MINISTRY OF EDUCATION AND SCIENCE, YOUTH AND SPORT OF UKRAINE

VLADIMIR DAHL EAST UKRAINIAN NATIONAL UNIVERSITY

FACULTY OF ELECTRICAL ENGNEERING SYSTEMS

DEPARTMENT OF ELECTROTECHNICAL SYSTEM OF POWER CONSUMPTION

EXPLANATORY NOTE

of master’s thesis on the topic:

INCREASING OF EFFICIENCY OF ENERGY SYSTEM OF THE INDUSTRIAL COMPLEX BY VOLTAGE REGULATION

PM 101.104.000 EN

The student of ET–101mag ______________________________ Al-Nussairi Mohammed
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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:

INCREASING OF EFFICIENCY OF ENERGY SYSTEM OF THE INDUSTRIAL COMPLEX BY VOLTAGE REGULATION

РМ 101.104.000 ПЗ

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Луганськ 2012

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"____" _______________ 2012

Task for the master's thesis.

1. **Student** Al-Nussairi Mohammed
2. **Group** ET-101mag
3. **Topic** Increasing of efficiency of energy system of the industrial complex by voltage regulation.
4. **Task for the master's thesis.**
   - Calculation and selection of main power supply elements of industry
   - Analysis and determined voltage regulation methods.
5. **Contents (the main questions) –** according to plan.
6. **Graph materials.**
   1. Suggestions side plan of enterprise of power supply.
   2. One-line principal scheme of power supply.
   3. Basic diagrams of voltage regulation methods.
   4. Output voltage of enterprise.
   5. Output voltage of enterprise under action methods of voltage regulation.

7. Consultant.

Chapter	Consultant	Signature
1 – 3	Kuzmenko D.I.	
4. Labor safety	Kozhin V.M.	

8. Plan.

Name of the chapter	Date
1. Chapter 1 (VOLTAGE REGULATION)	
2. Chapter 2 (CONFIGURATION AND DESIGN OF POWER SUPPLY)	
3. Chapter 3 (CALCULATIONS OF VOLTAGE REGULATION METHODS)	
4. Chapter 4 (LABOR SAFETY)	
5. (Execution of the work according to ISO)	

