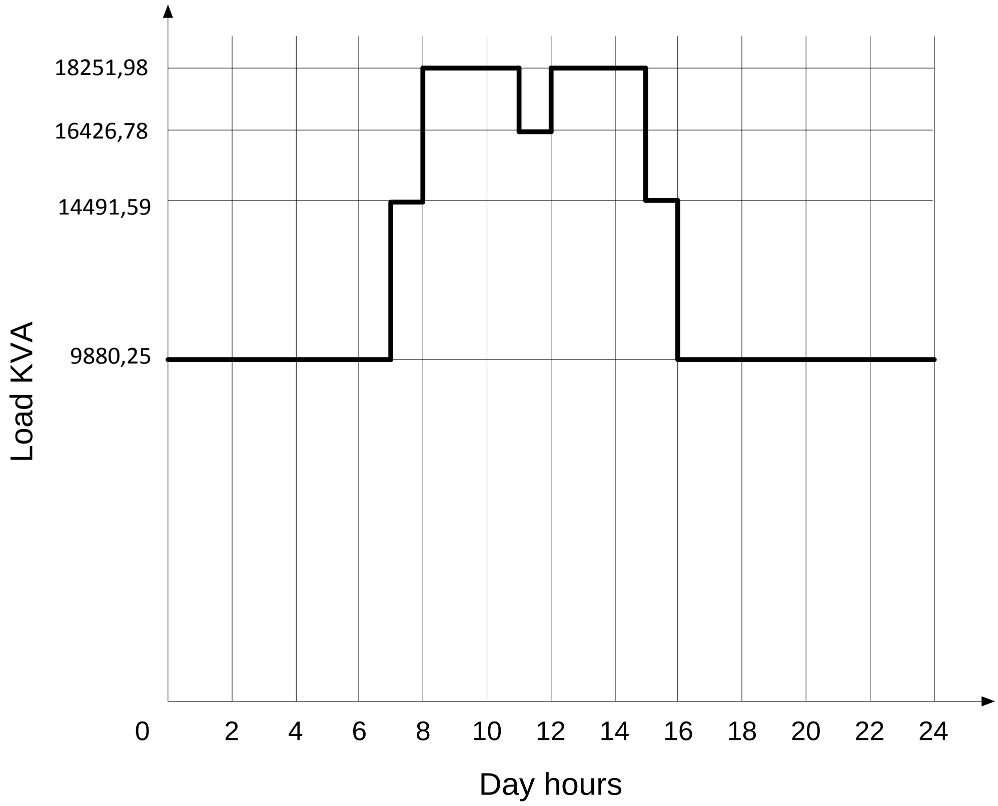

Fig 1.7Day load graph of industry

And step diagram

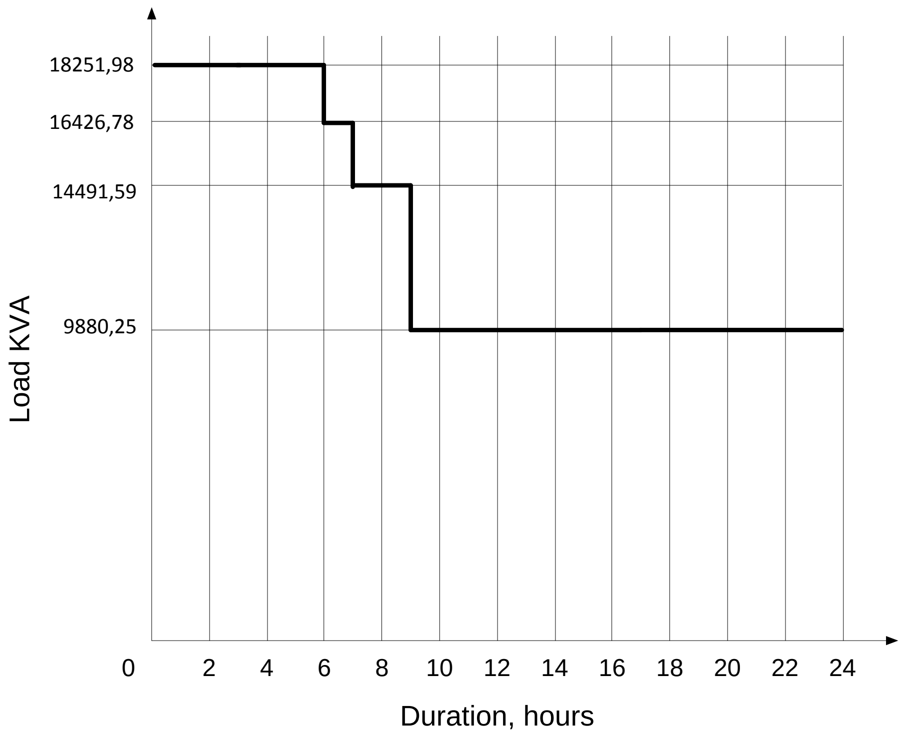

Fig 1.8Step load graph of industry

3. REDUCING OF POWER LOSS BY SMOOTHING OF DAY LOADS GRAPH

3.1 Smoothing of load by moving of shifts

One of the most important method of the reducing of power loss in industry is rational re-distribution of loads, making day graph load smoother. For the smoothing of the graph operating shift of the most loaded should be moved in the least loaded areas of time. Thus, the one-shift industry becomes three-shifted. In this case, loads ofworkshops 8 and 4 will move to shift 2 and 3 respectively. After that, assume graph of smoothed load.

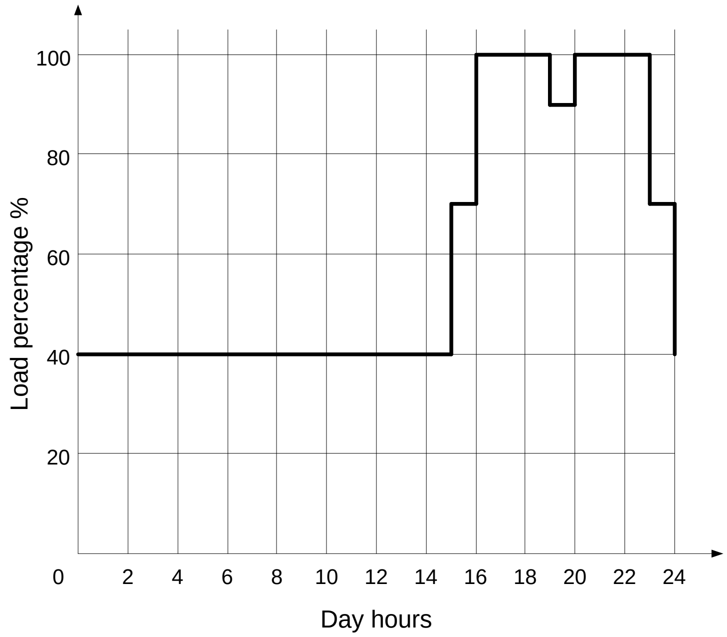

Fig 3.1Day load graph of shift 2

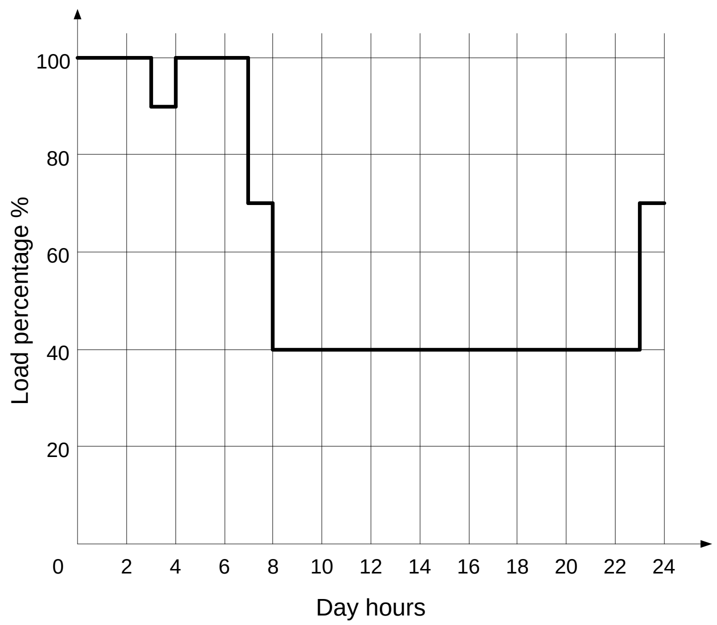

Fig 3.2Day load graph of shift 3

According to that moving of the workshop`s operating time, the day load will be equal:

Table 3.1

Time interval, t,hours	Power on the i-stage of the winter daily-load diagram, Piw, KW	Power on the i-stage of the summer daily-load diagram, Pis, KW	Total winter power of the load, S_{iw},KVA	Total summer power of the load, S_{is}, KVA	$P_{iw} \cdot t_i$,MW·hours	$P_{is} \cdot t_i$,MW·hours
0-1	11027,12	7718,98	11629,92	8140,94	11027,12	7718,98
1-2	11027,12	7718,98	11629,92	8140,94	11027,12	7718,98
2-3	11027,12	7718,98	11629,92	8140,94	11027,12	7718,98
3-4	10748,69	7524,08	11338,31	7936,81	10748,69	7524,08
4-5	11027,12	7718,98	11629,92	8140,94	11027,12	7718,98
5-6	11027,12	7718,98	11629,92	8140,94	11027,12	7718,98
6-7	11027,12	7718,98	11629,92	8140,94	11027,12	7718,98
7-8	12595,30	8816,71	13297,73	9308,41	12595,30	8816,71
8-9	13358,31	9350,82	14114,60	9880,22	13358,31	9350,82
9-10	13358,31	9350,82	14114,60	9880,22	13358,31	9350,82
10-11	13358,31	9350,82	14114,60	9880,22	13358,31	9350,82
11-12	12284,45	8599,12	12978,96	9085,27	12284,45	8599,12
12-13	13358,31	9350,82	14114,60	9880,22	13358,31	9350,82
13-14	13358,31	9350,82	14114,60	9880,22	13358,31	9350,82
14-15	13358,31	9350,82	14114,60	9880,22	13358,31	9350,82
15-16	12889,46	9022,62	13616,75	9531,73	12889,46	9022,62
16-17	11615,43	8130,80	12267,96	8587,57	11615,43	8130,80
17-18	11615,43	8130,80	12267,96	8587,57	11615,43	8130,80
18-19	11615,43	8130,80	12267,96	8587,57	11615,43	8130,80
19-20	11238,94	7867,26	11870,01	8309,00	11238,94	7867,26
20-21	11615,43	8130,80	12267,96	8587,57	11615,43	8130,80
21-22	11615,43	8130,80	12267,96	8587,57	11615,43	8130,80
22-23	11615,43	8130,80	12267,96	8587,57	11615,43	8130,80
23-24	11321,27	7924,89	11948,94	8364,26	11321,27	7924,89
Σ	–	–	–	–	287083,27	200958,29

Percentage of the load to the original load (in the same time interval) could be found by formula:

$$S_{smhi\%} = \frac{S_{smhi}}{S_{hmax}} \cdot 100\%$$

Table 3.2

Time interval, t,hours	Ordinate of daily diagram's respective stage, %
0-1	63,72
1-2	63,72
2-3	63,72
3-4	62,12
4-5	63,72
5-6	63,72
6-7	63,72
7-8	73
8-9	77
9-10	77
10-11	77
11-12	71
12-13	77
13-14	77
14-15	77
15-16	74,6
16-17	67,21
17-18	67,21
18-19	67,21
19-20	65,03
20-21	67,21
21-22	67,21
22-23	67,21
23-24	65,47

So, the graph after smoothing will be:

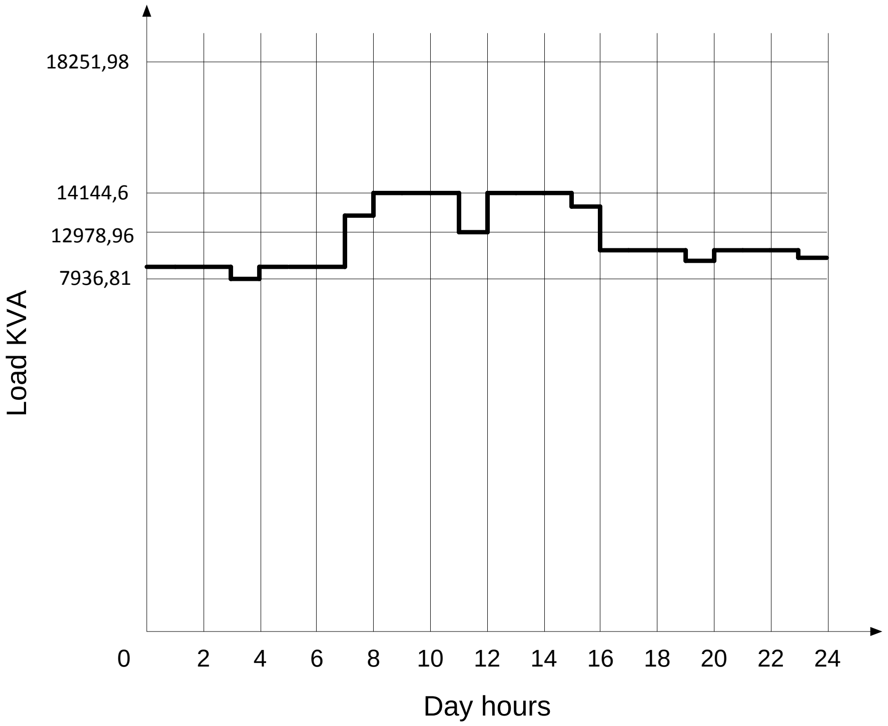

Fig 3.3Smoothed day load graph of industry

With following step graph:

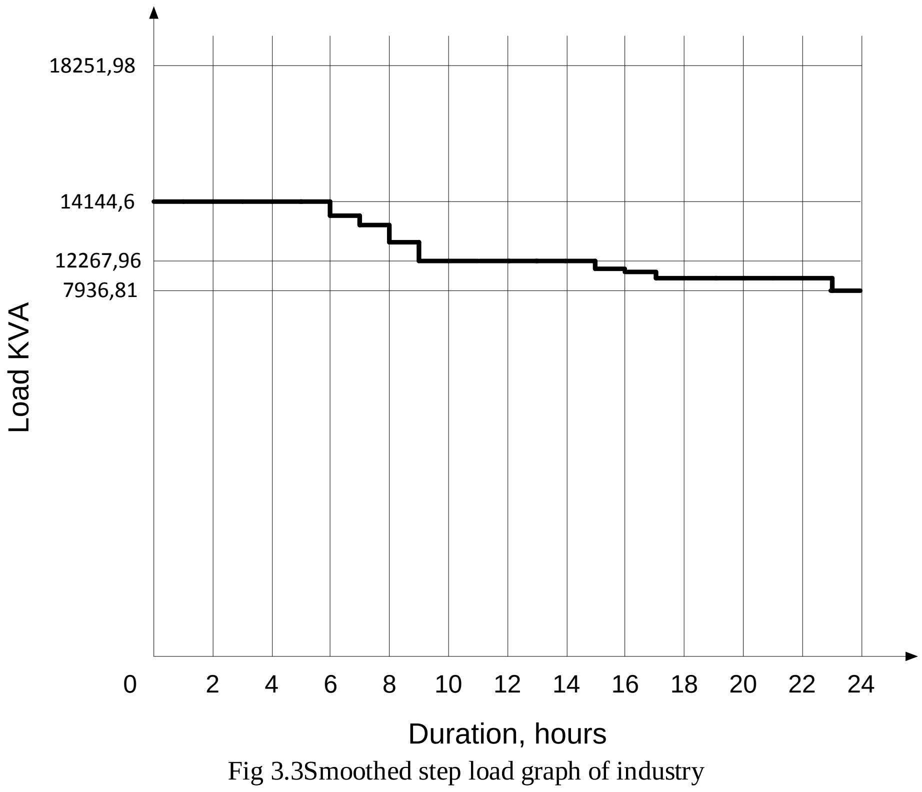

Fig 3.3Smoothed step load graph of industry

Both of the modes give some advantages in reducing of power loss. In the first mode two transformers of higher capacity should be selected. In the time of absence of operating load (17-7 hours with load of 54%) one of the transformers could be switched off. The second mode provide uniform load leading to reliable operation mode of transformers. The best mode will be selected after calculations of power losses and analyzing.

3.2. Calculation of power loss for original operation mode

Consumed daily active and reactive power would be found:

$$W_d = \sum_{i=1}^{n}(P_i \cdot t_i) = 287083.27 \text{ kW·h} \quad (3.1)$$

Where P_i – active power of i-step, t_i – duration of i-step.

$$V_d = \sum_{i=1}^{n}(Q_i \cdot t_i) = 99361.84 \text{kVAr·h} \quad (3.2)$$

Where Q_i – reactive power of i-step, t_i – duration of i-step.

The average total capacity of the enterprise per day:

$$S_{av} = \frac{S_d}{24} = \frac{\sqrt{{W_d}^2 + {V_d}^2}}{24} = \frac{\sqrt{287083.27^2 + 99361.84^2}}{24} = 12658 \text{ KVA} \quad (3.3)$$

Determine the number of hours of peak load:

Number of hours of maximum load (T_{max}) - is a time during which the electric network operating at maximum capacity, would be transferred the same amount of electricity that is passed through it during the year for the actual loading schedule:

Reconstruct the daily schedule of active power enterprise in the annual duration.

$$T_{max} = \frac{W_{an}}{P_{max}} = \frac{W_d \cdot 365}{P_{max}} = \frac{287083.27 \cdot 365}{17287.84} = 6061 \; hours \quad (3.4)$$

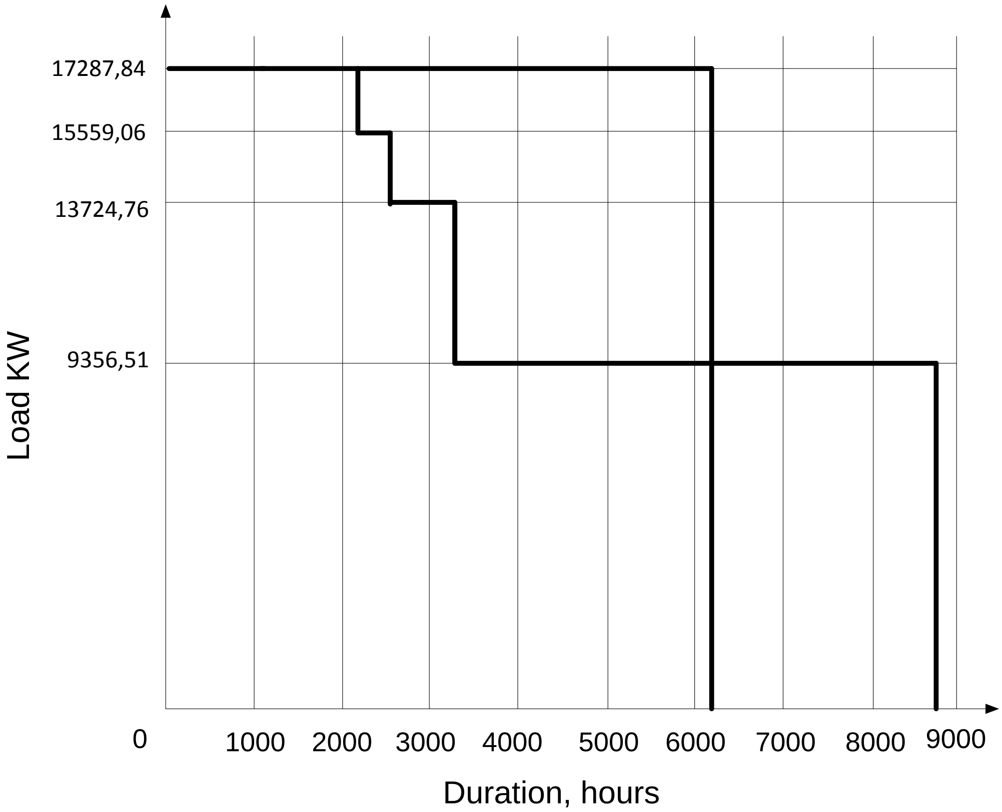

Fig 3.4Annual Tmaxof industry

Selection of transformer rated capacity by load graph.

The set of allowable loads, systematic and accidental overloading of transformers determines the load carrying capacity, which was based on the thermal deterioration of transformer insulation. The choice of the transformer without load-carrying capacity can lead to unnecessary overestimation of their installed capacity, which is economically impractical.

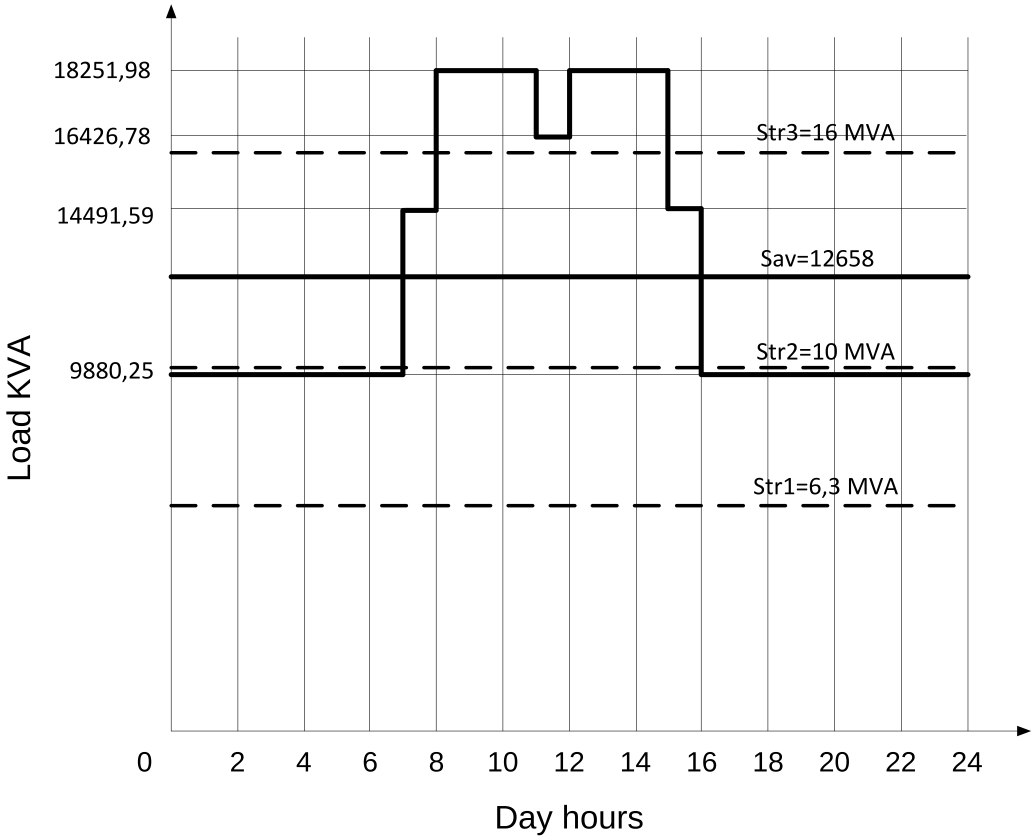

Fig 3.5Preliminary transformers` capacities for original operating mode

Allocated part of the peak - the highest part of an overload to the duration of H'(the intersection of the graph the total power and direct Sav);

Duration of the highest overload H'= 9hours

Determine primary load of graph K_1

$$K_1 = \frac{1}{S_{av}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta t_1 + S_2^2 \cdot \Delta t_2 + \cdots + S_n^2 \cdot \Delta t_n}{\Delta t_1 + \Delta t_2 + \cdots + \Delta t_n}} \qquad (3.5)$$

$$K_1 = \frac{1}{12658} \cdot \sqrt{\frac{9880^2 \cdot 15}{15}} = 0.78$$

Determine primary overload $K`_2$

$$K`_2 = \frac{1}{S_{av}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta H_1 + S_2^2 \cdot \Delta H_2 + \cdots + S_n^2 \cdot \Delta H_n}{\Delta H_1 + \Delta H_2 + \cdots + \Delta H_n}} \qquad (3.6)$$

$$K`_2 = \frac{1}{12658} \cdot \sqrt{\frac{14491.59^2 \cdot 2 + 18251.98^2 \cdot 6 + 16426.78^2 \cdot 1}{2 + 6 + 1}} = 1.37$$

The resulting value K`$_2$ is bigger than

$$0.9K_{max} = 0.9 \cdot \frac{S_{max}}{S_{av}} = 0.9 \cdot \frac{18251.98}{12658} = 1.3$$

therefore accept: K_2=1.37

and the duration of the overload H adjust the formula:

$$H = \frac{(0.9K_{max})^2 \cdot H`}{(K`_2)^2} = \frac{1.3^2 \cdot 9}{1.37^2} = 8.12 \approx 8\ hours \qquad (3.7)$$

According to the obtained values of K_1 and H define the permissible overload factor of systematic K_{2aux}.