Student ______________________

Scientific Head ______________________

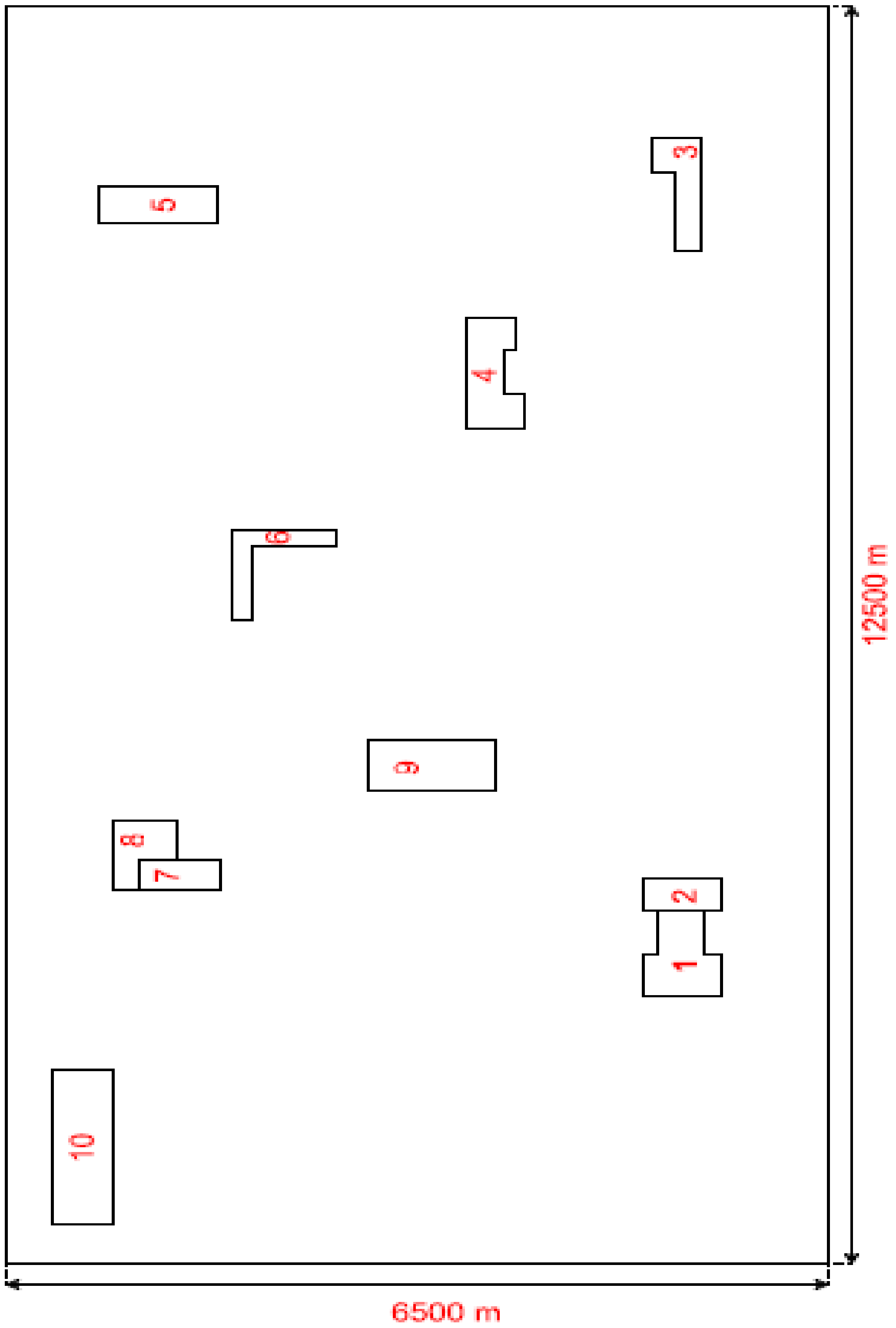
Date "____" ____________2012

Load characteristics of the plant	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
The active power, P , kW	1807	602	1472	828	636	1223	1527	1201	1642	1912
Power factor, cos φ	0.81	0.76	0.79	0.82	0.75	0.77	0.77	0.8	0.81	0.83
Summer load substation as a percentage of the winter load, Кл,%	70	90	75	85	90	75	80	85	65	60

Day load

Time interval ,t, hours	Name of workshops									
	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
0-1	30	25	35	50	60	40	30	35	45	50
1-2	30	25	35	50	60	40	30	35	45	50
2-3	40	35	45	60	70	50	40	45	55	60
3-4	65	60	70	85	95	75	65	60	70	85
4-5	65	60	70	85	95	75	65	60	70	85
5-6	65	60	70	85	95	75	65	60	70	85
6-7	75	90	80	95	100	85	80	70	80	75
7-8	75	90	80	95	100	85	80	70	80	75
8-9	90	95	90	100	100	100	95	90	95	95
9-10	100	100	100	100	100	100	100	100	100	100
10-11	100	100	100	100	100	100	100	100	100	100
11-12	75	90	80	95	100	85	80	70	80	70
12-13	75	90	80	95	100	85	80	70	80	70
13-14	80	90	90	90	85	90	95	90	95	95
14-15	80	90	90	90	85	90	95	90	95	95
15-16	80	90	90	90	85	90	95	90	95	95

16-17	80	90	90	90	85	90	95	90	95	95
17-18	80	90	90	90	85	90	95	90	95	95
18-19	80	90	90	90	85	90	95	90	95	95
19-20	75	90	80	95	100	85	80	70	80	70
20-21	75	90	80	95	100	85	80	70	80	70
21-22	80	85	75	80	70	75	80	85	85	85
22-23	25	25	25	35	35	30	30	30	30	35
23-24	25	25	25	35	35	30	30	30	30	35



Suggestion site plan site of enterprise

ABSTRACT

Explanatory note: Mohammed Al-Nussairi a master's degree thesis

on theme “Increasing of efficiency of energy system of the industrial complex by voltage regulation”

The work consists of introduction, 4 chapters and conclusions. It includes 113 pages, 16 figures, 6 of them on separate sheets and 25 tables. The reference includes 39 items.

The object of research includes electric power system industry, operate in constantly changing load.

The subject of research is changes in the parameters of the voltage during normal operation of the system power supply industry.

The purpose of work is to develop reduction measures of voltage fluctuations during the day.

Research Master's thesis are based on the basic principles of the theory of electrical engineering and electrodynamics and methods mathematical modeling.

This research studied the basis of voltage regulation in power systems industrial complex and the estimated the possibility of their application for change of the daily load diagram graph.

The first chapter analyzes methods of voltage regulation, and effect voltage regulation on some types of loads and characteristics of electrical power systems.

The second chapter includes the analyzes and calculations of main power supply equipment enterprise, the calculations show selection power transformers and transmission lines for voltage 10 kV and 110 kV.

The third chapter shows the analyzes and calculations of voltage and power losses in selected power elements enterprise according to load diagram graph by using iteration methods as first stage. Regulated the voltage of power supply elements by applying voltage regulation methods and estimate the results.

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

Developed by in the master's work measures will find a wide practical implementation to improve voltage regulation within 24 hours.

ELECTRICAL NETWORK, MATHEMATICAL MODELING, VOLTAGE FLUCTUATIONS, LOAD GRAPH, VOLTAGE REGULATION.

РЕФЕРАТ

Пояснительная записка Мохаммеда Аль-Нуссаири к магистерской работе на тему

«Повышение эффективности электрической системы промышленного комплекса при помощи регулирования напряжения»

Содержит 113 страниц, 16 рис., 25 табл., 39 источников.

Объектом исследования являются электрические распределительные сети 6-10 кВ, работающие с токоограничивающими реакторами, в режимах короткого замыкания и резкопеременной нагрузки.

Предметом исследования являются режимы работы сетей 6-10 кВ при возникновении многофазного замыкания или резкопеременной нагрузки.

Целью работы является разработка виртуального тренажера в среде Simulinc для исследования режимов работы электрических сетей с использованием токоограничивающих реакторов.

Исследование магистерской работы базируются на основных положениях теории переходных процессов в электрических сетях, а также методах математического моделирования.

В результате проведенных исследований изучены электрофизические основы установившихся и переходных процессов в электрических сетях при многофазных замыканиях или резкопеременной нагрузке и влияния на эти процессы токоограничивающих реакторов.

В первой главе анализируется методы регулирования напряжения, а эффект регулирования напряжения на некоторые виды нагрузок и характеристик систем электроснабжения.

Вторая глава включает в себя анализ и расчеты основных предприятий питания энергетического оборудования, расчеты показывают, выбор силовых трансформаторов и линий электропередачи напряжением 10 кВ и 110 кВ.

В третьей главе приведены анализ и расчеты напряжения и потери мощности в отдельных предприятий элементов питания в зависимости от нагрузки диаграммы графа с помощью итерационного расчета, как первый этап. Регулируемые напряжения элементов питания путем применения методов регулирования напряжения и оценить результаты.

Четвертая глава содержит расчет молниезащиты и заземления предприятия.

Разработанный в магистерской работе виртуальный тренажер найдет широкую практическую реализацию для повышения эффективности обучения студентов и упрощения проведения дальнейших исследований магистрами.

ЭЛЕКТРИЧЕСКАЯ СЕТЬ, ТОКООГРАНИЧИВАЮЩИЙ РЕАКТОР, МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ, КОРОТКОЕ ЗАМЫКАНИЕ, РЕЗКОПЕРЕМЕННАЯ НАГРУЗКА, ВИРТУАЛЬНЫЙ ТРЕНАЖЕР.

Contents:

INTRODUCTION

Electrical energy is a product and, like any other product, should satisfy the proper quality requirements. If electrical equipment is to operate correctly, it requires electrical energy to be supplied at a voltage that is within a specified range around the rated value. Equipment can be divided into two main groups; that which is used to supply the electrical power (network equipment), and that which consumes the electrical power in the form of appliances such as motors (customer loads).