In 20^O C K_{2aux}will be 1.3

$$S_{ntr} = \frac{S`_{eq\,2}}{N \cdot K_{2aux}} \qquad (3.8)$$

$$S_{ntr} = \frac{\sqrt{\frac{14491.59^2 \cdot 2 + 18251.98^2 \cdot 6 + 16426.78^2 \cdot 1}{2+6+1}}}{2 \cdot 1.3} = 6647$$

Based on the received power planning two versions of the nearest transformer rated power:

S_{ntr1}=6300 KVA

S_{ntr2}=10000 KVA

Perform the calculation of the coefficients K1 and K2 for each of the variants of the nominal power transformers

Firstly, for S_{ntr1}=6300 KVA

The duration of the largest overload is H '= 24 hours

Determine initial load of graph

$$K_1 = \frac{1}{S_{av}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta t_1 + S_2^2 \cdot \Delta t_2 + \cdots + S_n^2 \cdot \Delta t_n}{\Delta t_1 + \Delta t_2 + \cdots + \Delta t_n}}$$

$$K_1 = 0$$

Pre-define overload$K`_2$

$$K`_2 = \frac{1}{S_{ntr\,1}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta H_1 + S_2^2 \cdot \Delta H_2 + \cdots + S_n^2 \cdot \Delta H_n}{\Delta H_1 + \Delta H_2 + \cdots + \Delta H_n}}$$

$$K`_2 = \frac{1}{6300} \cdot \sqrt{\frac{14491.59^2 \cdot 2 + 18251.98^2 \cdot 6 + 16426.78^2 \cdot 1 + 9880.25^2 \cdot 15}{2 + 6 + 1 + 15}} = 2.09$$

The resulting value is less than

$$0.9K_{max} = 0.9 \cdot \frac{S_{max}}{S_{av}} = 0.9 \cdot \frac{18251.98}{6300} = 2.6$$

therefore accept: K_2=2.6

By this value selected transformer couldn`t operate on this overload time

S_{ntr2}=10000 KVA

The duration of the largest overload is H '= 9 hours

Determine initial load of graph

$$K_1 = \frac{1}{S_{ntr\,2}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta t_1 + S_2^2 \cdot \Delta t_2 + \cdots + S_n^2 \cdot \Delta t_n}{\Delta t_1 + \Delta t_2 + \cdots + \Delta t_n}}$$

$$K_1 = \frac{1}{10000} \cdot \sqrt{\frac{9880^2 \cdot 15}{15}} = 0.99$$

Pre-define overload$K`_2$

$$K`_2 = \frac{1}{S_{ntr\,2}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta H_1 + S_2^2 \cdot \Delta H_2 + \cdots + S_n^2 \cdot \Delta H_n}{\Delta H_1 + \Delta H_2 + \cdots + \Delta H_n}}$$

$$K`_2 = \frac{1}{10000} \cdot \sqrt{\frac{14491.59^2 \cdot 2 + 18251.98^2 \cdot 6 + 16426.78^2 \cdot 1}{2 + 6 + 1}} = 1.73$$

The resulting value $K`_2$ is bigger than

$$0.9K_{max} = 0.9 \cdot \frac{S_{max}}{S_{ntr\,2}} = 0.9 \cdot \frac{18251.98}{10000} = 1.64$$

So accept K_2=$K`_2$ and the duration of overload H=H`=9 hours

Comparing K_2 and K_{2aux} that could be found using K_1 and temperature of 20^O C $K_{2aux}<K_2$ so transformer couldn`t carry such overload.

So, picked variant is transformer with bigger capacity of 16000 KVA.

The duration of the largest overload is H '= 7 hours

Determine initial load of graph

$$K_1 = \frac{1}{S_{ntr\,2}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta t_1 + S_2^2 \cdot \Delta t_2 + \cdots + S_n^2 \cdot \Delta t_n}{\Delta t_1 + \Delta t_2 + \cdots + \Delta t_n}}$$

$$K_1 = \frac{1}{16000} \cdot \sqrt{\frac{9880^2 \cdot 15 + 14491.59 \cdot 2}{15 + 2}} = 0.65$$

Pre-define overload $K`_2$

$$K`_2 = \frac{1}{S_{ntr\,3}} \cdot \sqrt{\frac{S_1^2 \cdot \Delta H_1 + S_2^2 \cdot \Delta H_2 + \cdots + S_n^2 \cdot \Delta H_n}{\Delta H_1 + \Delta H_2 + \cdots + \Delta H_n}}$$

$$K`_2 = \frac{1}{16000} \cdot \sqrt{\frac{18251.98^2 \cdot 6 + 16426.78^2 \cdot 1}{6 + 1}} = 1.42$$

The resulting value $K`_2$ is bigger than

$$0.9K_{max} = 0.9 \cdot \frac{S_{max}}{S_{ntr\,2}} = 0.9 \cdot \frac{18251.98}{16000} = 1.02$$

So accept K_2=$K`_2$ and the duration of overload H=H`=7 hours

Comparing K_2 and K_{2aux} that could be found using K_1 and temperature of 20^O C $K_{2aux}>K_2$ so transformer could carry such overload.

Checking on overload conditions:

$$\beta = \frac{S_{max}}{2 \cdot S_{ntr}} = \frac{18251.98}{2 \cdot 16000} = 0.57$$

With acceptable overload of 40%, in postemergency conditions transformer could feed consumers of II and III category.

Economical mode of transformer

During operation and design should provide for economically viable operation of transformers, which is determined by their parameters and the load substation. Substation load varies during the day, and daily schedules - during the year. Significant reduction of the load fall to spring and summer.

During such periods, transformers are underloaded for a long time. It causes them a relative increase in energy losses. By reducing the work load it is advisable to leave only part of the transformers. In this case the load substation is not enough to take on the transformers, it is necessary to cover the most economical way, providing a minimum active power loss in the network.

Total losses of the transformer can be shown by using the formula:

$$\Delta P`_{tr} = \Delta P`_{nl} + k_l^2 \cdot \Delta P`_{sc} \tag{3.9}$$

Where

$\Delta P`_{nl} = \Delta P_{nl} + k_{ec} \cdot \Delta Q_{nl}$ - modified no-load losses of the transformer

$\Delta P`_{sc} = \Delta P_{sc} + k_{ec} \cdot \Delta Q_{sc}$ – modified short circuit losses of the transformer

k_{ec} - Economic equivalent of reactive power, account active power loss relating to production and distribution of reactive power;

$k_{ec} = \frac{S_{hi}}{S_{ntr}}$ – Coefficient of transformer loading

Main parameters for transformer

Table 3.3

Transformer	Rated capacity, MVA	Average nominal voltage, kV	ΔU$_K$, %	ΔP$_K$, kW	ΔPx kW	Ix, %
ТМН-16000/110	16	115/11	10,5	21	18	0.7

Modified losses:

$$\Delta Q_{nl} = \frac{I_{nl\%} \cdot S_{ntr}}{100} = \frac{0.7 \cdot 16000}{100} = 144\ kVAr$$

$$\Delta P`_{nl} = \Delta P_{nl} + k_{ec} \cdot \Delta Q_{nl} = 18 + 0.1 \cdot 144 = 32.4\ kW$$

Where $k_{ec} = 0.1$ for 110 kV

$$\Delta Q_{sc} = \frac{U_{sc\%} \cdot S_{ntr}}{100} = \frac{10.5 \cdot 16000}{100} = 1680\ kVAr$$

$$\Delta P`_{sc} = \Delta P_{sc} + k_{ec} \cdot \Delta Q_{sc} = 33.2 + 0.1 \cdot 1680 = 201.2$$

Modified losses for one transformer:

$$\Delta P`_{tr} = \Delta P`_{nl} + \Delta P`_{sc} \cdot \left(\frac{S_{hi}}{S_{ntr}}\right)^2 = 32.4 + 201.2 \cdot (\frac{S}{16000})^2 \quad (3.10)$$

Modified losses for two transformers:

$$\Delta P`_{tr} = 2 \cdot \Delta P`_{nl1,2} + (\Delta P`_{sc1} + \Delta P`_{sc2}) \cdot \left(\frac{S_{hi}}{2 \cdot S_{ntr}}\right)^2 = 64.8 + 402.4 \cdot (\frac{S}{32000})^2 \quad (3.11)$$

Determine the load at which it is expedient to proceed to work with two transformers:

$$S = S_{ntr} \cdot \sqrt{n \cdot (n+1) \cdot \frac{\Delta P`_{nl}}{\Delta P`_{sc}}} = 16000 \cdot \sqrt{1 \cdot (1+1) \cdot \frac{32.4}{201.2}} = 9080.16 \quad (4.12)$$

Table 3.4

S, kVA	K_l	$K_{0.5l}$	Duration of load step, h/year	Losses in transformer, kW	Power losses in transformers, kWh/year
9880,25	0.62		5475	109.12	597446,4
14491,59		0.45	730	147.33	107547,87
16426,78		0.51	365	170.84	62356
18251,98		0.57	2190	195.71	428608,3

Total for year ΔW=1195958,63 kWh/year

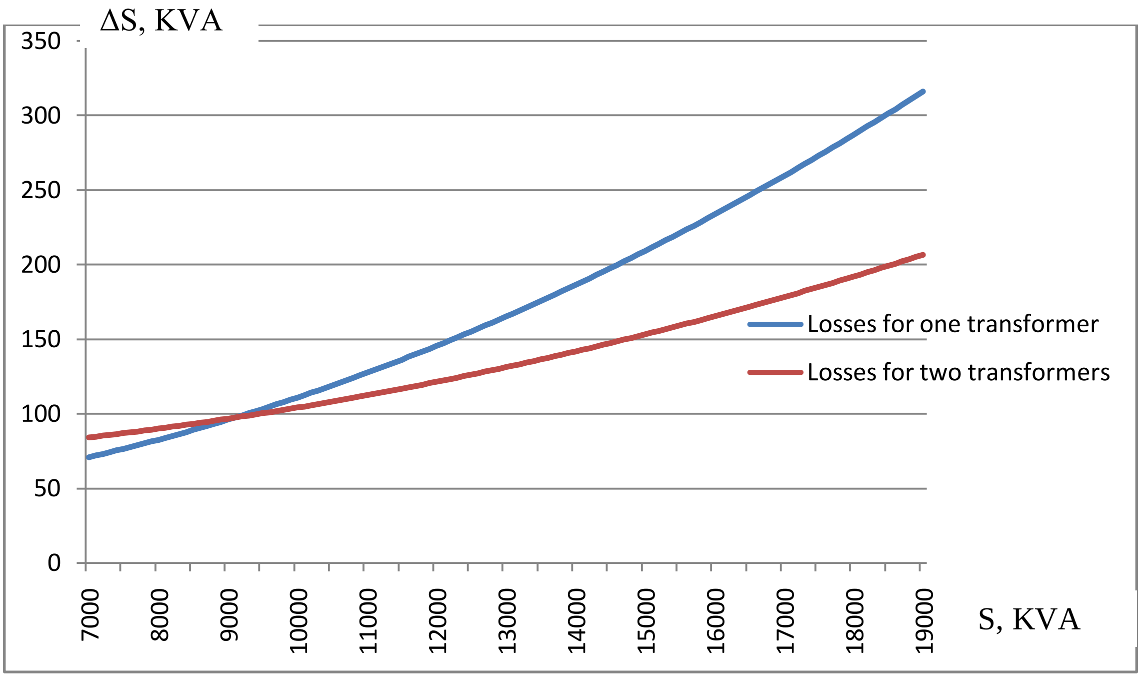

Fig 3.6Expediency of transformer mode

As seen for the graph, losses for two transformers in minimum load is less than losses for one transformer, but we could neglect this difference in point of reliability.