While network equipment and customer appliances may have associated maximum voltage ranges within which they will function satisfactorily, they may only be able to operate near the extremes of this voltage range at the expense of attributes such as life span, performance and efficiency. The operating voltage ranges for equipment and appliances are usually standardized nationally, and due to the forces of the global market place, there is continual pressure to rationalize and standardize specifications.

Keep the specified range around the rated value of voltage in electrical power systems constrained many problems.When power, and hence current, flow in an electrical system the resultant voltage drops in the network impedances result in a change in the magnitude of the delivered voltage. While there are different types of voltage variations, such as those resulting from system faults, load rejection, motor starting, non linear loads and rapidly varying loads.

The equipment connected to a utility system is designed to operate at a specific voltage. It is difficult to supply power to each customer at a voltage exactly equal to what is written on the customer equipment nameplates. The main cause of this difficulty is that there is a voltage drop in each element of the power system: generation, transmission, and distribution, in addition to the internal wiring of the customer ’ s installation. The customer who has a large power demand or receives its power through large impedance is exposed to lowest voltage. This is because the voltage drop is proportional to the magnitude of demand current and the entire impedance between the source and the customer.

The customers nearest to the power source, has the least voltage drop, while the last and the farthest customer has the largest voltage drop regardless of the voltage drop resulting from the internal wiring of the customer installation.

To supply power to customers at a voltage of constant magnitude or within narrow limits, the power cost on utility side will be highly increased. On the other hand, if the supplied voltage is within broad limits to avoid the cost increase on utilities, the equipment must be designed to withstand a wide range of voltage variation. In this case, the equipment is expensive, that is, the cost on the customer's side is increased.

Reactive power plays a role in the variations of voltage in power supply system. The voltage magnitudes can be controlled to desired values by control of the reactive power. Increased production of reactive power results in higher voltage near the production source, while an increased consumption of reactive power results in lower voltage. Increasing reactive power in power system will cause to increase current in transmission line and for over long distances , voltage drop at customer will also increase. Because power flow is the product of active current and voltage, any drop in voltage will result in an increase in active current. For example, a drop in voltage is accompanied by an increase in active current. Likewise, the current associated with any reactive power flowing in the same circuit will also increase, though we are ignoring that effect here. This increase in current increases I^2X losses in lines and transformers.

Therefore, voltage control in power system to deliver voltage to customers within a suitable range is necessity. The amount of energy consumed by appliances varies with the magnitude of the applied voltage. Considerable research into the relationships between voltage, demand and energy consumption has been performed. The results of applied research in reference concluded that for every 1% reduction in the average voltage supplied to the consumer the energy consumption (and hence revenue) reduces by between 0.9% and 1.6% for residential, 0.5% to 1.2% for commercial, and 0.6% and 1.2% for industrial loads.

1. VOLTAGE REGULATION

1.1. METHODS AND MEANS OF VOLTAGE REGULATION IN POWER NETWORKS.

Voltage regulation in power networks is difficult to implement, modifying:

a) voltage power plants (voltage generators);

b) the transformation coefficient of transformers and autotransformers

c) magnitude of reactive power flowing through the network.

d) parameters of transmission line

Application of these methods provides centralized voltage regulation, but the last three of these can be applied to local regulation.

Consider, for more methods of voltage regulation applied to electrical networks.

1.1.1. Regulation of voltage electric generators at power plants

Generators power energy systems operate on a common power grid and therefore the mode of their operation is subject to the general requirements for electrical systems. For example, the basis of providing the design levels of the voltage at the nodal points of electrical networks, power plants, together with the assignment to develop active power schedules are given as reactive power generation; maximum - in the morning and evening peaks of the active load and a minimum-night.

Generators operating in the blocks with a step-up transformer, it do not have direct connection with the voltage system of with distribution networks, and load their own needs, generally is fed through transformers with voltage regulation under load. Therefore, a wide variation of reactive power generation and the consequent large change in voltage at the terminals of the generators do not cause much difficulty. Typically, the block generators use the full limit of the possible changes in the voltage according to the ГОСТ 13109-97: -5% to 10% U_n.