3.3. Calculation of power loss for smoothed operation mode

Consumed daily active and reactive power would be found:

$$W_d = \sum_{i=1}^{n}(P_i \cdot t_i) = 287083.27 \text{ kW·h}$$

$$V_d = \sum_{i=1}^{n}(Q_i \cdot t_i) = 97302.9 \text{kVAr·h}$$

The average total capacity of the enterprise per day:

$$S_{av} = \frac{S_d}{24} = \frac{\sqrt{{W_d}^2+{V_d}^2}}{24} = \frac{\sqrt{287083.27^2+97302.9^2}}{24} = 12630.2 \text{ KVA}$$

Determine the number of hours of peak load:

Reconstruct the daily schedule of active power enterprise in the annual duration.

$$T_{max} = \frac{W_{an}}{P_{max}} = \frac{W_d \cdot 365}{P_{max}} = \frac{287083.27 \cdot 365}{13358.31} = 7844 \; hours$$

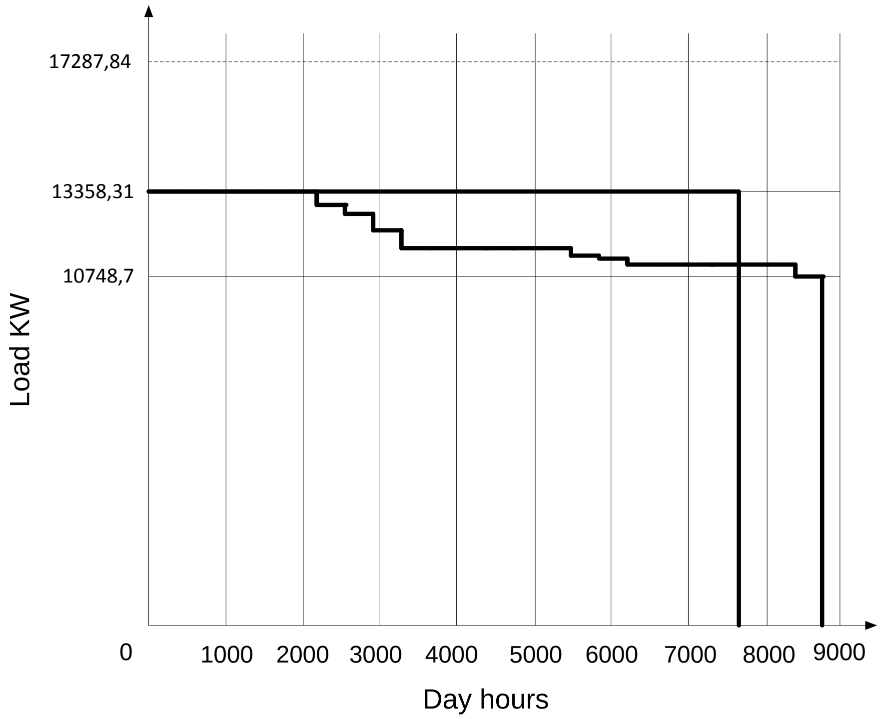

Fig 3.8Annual Tmaxof industry

Selection of transformer rated capacity by load graph.

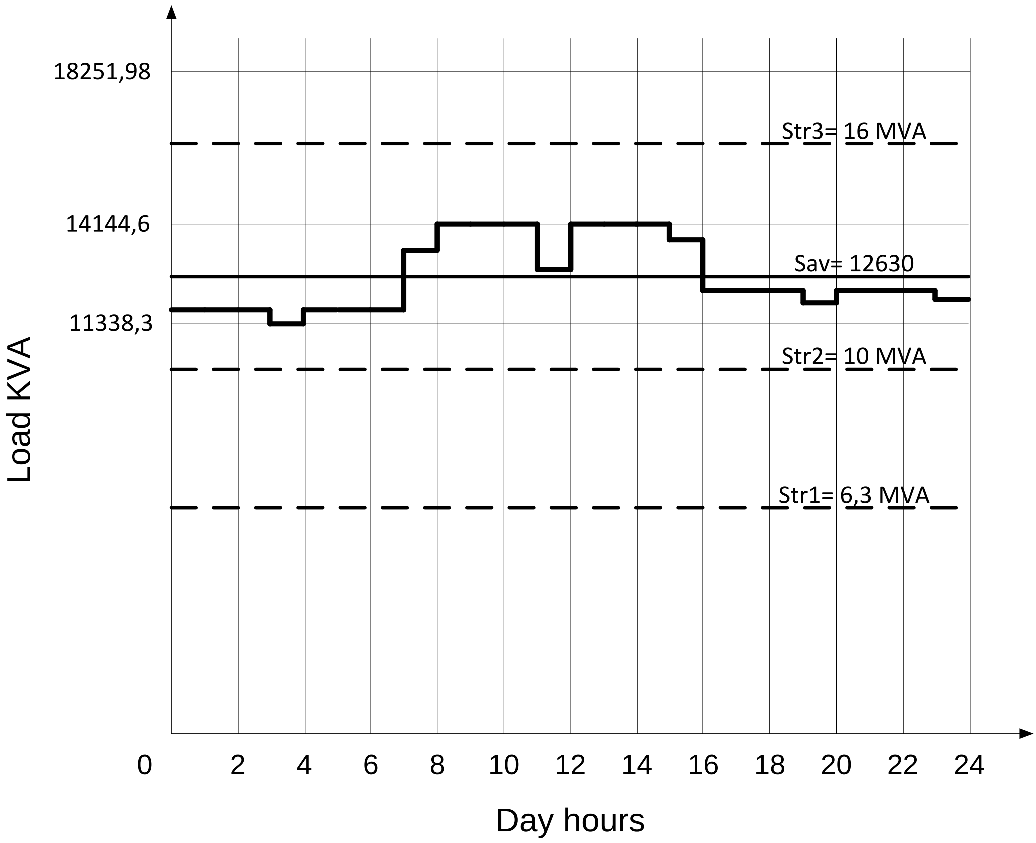

Fig 3.9Preliminary transformers` capacities for smoothed operating mode

Duration of the highest overload H'= 9hours

Determine primary load of graph K_1

$$K_1 = \frac{1}{12630} \cdot \sqrt{\frac{11629.92^2 \cdot 6 + 11338.31^2 \cdot 1 + 12267.96^2 \cdot 6 + 11870 \cdot 1 + 11948.94^2 \cdot 1}{15}} = 0.94$$

Determine primary overload $K`_2$

$$K`_2 = \frac{1}{12630} \cdot \sqrt{\frac{13297.73^2 \cdot 1 + 14441.6^2 \cdot 6 + 12978.96^2 \cdot 1 + 13616.75^2 \cdot 1}{1+1+6+1}} = 1.09$$

The resulting value $K`_2$ is less than

$$0.9K_{max} = 0.9 \cdot \frac{S_{max}}{S_{av}} = 0.9 \cdot \frac{14114.6}{12630} = 1$$

therefore accept: K_2=1.09

and the duration of the overload H would be 9 hours:

According to the obtained values of K_1 and H define the permissible overload factor of systematic K_{2aux}.

In 20^O C K_{2aux}will be 1.3

$$S_{ntr} = \frac{\sqrt{\frac{13297.73^2 \cdot 1+14441.6^2 \cdot 6+12978.96^2 \cdot 1+13616.75^2 \cdot 1}{1+1+6+1}}}{2 \cdot 1.3} = 5326\ KVA$$

Based on the received power planning two versions of the nearest transformer rated power:

S_{ntr1}=6300 KVA

S_{ntr2}=10000 KVA

Perform the calculation of the coefficients K1 and K2 for each of the variants of the nominal power transformers

Firstly, for S_{ntr1}=6300 KVA

The duration of the largest overload is H '= 24 hours

Determine initial load of graph

$$K_1 = 0$$

Pre-define overload $K`_2$

$$K`_2 = \frac{1}{6300} \cdot \sqrt{\frac{\sum_{i=1}^{24} s_i^2 \cdot t}{24}} = 2.01$$

The resulting value is less than

$$0.9K_{max} = 0.9 \cdot \frac{S_{max}}{S_{av}} = 0.9 \cdot \frac{18251.98}{6300} = 2.02$$

therefore accept: K_2=2.02

By this value selected transformer couldn`t operate on this overload time

S_{ntr2}=10000 KVA

The duration of the largest overload is H '= 24 hours

Pre-define overload $K`_2$

$$K`_2 = \frac{1}{10000} \cdot \sqrt{\frac{\sum_{i=1}^{24} s_i^2 \cdot t}{24}} = 1.27$$

The resulting value $K`_2$ is equal to

$$0.9K_{max} = 0.9 \cdot \frac{S_{max}}{S_{ntr\,2}} = 0.9 \cdot \frac{14114.6}{10000} = 1.27$$

So accept K_2=$K`_2$ and the duration of overload H=H`=24 hours

Comparing K_2 and K_{2aux} that could be found using $K_1$and temperature of 20^O C =1.3 K_{2aux}<K_2 so transformer couldn`t carry such overload.

So, picked variant is transformer with bigger capacity of 10000 KVA.

Checking on overload conditions:

$$\beta = \frac{S_{max}}{2 \cdot S_{ntr}} = \frac{14114.6}{2 \cdot 10000} = 0.7$$

With acceptable overload of 40%, in postemergency conditions transformer could feed consumers of II and category.

Table 3.5

Main parameters for transformer

Transformer	Rated capacity, MVA	Average nominal voltage, kV	ΔU_{sc}, %	ΔP_{sc}, kW	ΔP_{nl} kW	I_{nl}, %
ТМН-10000/110	10	115/11	10,5	60	14	0.7

Modified losses:

$$\Delta Q_{nl} = \frac{I_{nl\%} \cdot S_{ntr}}{100} = \frac{0.7 \cdot 10000}{100} = 70\ kVAr$$

$$\Delta P`_{nl} = \Delta P_{nl} + k_{ec} \cdot \Delta Q_{nl} = 18 + 0.1 \cdot 70 = 25\ kW$$

Where $k_{ec} = 0.1$ for 110 kV

$$\Delta Q_{sc} = \frac{U_{sc\%} \cdot S_{ntr}}{100} = \frac{10.5 \cdot 10000}{100} = 1050\ kVAr$$

$$\Delta P`_{sc} = \Delta P_{sc} + k_{ec} \cdot \Delta Q_{sc} = 21 + 0.1 \cdot 1050 = 189$$

Modified losses for one transformer:

$$\Delta P`_{tr} = \Delta P`_{nl} + \Delta P`_{sc} \cdot \left(\frac{S_{hi}}{S_{ntr}}\right)^2 = 25 + 189 \cdot (\frac{S}{10000})^2$$

Modified losses for two transformers:

$$\Delta P`_{tr} = 2 \cdot \Delta P`_{nl1,2} + (\Delta P`_{sc1} + \Delta P`_{sc2}) \cdot \left(\frac{S_{hi}}{2 \cdot S_{ntr}}\right)^2 = 50 + 378 \cdot (\frac{S}{20000})^2$$

Determine the load at which it is expedient to proceed to work with two transformers:

$$S = S_{ntr} \cdot \sqrt{n \cdot (n+1) \cdot \frac{\Delta P`_{nl}}{\Delta P`_{sc}}} = 10000 \cdot \sqrt{1 \cdot (1+1) \cdot \frac{25}{189}} = 5143.45$$

Table 3.6

S, kVA	K_l	$K_{0.5l}$	Duration of load step, h/year	Losses in transformer, kW	Power losses in transformers, kWh/year
11338.31		0,57	365	171,49	62592,59
11629.92		0,58	2190	177,82	389416,97
11870		0,59	365	183,15	66848,91
11948.94		0,60	365	184,92	67497,4
12267.96		0,61	2190	192,23	420973,06
12978.96		0,65	365	209,19	76353,81
13297.79		0,66	365	217,10	79242,99
13616.75		0,68	365	225,22	82204,6
14441.6		0,71	2190	238,26	521799,52