On generators, at operating the voltage bus connected to distribution system, voltage is regulated to smaller limits, as a profound change in voltage would have been unacceptable for consumers. When regulating reactive power on these generators on schedule load of the system voltage level on the buses, necessary for normal operation of the consumers, achieved by changing the transformer ratio of transformers with tap changer. Generators connecting to the high voltage network.

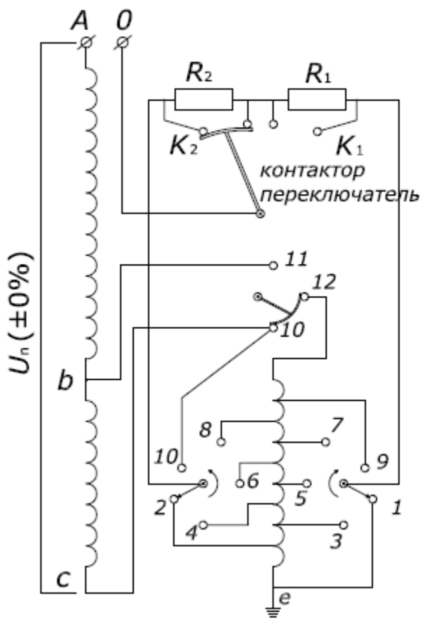
In cases where the generator transformers connection to the HV network do not have tap changer, voltage regulation on the buses of the generator voltage by varying the generator excitation, with automatic change of reactive power. Regulation - the counter and implemented on the daily schedule the voltage specified by the controller of electrical networks.

1.1.2. regulation of voltage change of ratio transformers, change network parameters, change magnitude of reactive power.

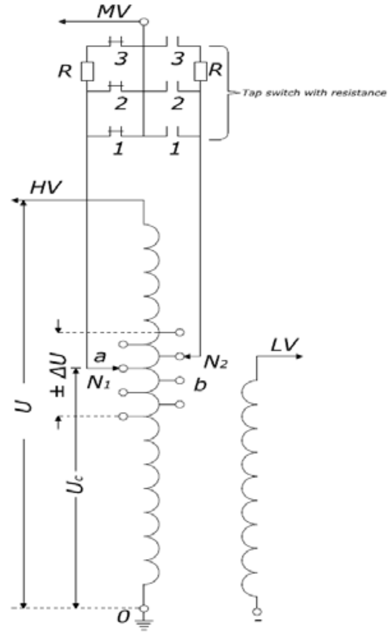
Both urban and rural distribution networks for voltage 6-10 kV, usually, transformers are equipped with of low power (up to 400-630 kVA), in which transformation coefficient to within ± 5% changes by switching winding taps in HV transformer is disconnected from the network, i.e., without excitation of the transformer . Therefore, transformation coefficient of the transformer, or just change when changing power supply schemes, or in going from seasonally peak loads to a minimum and vice versa, i.e., is seasonally regulation. The daily voltage regulation in these networks is assigned on the substation. The proper transformation coefficient for the long seasonal period selected based on the voltage levels on the buses and the substation and voltage losses in the distribution network.

In order to ensure centralized regulation voltage at the substations daily , which feed the distribution network, install transformers with tap changer, tap switches which is performed without interruption of electricity consumers. The transformers are equipped with automatic control equipment - voltage regulators that are included in complete supply.

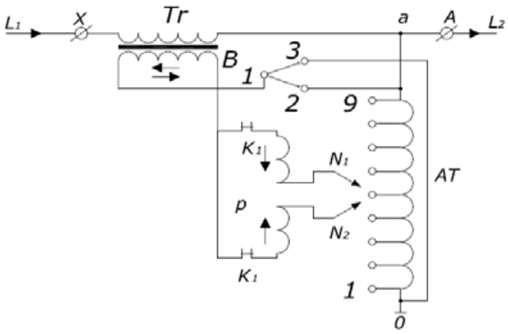
Built-in adjustment device in 35-330 kV voltage transformers located in the neutral of HV winding. The range of voltage regulation ± 12% or ± 16% of rated voltage in steps of 1.5 or 1.78%. Three-winding transformers 110 and 220 kV are manufactured with just tap changer on the winding HV, MV has a winding branch to change the transformer ratio ± 2 - 2.5% switched without excitation of the transformer .