Total for year ΔW=1766930 kWh/year

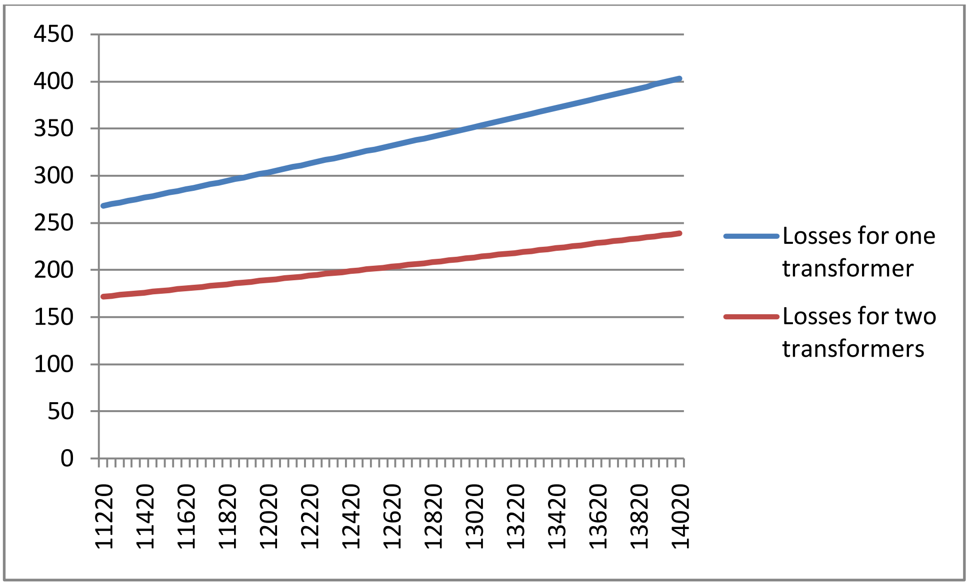

Fig 3.10Expediency of transformer mode

As seen for the graph, losses for two transformers are much less for two transformers, working in parallel mode. So, operation of one transformer is no economical mode.

For the full analysis, calculations with bigger capacity of power transformers should be made. Transformer TMH-16000/110 was selected.

Main parameters for transformer

Table 3.7

Transformer	Rated capacity, MVA	Average nominal voltage, kV	ΔU_K, %	ΔP_K, kW	ΔPx kW	Ix, %
TMH-16000/110	16	115/11	10,5	21	18	0.7

Modified losses:

$$\Delta Q_{nl} = \frac{I_{nl\%} \cdot S_{ntr}}{100} = \frac{0.7 \cdot 16000}{100} = 144\ kVAr$$

$$\Delta P`_{nl} = \Delta P_{nl} + k_{ec} \cdot \Delta Q_{nl} = 18 + 0.1 \cdot 144 = 32.4\ kW$$

Where $k_{ec} = 0.1$ for 110 kV

$$\Delta Q_{sc} = \frac{U_{sc\%} \cdot S_{ntr}}{100} = \frac{10.5 \cdot 16000}{100} = 1680\ kVAr$$

$$\Delta P`_{sc} = \Delta P_{sc} + k_{ec} \cdot \Delta Q_{sc} = 33.2 + 0.1 \cdot 1680 = 201.2$$

Modified losses for one transformer:

$$\Delta P`_{tr} = \Delta P`_{nl} + \Delta P`_{sc} \cdot \left(\frac{S_{hi}}{S_{ntr}}\right)^2 = 32.4 + 201.2 \cdot (\frac{S}{16000})^2$$

Modified losses for two transformers:

$$\Delta P`_{tr} = 2 \cdot \Delta P`_{nl1,2} + (\Delta P`_{sc1} + \Delta P`_{sc2}) \cdot \left(\frac{S_{hi}}{2 \cdot S_{ntr}}\right)^2 = 64.8 + 402.4 \cdot (\frac{S}{32000})^2$$

Determine the load at which it is expedient to proceed to work with two transformers:

$$S = S_{ntr} \cdot \sqrt{n \cdot (n+1) \cdot \frac{\Delta P`_{nl}}{\Delta P`_{sc}}} = 16000 \cdot \sqrt{1 \cdot (1+1) \cdot \frac{32.4}{201.2}} = 9080.16$$

Table 3.8

S, kVA	K_l	$K_{0.5l}$	Duration of load step, h/year	Losses in transformer, kW	Power losses in transformers, kWh/year
11338.31		0,35	365	115,32	42091,42
11629.92		0,36	2190	117,95	258312,66
11870		0,37	365	120,17	43861,37
11948.94		0,37	365	120,91	44131,04
12267.96		0,38	2190	123,94	271434,94
12978.96		0,41	365	131,00	47813,88
13297.79		0,42	365	134,29	49015,32
13616.75		0,43	365	137,66	50246,88
14441.6		0,44	2190	143,09	313362,61

Total for year ΔW=1120270 kWh/year

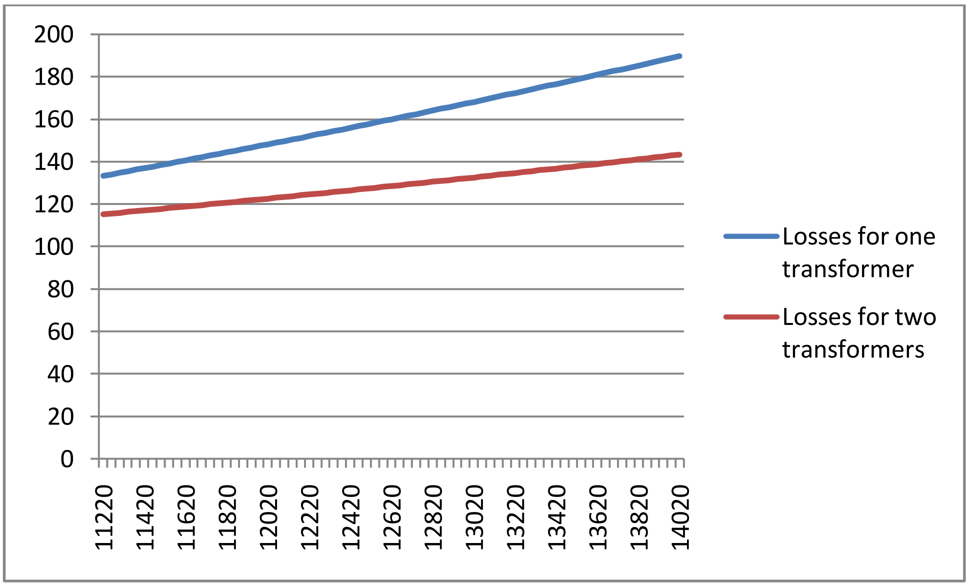

Fig 3.11Expediency of transformer mode

According from that, the best economical mode of industry operation is shifted mode with transformers of 16 MVA.

$\Delta W = \Delta W_{original} - \Delta W_{shifted} = 1195958{,}63 - 1120270 = 75688{,}63$ KVA/year

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As the advantage of this mode with a transformer of 16 MVA is the possibility to switch off one of the transformers at any moment, still providing reliable power supply for all the industry.

One more advantage of this method is economy in the case of cheaper night energy. Usually, the cost of 1 KVA in the time of 23.00-7.00 is just 70% of day cost. Costs of power are given in following table. The cost of 1 KVA·h is 0,1$ from 7.00 to 23.00 and 0,07$ from 23.00 to 7.00.

Table 3.9

Time interval, t,hours	Cost of KVA·h, $	Total power of the original load, S_{ori},KVA	Total power of the smoothed load, S_{smi},KVA	Cost of power for hour for original load, $	Cost of power for hour for smoothed load, $
0-1	0,07	9356,51	11629,92	691,6172	814,0943
1-2	0,07	9356,51	11629,92	691,6172	814,0943
2-3	0,07	9356,51	11629,92	691,6172	814,0943
3-4	0,07	9356,51	11338,31	691,6172	793,6814
4-5	0,07	9356,51	11629,92	691,6172	814,0943
5-6	0,07	9356,51	11629,92	691,6172	814,0943
6-7	0,07	9356,51	11629,92	691,6172	814,0943
7-8	0,1	13724,76	13297,73	1449,159	1329,773
8-9	0,1	17287,84	14114,60	1825,198	1411,46
9-10	0,1	17287,84	14114,60	1825,198	1411,46
10-11	0,1	17287,84	14114,60	1825,198	1411,46
11-12	0,1	15559,06	12978,96	1642,678	1297,896
12-13	0,1	17287,84	14114,60	1825,198	1411,46
13-14	0,1	17287,84	14114,60	1825,198	1411,46
14-15	0,1	17287,84	14114,60	1825,198	1411,46
15-16	0,1	13724,76	13616,75	1449,159	1361,675
16-17	0,1	9356,51	12267,96	988,0246	1226,796
17-18	0,1	9356,51	12267,96	988,0246	1226,796
18-19	0,1	9356,51	12267,96	988,0246	1226,796
19-20	0,1	9356,51	11870,01	988,0246	1187,001
20-21	0,1	9356,51	12267,96	988,0246	1226,796
21-22	0,1	9356,51	12267,96	988,0246	1226,796
22-23	0,1	9356,51	12267,96	988,0246	1226,796
23-24	0,07	9356,51	11948,94	691,6172	836,4257
Σ		287083,27	287083,27	27941,29	27520,55

So, savings for year would be equal:

$$\Delta M_{gr} = (\Delta M_{or} - \Delta M_{sm}) \cdot 365 = (27941{,}29 - 27520{,}55) \cdot 365 = 153571{,}38\ \$$$

4. TECHNICAL CALCULATION OF INTERNAL POWER SUPPLY

Power supply diagrams are built with staged principle. The number of stages of power distribution in the enterprise is determined by the power input and topological arrangement of electrical loads in the undertaking. The number of stages of distribution should be not more than 2-3. With increasing the number of stages reliability of circuits reduces and they become uneconomic.

In small and medium-sized enterprises, as well as on the second and subsequent stages of large enterprises electricity supply is distributed to 10 kV mainly on cable lines.Application of voltage of 6 kV is wasted and is used only when a large number of engines rated from 200 to 800 kW (chemistry, petrochemistry).

Two main power distribution circuits - radial and backbone are used depending on the number and mutual arrangement of the substations or other electricity consumers towards their point of feed.In the performance of both diagrams the necessary reliability of electricity supply of any category is provided.

Radial circuits are used in cases where the load dispersed from the center of power, as well as for power supply of distribution center (DC) and high voltage consumers.

The backbone circuits should be applied in the distributed loads and such mutual location of substations where the line from the power supply to consumers can be laid without significant reverse. The backbone circuits have the following advantages:

allow better loading of cables;

allow to save or the number of PKK cases or CSR on the power spot;

make it easier to make a reservation of shop stations.

The disadvantages of backbone circuits include: difficulty of switching circuits of shop stations (they have to be connected through the switch load).

The number of shop transformers, which are joined with the samebackbone main, depends on the power and responsibility of supply consumers. 2-3 are admitted when the capacity of transformer is 1000-2500 kVA and 4-5 when the capacity 250-630 kVA.

If there is the large number of consumers,mixed scheme of power supply is used, that is the part of consumers is supplied by radial pattern (DC, high voltage consumers), andthe part of consumers is supplied by the backbone circuit.

Analyzing the size and placement of electrical loads in shops on the factory and taking into account consumers' categories on the degree of continuity of power supply we choose the radial-backbone scheme with reservation for the system of internal power supply. Power distributors of shops, that consumer have above 1000 V, powered by the radial diagram with reservation from the buses ofMSS. Distribution network above 1000 V on the territory of factory is performed by cable lines lying in trenches. The of distribution of electricity we perform drawing A1 "Situation plan of enterprise" where also plotcartogramsof electrical loads.

4.1. Selection of the section of cable lines

The following types of connection are admitted:

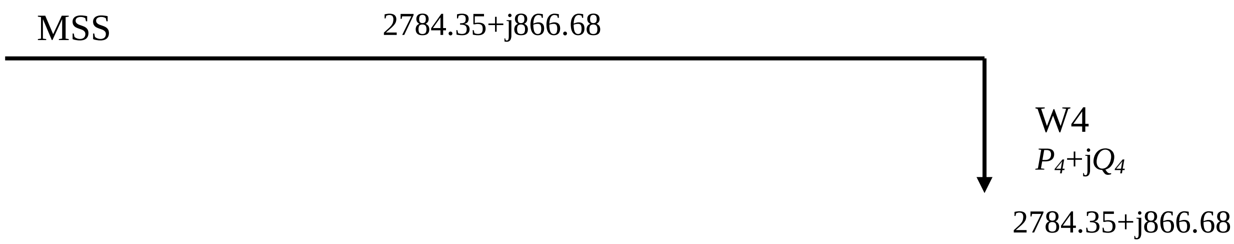
Radial: MSS-W4, MSS-W7,MSS-W8;

Ring: MSS-W3-W9-MSS;

Backbone: MSS-W5-W6;

Backbone with branches: MSS-W10-W1,W2.

We carry out selection of the section of cable lines on the example of MSS line - W4, which according to the accepted scheme of power distribution supplies to radial



scheme with reservation from MSSbuses (figure 4.1).

Fig. 4.1 - Feed circuit MSS–W4

Operating current of line MSS–TS4is equal to consumed current of workshop number 4 ${}^{2}{}_{l4} = {}^{2}{}_{lw4}$, A:

$$ {}^{2}{}_{l4} = \frac{S_{w4}}{n_{cab4}\sqrt{3}\cdot U_{í}} = 2916.12/(2\cdot 1,73\cdot 10)=84.3 \qquad (4.1) $$

where $n_{каб}$ =2 is the number of lying cables for the line.

Cross-section of the line, mm^2:

$$ F = \frac{I_p}{j_{ек}} = 84.3/1,1=76.6 \qquad (4.2) $$

where $j_{ек}$ = 1,1 A/mm^2 is economic current density for cables with aluminum core in [1].

We accept cross-section of cable by the table A5-A6

The selected cable crossing by the terms of the economic current density of cable mark	ASB (3×95)
Corrected cross-section of cable after checking for voltage losses	ASB (3×95)

Permissible current of cable I_{adm} =225 A.

Cable checkingon heating:

- in normal mode, A:

$$I_{adm} > Ip\,,$$

225>76.6,

in post-emergency conditions (current flows in one cable), A:

$$I_{adm} > 2 \cdot Ip$$

225>2·76.6=153.2

Conditions are satisfied.

Cable checking on voltage losses:

$$\Delta U_{cab4} = \frac{\mathrm{P}_4 \cdot l_4 \cdot r_{cab4} + Q_4 \cdot l_4 \cdot \tilde{o}_{cab4}}{2 \cdot \mathrm{U}_\mathrm{n}^2} \cdot 0{,}1\,, \qquad (4.3)$$

where r_{cab4} =3.1 ohm / km, $\tilde{o}_{cab4}$= 0,122ohm / km - specific active and reactive resistance of cable by tableA4;

l_{cab4} is length of cable.

l_4=0,7275 km

$\Delta U_{кабг1}$=(2784,35·0,7275·0,326+866,68·0.7275·0.083)·0,1/(2·10^2)=0,36< 5%

We check cable according to voltage losses in the post-emergency condition (current flows in one cable),%:

$$\Delta U_{кабавг1} = 2 \cdot \Delta U_{кабг1} = 2 \cdot 0{,}36 = 0{,}72 < 10\%. \qquad (4.4)$$

If the condition $\Delta U_{\hat{e}\grave{a}\acute{a}\tilde{a}1} < \Delta U_{\ddot{i}\eth\grave{e}\ddot{i}}$ =5% is not satisfied than we select cable from the table A5-A6 with the nearest larger section than the selected

$F_{г1}$=90mm^2, and again check according to voltage losses.

So finally we select type of cable.

We determine the active power losses in cables, kW:

$$\Delta P_{кабг1} = \frac{S_{ц1}^2}{U_н^2}\frac{r_{кабг1}}{2}10^{-3} = (2916,17^2 \cdot 0,326 \cdot 10^{-3})/(10^2 \cdot 2) = 13,8 \qquad (4.5)$$

We determine the reactive power losses in cables, kVAr:

$$\Delta Q_{кабг1} = \frac{S_{ц1}^2}{U_н^2}\frac{x_{кабг1}}{2}10^{-3} = (2916,17^2 \cdot 0,083 \cdot 10^{-3})/(10^2 \cdot 2) = 3.53 \qquad (4.6)$$

We determine the active energy losses in cables, kW / year:

$$\Delta A_{акабг1} = \Delta P_{кабг1} \cdot \tau_a = 13,8 \cdot 7289 = 99755,6 \qquad (4.7)$$

where τ_a is the time of maximum losses that is determined by the formula, hours / year:

$$\tau_a = \left(0,124 + \frac{T_{ма}}{10000}\right)^2 8760 = (0,124+7844/10000)^2 \cdot 8760 = 7289 \qquad (4.8)$$

where $T_{ма}$ is number of hours per year of maximum active power usage (according to task for metal enterprises we select from the table A7)

$T_{ма}$=7289 hours per year.

We determine the reactive power loss in cables, kVAr / year:

$$\Delta A_{ркабг1} = \Delta Q_{кабг1} \cdot \tau_p = 0.05 \cdot 4441 = 222 \qquad (4.9)$$

where τ_p is the time of maximum losses that is determined by the formula, hours / year:

$$\tau_p = \left(0,124 + \frac{T_{мр}}{10000}\right)^2 8760 = (0,124+5880/10000)^2 \cdot 8760 = 4441, \qquad (4.10)$$

where $T_{мр}$ is number of hours per year of maximum reactive power usage (according to task for metal enterprises we select from the table A7)

$T_{мр}$ = 5880 hours per year.

For next radial lines:

l_7=0,545 km

l_8=0,297 km

Table 4.1

Subcircuit	Operating current, Ip, A	Calculated cable cross-section, F, mm2	Selected cable cross-section, F, mm2	Permissible current of cable, I_{adm}, A	Specific resistance of cable $r_{ïcab}$ Om/km,	Specific reactance of cable $õ_{ïcab}$ Om/km	Voltage losses, ΔU_{cab}, %
MSS-W4	84.3	76.6	95	225	0.326	0.083	0.36
MSS-W7	78.4	71.2	95	225	0.326	0.083	0.24
MSS-W8	115	104.5	120	260	0.258	0.079	0.16

Table 4.2

Subcircuit	Active power losses, $\Delta P_{ñab}$, kW	Reactive power losses, ΔQ_{cab} ,kVA	Active energy losses, ΔA_{acab}, kW/year	Reactive energy losses, $\Delta À_{rcab}$, kVA/year
MSS-W4	10,08	2,57	73501	11402
MSS-W7	5,54	1,66	47645	73901
MSS-W8	6,07	1,86	44225	8250

For ring line MSS-W3-W9-MSS cables MSS-W3 and MSS-W9 must carry load of both powers of W3 and W9 and cable W3-W9 must carry load of most loaded workshop: W3

l_3=1.084 km

l_9= 0.577 km

l_{3-9}=0.518 km

$$I_3 = I_{w3} + I_{w9}.$$

$$I_9 = I_{w3} + I_{w9}$$

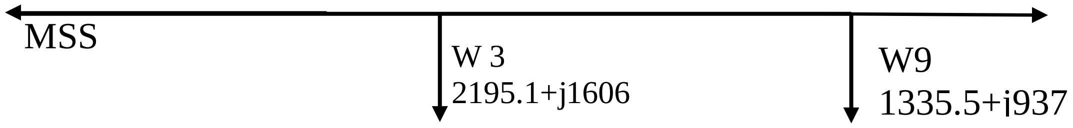


Fig.4.2Power scheme MSS– W3–W9 – MSS

Table 4.3

Subcircuit	Operating current, Ip, A	Calculated cable cross-section, F, mm2	Selected cable cross-section, F, mm2	Permissible current of cable, $I_{прип}$,A	Specific resistance of cable $r_{пкабг1}$ Om/km,	Specific reactance of cable $x_{пкабг1}$ Om/km	Voltage losses, $\Delta U_{каб}$, %
MSS-W3	107,8	98	120	260	0.258	0.079	1.08
W3-W9	67,5	61,3	70	190	0,443	0,086	0.32
MSS-W3	107,8	98	120	260	0.258	0.079	0.58

Table 4.4

Subcircuit	Active power losses, $\Delta P_{каб}$, kW	Reactive power losses, $\Delta Q_{каб}$,kVA	Active energy losses, $\Delta A_{акаб}$, kW/year	Reactive energy losses, $\Delta A_{ркаб}$, kVA/year
MSS-W3	38.94	11.92	283808	52948
W3-W9	6,21	1,21	90540	10760
MSS-W3	10,37	3,18	151198	28208

or backbone line MSS-W5-W6 cable MSS-W5 must carry load of both powers of W5 and W6

l_5=0.869 km

l_{5-6}= 0.303 km

$$I_5 = I_{w5} + I_{w6} .$$

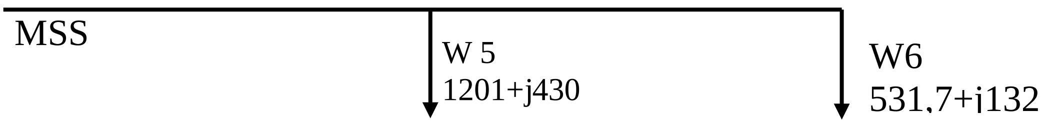


Fig.4.3Power scheme MSS– W5–W6

Table 4.5

Subcircuit	Operating current, Ip, A	Calculated cable cross-section, F, mm2	Selected cable cross-section, F, mm2	Permissible current of cable, $I_{прип}$,A	Specific resistance of cable $r_{пкабг1}$ Om/km,	Specific reactance of cable $x_{пкабг1}$ Om/km	Voltage losses, $\Delta U_{каб}$, %
MSS-W5	52,7	47,9	50	155	0.62	0.09	0,49
W5-W6	15,6	14,2	16	80	1,94	0,113	0,16

Table 4.6

Subcircuit	Active power losses, $\Delta P_{каб}$, kW	Reactive power losses, $\Delta Q_{каб}$,kVA	Active energy losses, $\Delta A_{акаб}$, kW/year	Reactive energy losses, $\Delta A_{ркаб}$, kVA/year
MSS-W5	8,95	1,3	65261	5772
W5-W6	0,88	0,05	6427	228,1

For backbone line MSS-W10-W1,W2 cable MSS-W10 must carry load of both powers of W10, W1 and W2

k_{10}=0.602 km

l_{10-1}= 0.18 km

l_{10-2}= 0.272 km

$$I_{10} = I_{w10} + I_{w1} + I_{w2} .$$

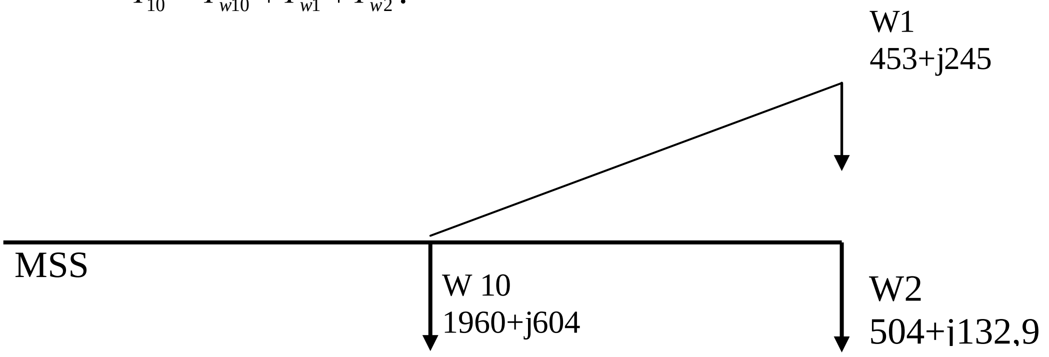


Fig.4.4Power scheme MSS– W10–W1, W2

Table 4.7

Subcircuit	Operating current, Ip, A	Calculated cable cross-section, F, mm2	Selected cable cross-section, F, mm2	Permissible current of cable, $I_{прип}$,A	Specific resistance of cable $r_{пкабг1}$ Om/km,	Specific reactance of cable $x_{пкабг1}$ Om/km	Voltage losses, $\Delta U_{каб}$, %
MSS-W10	89,2	81,1	95	225	0.326	0.083	0,32
W10-W1	14,9	13,5	16	80	1,94	0,113	0,08
W10-W2	15,1	13,7	16	80	1,94	0,113	0,14

Table 4.8

Subcircuit	Active power losses, $\Delta P_{каб}$, kW	Reactive power losses, $\Delta Q_{каб}$,kVA	Active energy losses, $\Delta A_{акаб}$, kW/year	Reactive energy losses, $\Delta A_{ркаб}$, kVA/year
MSS-W10	9,49	2,42	69152	10727
W10-W1	0,46	0,03	3382	120
W10-W2	0,72	0,04	5225	185

4.2. Expediency of cable cross section

The main method of reducing of power losses in cables is selection of cable with bigger cross section. But selection of cable with maximum cross section is not always expedient way. For expedient selection we build graphs, showing cost of cables with different cross section and cost of losses for 2 years (payoff term) for corresponding cables.