a)



b)



c)

Fig 1.1

a) Diagram of voltage transformer with a tap (for one phase).

b) Diagram of voltage autotransformer 220-330/110 kV.

c) Diagram of one phase of linear adjustment of the autotransformer type (LTDN)

1.1.3. Voltage regulation in networks by compensating reactive power

To effectively regulate voltage by changing the reactive power in the network by using the synchronous compensators, or capacitors, batteries when you turn on them in parallel load. Synchronous Compensator (SC) set on the destination are connected to the substation and the substation LV bus bars or LV winding autotransformer. Which is the compensator and the synchronous motor with over excitation is a capacitive load to the network or, equivalently, Such a compensator is a synchronous motor and overexcitation is capacitive load to the network or, equivalently, the generator reactive power of the inductive, while under excitation becomes a consumer of reactive power. Mayor way by changing the excitation of a synchronous compensator, directly affect the magnitude of reactive power flowing through the network, and thus the voltage at the consumer.

Let us show a simple example of power transmission lines with over the radial load on the end and a synchronous compensator SC connected parallel with the load (Figure 1.2).

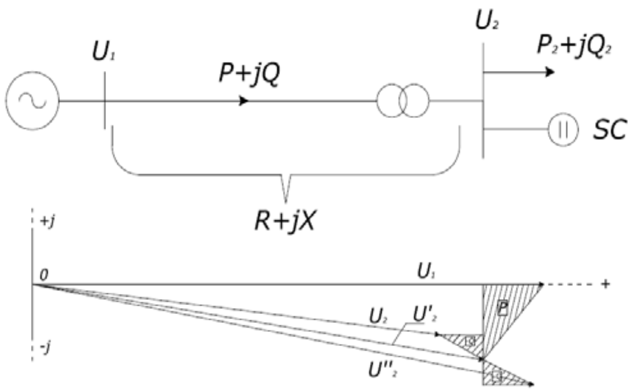


Fig 1.2- synchronous compensator SC connected parallel with the load

Suppose for simplicity that power transmission shown in Fig.(1.1), and can provide a element with an impedance R + jX. Then the voltage at the end of transmission power

P + jQ is:

$$U_2 = U_1 - \frac{P_1 \cdot R + Q_1 \cdot X}{U_1} - j \cdot \frac{P_1 \cdot X - Q_1 \cdot R}{U_1} \qquad (1.1)$$

Voltage regulation with SC proceeds smoothly. Regulation range depends on the power SC and the value of reactive load line.

Nominal power of synchronous compensator is generating power at their reactive (the inductive) power, i.e., when working with over excitation. When working with a compensator under excitation or without excitation, i.e., in the mode of consumption of reactive power (which requires at minimum load), its maximum capacity is 40-60% of the face. It is because the excitation current SC decreases, approaching with an increase in reactive power consumption to zero. To increase the capacity of the SC in the mode of consumption of reactive power resorted to the use of it negative arousal. In this case, its power is generated by at least 0.65 of the nominal power.

Synchronous compensators are made on the power of 10 and 16 MVA for voltage 6.3-10.5 kV and 25-100 MVA for voltage 10.5 kV. SC power more than 25 MB are manufactured with a hydrogen cooling. The large SC is usually used to schedule the generation of reactive power in the system and so provide a centralized voltage regulation.

In some cases, when the calculated power is less than the minimum set of compensating power SC, or when you do not want her work in the mode of consumption of reactive power, install controlled capacitor banks (CCB), divided by number of sections. Maximum capacity of the sections determined by the allowable deviation of voltage at the secondary substation buses receiver. CCB are more economical than the SC and, therefore, are spreading.

The CCB high power (100 or more MVA) set also in large regional power substations, with a sufficient number of SC for the operation, consumption of reactive power at

night. CCB high power bus are included directly on the high voltage - 110 kV.