Following table represents characteristics and costs for cable AAB

Table 4.9

Cross section of cable, mm^2	Resistance per 1 km Ohm\km	Reactance per 1 km Ohm\km	Cost per 1 km, $\km
10	3,1	0,128	1020
16	1,94	0,122	1415
25	1,24	0,113	2230
35	0,89	0,099	2953,75
50	0,62	0,095	3896,25
70	0,443	0,09	5446,25
95	0,326	0,086	7097,5
120	0,258	0,081	8760
150	0,206	0,079	10656,25
185	0,167	0,077	12897,5

Cost of cable equals:

$$M_{ci} = M_{0i} \cdot l \quad (4.11)$$

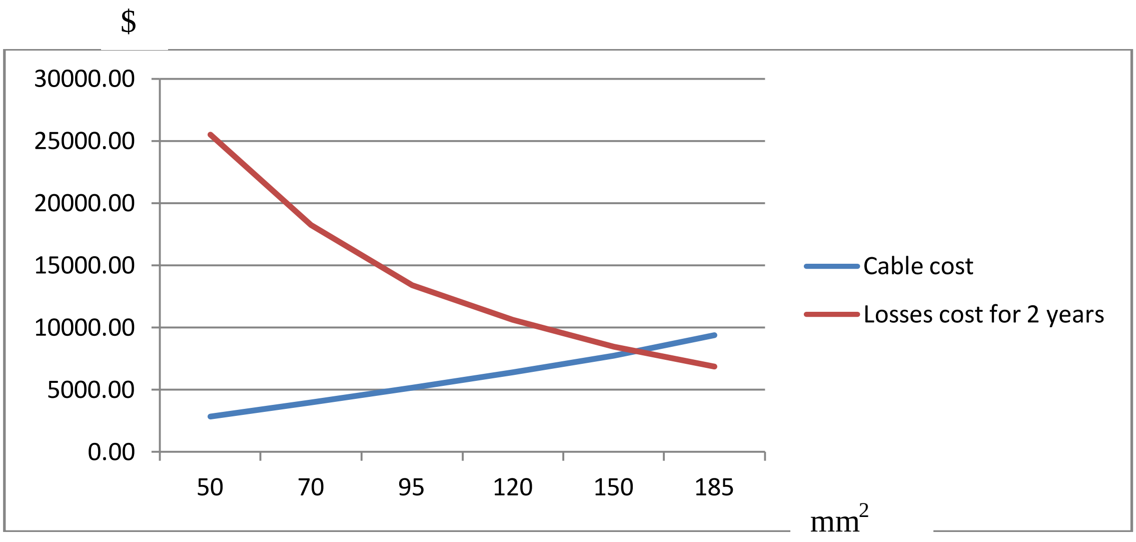
Cost of losses equals:

$$M_{\Delta Wi} = \Delta W_i \cdot 0.1\$ \quad (4.12)$$

Table 4.10

For cable MSS-W4

Cross section of cable, mm^2	Cost of cable plot, $	Cost of losses for 2 years, $
10	742,05	127442,35
16	1029,41	79755,08
25	1622,33	50978,51
35	2148,85	36590,11
50	2834,52	25491,07
70	3962,15	18215,29
95	5163,43	13406,26
120	6372,90	10611,30
150	7752,42	8474,51
185	9382,93	6872,21



From the graph, expedient cross section of cable is 150 mm^2, not 95, as in primary calculations.

Table 4.12

Cable	Preliminary cross section, mm^2	Expedient cross section, mm^2	Reducing of power loss, kVA/year
MSS-W4	95	150	24659
MSS-W7	95	150	15562
MSS-W8	120	185	13952
MSS-W9	120	185	47003
MSS-W3	120	185	88304
W3-W9	70	185	11338
MSS-W5	50	95	27896
W5-W6	16	25	2179
MSS-W10	95	185	29668
W10-W1	16	25	942
W10-W2	16	25	1762

ΔW_{cable}=263265

5. LABOR SAFETY

5.1. Protection against direct lightning hit

Atmospheric electricity (lightning) is an electrical discharge in the atmosphere between clouds and earth or between dissimilar charges of clouds.

In most cases the lower part of thunderclouds charged negatively and the surface are iducted with positive charges. It is formed as it a giant charged capacitor, oneside of which is stormy field, and other land. As the concentration of charge increases the electric field of the capacitor reaching a value of 300 kV / m creates a condition for the occurrence of lightning. Effects of lightning charges can be of two types:

- lightning - strikes the building and installation (direct lightning),
- lightning provides secondary effects, be explained by electrostatic and electromagnetic induction.

Electrostatic induction is the fact that the isolated metal objects are dangerous electrical potentials, resulting in possible arcing between individual metal in construction and equipment.

As a result of electromagnetic induction, due to the rapid change in the value of lightning current in metal unclosed contours, appear electromotive force, which leads to danger spark creating between places in the convergence of these paths.

Instruction for the design and lightning protection devices are divided into three categories. Provides lightning protection of buildings and structures, depending on purpose and intensity of thunderstorms in the area of their location and the expected number of lightning injuries in year for one of three categories of devices and lightning protection zone taking into account the type of protection. Lightning Protection Zone - a part of the space inside the building or put protected against direct lightning strikes with some degree of reliability. Area Protection Type A - 99.5% reliability and higher, Zone B - the reliability of 95% and above.

External installation, lightning protection device included in the second category, protect from direct lightning strikes and static induction, and included a third category - only from direct lightning strikes.

Often there are linear lightning, which duration is tenths of seconds. Such lightning the most dangerous in case of direct impact. Basically, they hit objects with large height, the other located in proximity to it for protection against lightning using lightning rods, which are located above the object, which is protected, and have metal devices that accept direct lightning and drainage parts diversion of lightning into the ground.

In the thesis project is calculated lightning protection step-down substation, which has the following parameters:

Zone defense type	A	
The width of the substation	42	, m
The length of the substation	85	, m
The maximum height of the portal	10	, m
Average number of lightning strikes	8	, in 1 km^2
Number of lightning rods	4	pcs
The height of lightning rod	12	, m

Each district has the intensity of thunderstorms. This is an important factor when choosing the type and design of lightning protection. It is therefore necessary to know the expected number of lightning injuries per year in the building and construction.

This number is founded by the formula:

$$N = (S+6h)(L+6h)\cdot n\cdot 10^{-6} = (42+6\cdot 10)\cdot(85+6\cdot 10)\cdot 8\cdot 10^{-6} = 0{,}118;$$

where S and L - the width and length of the building (structure), which is protected and has a rectangular shape in plan, m; h - the maximum height of buildings (structures), which is protected, m; n - the average number of lightning strikes in 1 km2 land surface in the location of the building, the value of n at different intensity thunderstorms that:

The intensity of thunderstorm per year, h	10-20	20-40	40-60	60-80	80 andmore
Average number of lightning strikes	1	3	6	9	12

in 1 km of surface

When the lightning protection of buildings and structures to enhance the safety of people and animals need earthing switches lightning rods (except depth) placed in rarely visited places at a distance of 5 m or more of the major soil and travelers and pathways.

Protection against direct lightning strikes buildings belonging to the first category, is performed lightning rod, which is separately fixed to the protective object. This provides lightning protection zone of type B.

This substation belongs to the first category by lightning protection. For the protection of this category apply lightning rod. Lightning rod consists of these elements:

lighting reciever that directly takes lightning;

structure that is intended to set lightning rod;

shunts, which provides output current of lightning into the ground.

Zone of protection of single rod lightning rod with height of $h < 150$ m and is cone, the apex of which has a height $h_0 < h$. At ground level area forms a circle of radius r_0. Horizontal cross section area of protection at the height of buildings h_x, the defending circle radius is r_x.

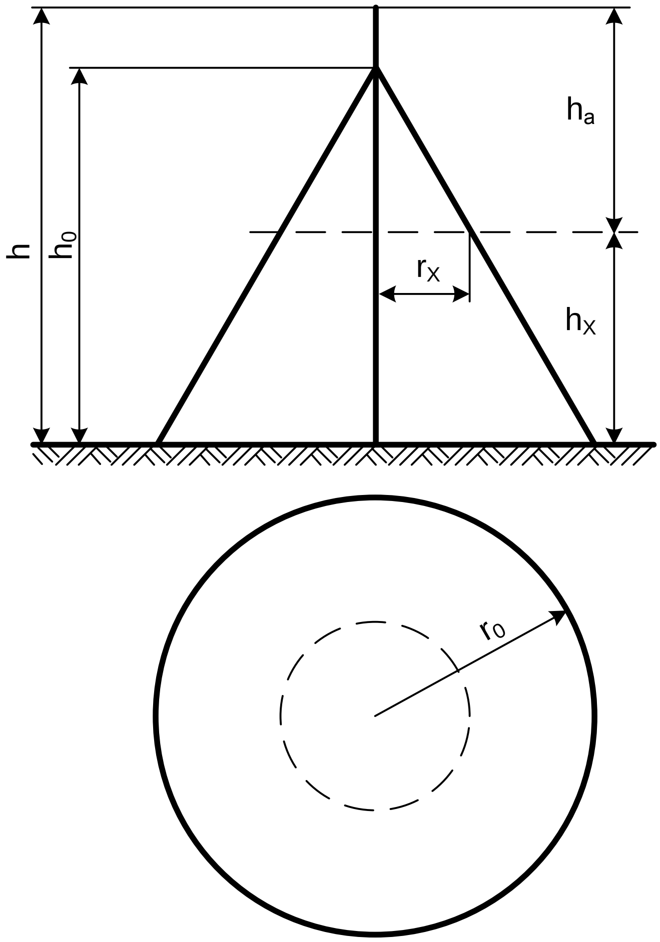


Fig. 5.1 Protection zone of single lightning rod

Zone of protection type B has dimensions:

h_0 = 0,92h

r_0 =1,5h

r_x =1,5(h-h_x /0.92)

We perform the calculation for the object of the first category of building lightning protection. Height of lightning rod is 12 m, lightning rod set on the portal height of 10 m protective zone B. We accept lightning protection with 4 Lightning rod type. The length of the zone 85 m, width 42 m Fig. 6.2.

Dimensions substation and installation of lightning rod

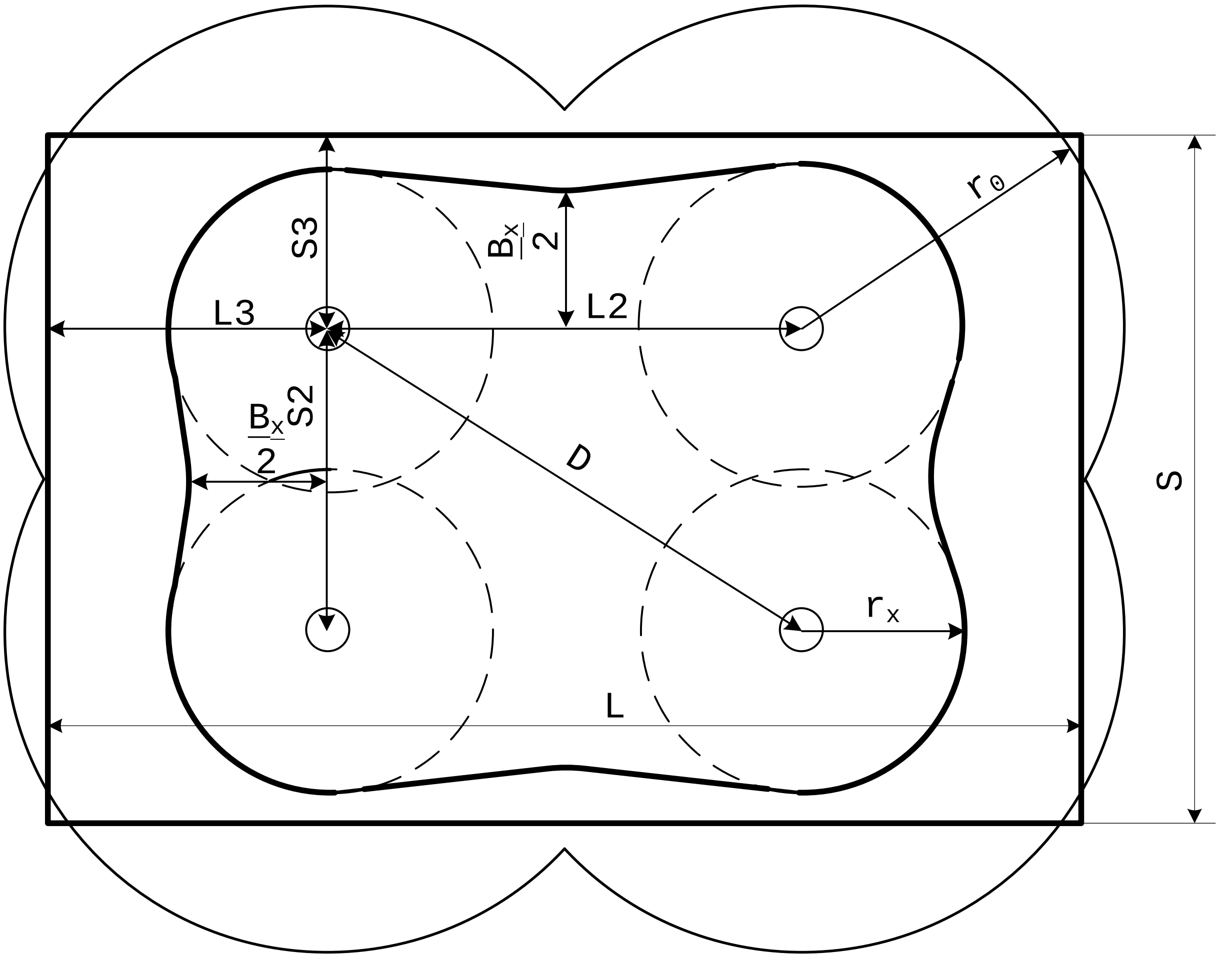


Fig. 5.2. Zone of substation lightning protection

h_0 = 0,92·22=20,24 м

r_0 =1,5·22=33 м

Zone Protection level to build

h_x = 10 м

Radius Protection is in accordance:

r_x = 1,5(22-10/0,92)= 16,7 м

Determine the smallest width of the zone is protected, at a height h_x

$b_x = 0{,}9 \cdot 2 \cdot h_a$=0,9·2·12=21,6

Check the condition of security in the entire area of the substation at the height h_x of the largest distance between the four lightning rods, diagonally:

$$D \leq 8 \cdot h_a;$$

$$36 \le 8 \cdot 12;$$

$$36 \le 96$$

Lightning protection is calculated correctly

5.2. Calculation of earthing devices

Earthing device substation is made in accordance with [10]. In resistance grounding device for electrical voltages above 1 kV network with effectively grounded neutral at any time of year should be no more than 0.5 ohms, including natural resistance grounding.

Vertical ground loop electrodes are made:

From steel bxbx5	bx=	80	, mm;
length	*le*=	6	, m;
number of electrodes	n=	80	, psc.
The length of ground loop		81	, m.
Width of ground loop		38	, m.
Horizontal earthing switches made of steel strip bx4	b=	40	, mm.
Depth of installation of bands	h=	0,6	,m.
Strips are laid away from the foundation equipment		1,0	
Measured resistivity of topsoil	$\rho_{изм1}$=	420	Ohm·m.
Measured resistivity bottom layer of soil	$\rho_{изм2}$=	210	Ohm·m.
Depth of bottom layer	H=	1,5	, m.

Circuit grounding device is located within the outer fence of the substation at a distance of 2 meters from it.

The connection of individual elements circuit grounding is performed with reliable welding.

Perform verification calculation of substation grounding device.

Calculated resistivity of the soil is determined by the formula

$$\rho_{расч}=K_1 \cdot \rho_{изм2} \qquad (5.1)$$

where K_1 – relative resistivity of the soil takes into account the heterogeneity of land surface grids is determined by the curves [10].

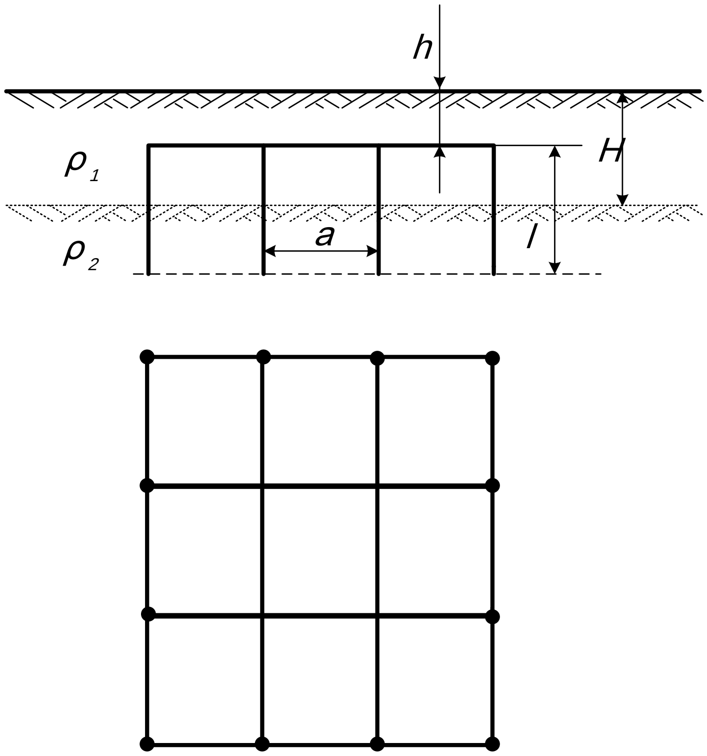


Fig. 6.3 Location of grounding

At $\frac{\rho_1}{\rho_2}$=420/210=2, $\frac{H-h}{l}$=(1,5–0,6)/6=0,15, $\frac{a}{l}$=1,

K_1= 1,15

By (**Ошибка! Источник ссылки не найден.**.1) find

$\rho_{расч}$=1,15·210 =241,5 (Ом·м)

Define artificial grounding resistance by the formula

$$R_u = \frac{R_{\in} \cdot R_3}{R_{\in} + R_3} \qquad (5.2)$$

where R_e- resistance to leakage of natural grounding Ohm· m;

R_3- required by [10] resistance of grounding device

In this substation as a natural earthing cables used lighting protection air lines of 110 kV, which allowed for [10]. Measured resistance spreading natural grounding is

R_e= 2,1 Ohm·m.

Then by formula (6.2) we obtain

R_u =(2,1·0,5)/(2,1+0,5)= 0,4

Determine the resistance of horizontal bands of ground, forming a grid. The resistance of a horizontal strip can be determined by the formula

$$R_n = \frac{\rho_{расч}}{2\pi l} \cdot lg\frac{2l^2}{b \cdot h} \qquad (5.3)$$

where l – band length, m;

b – width, m;

h – depth of band, m.

By formula (8.3) we find the resistance spreading longitudinal stripes

lg(120333,333)= 5,13

R_{n1}==241,5/(2·3,14·38)·lg(2·38^2/(0,04·0,6))=3,708, Ohm

The resistance of longitudinal strips of coefficient of usage is determined by the formula

$$R_{n\Sigma} = \frac{R_n}{n \cdot \eta_n} \qquad (5.4)$$

where n – quantitybands; acceptn= 4

η – coefficient of use of horizontal bands [10].

accept η = 0,36

Using the formula (8.4) we find resistance spreading of longitudinal strips.

$R_{n1\Sigma}$ ==3,708/(4·0,36)= 2,58

Similarly to formulas (8.3) and (8.4) we find the spreading resistance of a cross-band and equivalent resistance of the transverse bands

ln(546750)= 5,51

R_{n2}==241,5/(2·3,14·81)·lg(2·81^2/(0,04·0,6))=1,87

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acceptn$_2$= 5

$$R_{n2\Sigma} = \frac{4{,}33}{4 \cdot 0{,}36} = 3{,}03(Ом)$$ =1,87/(5·0,36)= 1,04

The total resistance of equal grid of horizontal bands

$$R_c = \frac{R_{n1\Sigma} \cdot R_{n2\Sigma}}{R_{n1\Sigma} + R_{n2\Sigma}} \cdot \frac{1}{\eta} \quad (5.5)$$

where η - utilization of grid lines [10];

$R_c =$ =(2,58·1,04)/(2,58+1,04)·1/0,8=0,93

The required resistance grounding rod is determined by the formula $R_{cm} = \frac{R_c \cdot R_н}{R_c - R_н}$

(5.6)

where $R_н$ – required by GOST resistance

$$R_{cm} = \frac{1{,}126 \cdot 0{,}656}{1{,}126 - 0{,}656} = 1{,}3(Ом)$$ =(0,93·0,5)/(0,93-0,5)=1,0814

Defining a single vertical rod earthing conducted by formula

$$r_в = \frac{0.366\rho}{le}\left(\lg\frac{2le}{0{,}95bx} + \frac{1}{2}\lg\frac{4l_t + le}{4l_t - le}\right) \quad (5.7)$$

where *le* – lengthof rod, м;

l_t – distance from soil surface to the middle of the rod, м;

bx – width shelf angles, m;

By formula (8.7) yields

lg(2·6/(0,95·0,08)) =lg157,89= 2,02

lg((4·3,6+6)/(4·3,6-6))=lg3,143= 0,47

$r_в$ =(0,366·241,5)/6·(lg(2·6/(0,95·0,08))+1/2·lg((4·3,6+6)/(4·3,6-6)))=33,22Ом.

Determine the required number of vertical grounding by formula

$$n_e = \frac{r_в}{R_{ст} \cdot \eta_6} \qquad (5.9)$$

where η_6 – coefficient of use of vertical grounding, [10];

$$n_e = 33{,}22/(1{,}0814 \cdot 0{,}7) = 43{,}884911$$

Thus, the results of the calculations can be said that resistance grounding unit substation does not exceed 0.5 ohms, it is $R_з$=0,42<0,5 Ohm.

In electrical voltages above 1 kV in networks with grounded neutral grounding conductors tested for thermal stability by the formula.

$$S_т = I_p \cdot \frac{\sqrt{tn}}{K_т} \qquad (5.10)$$

Where $S_т$- The minimum allowable section of heat resistance, mm^2;

I_p – calculated current through the conductor, A;

T_n – the time of flowing of SC current on the ground, sec;

$К_т$ – temperature coefficient, for steel $К_т$=74;

$$S_т = 3200 \cdot \frac{\sqrt{2{,}6}}{74} = 69{,}7\left(мм^2\right)$$

Since the intersection of earthing conductors is 775 mm2 is obvious that the condition of thermal stability is performed.

CONCLUSION

In these work main types, places and methods of reduction of power losses were analized.

During this work next methods were implemented: compensation of reactive power, leveling of main transformers` load factor by smoothing day load graph and specified selection of cable cross section as the best methods, allowed for already operating industry.

Calculation and selection of main power supply elements of industry for voltage of 10 kV were performed.

Analysis of day load of workshop and industry was performed. Smoothed graph of load for leveling of main transformer`s load factor was proposed. Specified calculations of main transformer`s rated capacity were performed. Optimal operating mode of industry was picked.

Scheme of internal power supply of industry was designed. Preliminary and expedient calculations of cross-section were performed.

Calculation of the lightning protection and grounding of enterprise were performed.

As a result of the master`s thesis, analysis of optimal methods was made. The most effective method proved to be compensation of reactive power. With initial data of this master thesis this method allowed to decrease power losses of 81.7% in a share holding to the effect of implements of all the methods.

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