For local voltage regulation in large industrial enterprises, especially in the cases, where their power is produced along the lines with a large reactance, are effectively used asynchronous motors with capacity 1000-10 000 kVA. During normal motor load factor (0.7 pH), the available reactive power at a voltage of the terminals 0.9 - 1.0 U_N is from

1.3 to 1.5 Q_N. The regulation, as well as synchronous compensators, is smooth, and this process can be automated. In those factories where there are UBC established for reactive power compensation, they can be used as a tool for voltage regulation, not engaging in conflict with their main purpose.

1.1.4. Voltage regulation in networks change network parameters

In certain limits, the voltage can be regulated by changing the resistance of power supply. So, So if the power supply or a site consists of several parallel lines, then turning off during the hours of minimum load one of these lines, can be increase the loss of voltage in power supply and the lower the voltage at the consumer.

Reduce the reactance circuit and, therefore increasing the voltage at the maximum load can be achieved by applying a longitudinal line inductance compensation.

The voltage level at the receiving end of a line in the presence of longitudinal compensation with resistance X_C is given by:

$$U_2 = U_1 - \frac{P_1 \cdot R + Q_1 \cdot (X - X_C)}{U_1} - j \cdot \frac{P_1 \cdot (X - X_C) - Q_1 R}{U_1} \qquad (1.2)$$

The formula shows that the change in the value of X_C (eg, shunt capacitors at lower loads) can be performed step regulation voltage.

In the long transmission lines, series compensation is used to increase their capacity. The number of capacitors in series compensation for a battery is determined by the desired voltage level at the receiving substation and maximum load of the line. In the high-voltage typically compensate for up to 40-50% of the inductance of the line, since a large degree of compensation can lead to wrong operations protection relay, and under certain conditions and to an oscillatory mode of synchronous generator.

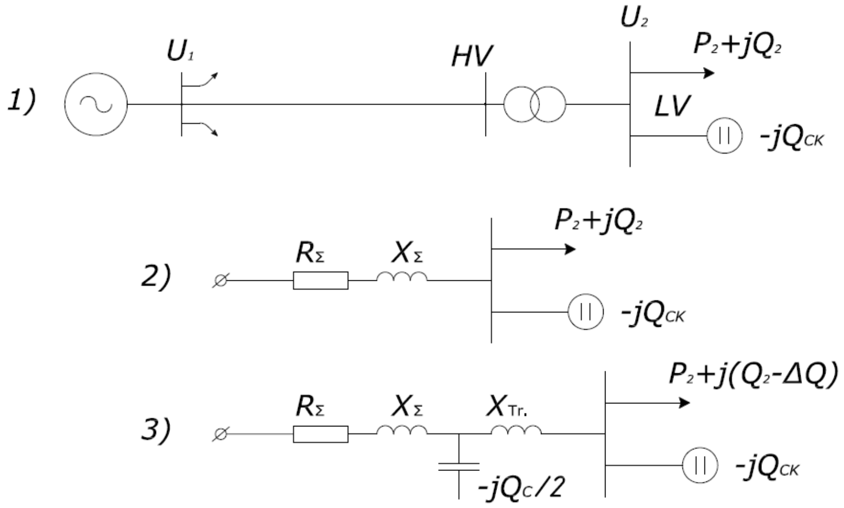


Fig 1.3- Power transmission with SC at busses LV and its equivalent circuit.

1.2. Problems of Voltage Regulation in Distribution Electrical Networks in Terms of Quality Electric Power and Reduction Energy Losses

One of the most important characteristics of power quality is a tolerance of voltage at the points supply electric power to consumers. The steady-state voltage tolerance is a measure of the quality local electric power, and regulation of the level of voltage can be performed at power plants in the production, and in transmission line and distribution of electrical energy.

Therefore, to maintain concert the steady tolerance of voltage at the terminals for power consumers must involve all organizations, engaged in the production, transmission and distribution of electric energy, and also the consumers of electricity have the means of regulation voltage and reactive power compensation, impacting to mode voltage in power supply .

For the consumer ,it is important to the voltage tolerance were maintained at points supply within such limits, which provide normal operation of electrical of electrical receivers and the consumer. According to ГОСТ 13109-97 values of voltage tolerance at the terminals of for power consumers should be within ± 5% with 95% , and does not extend beyond the ± 10% of rated voltage. Taking into account that a point supply of electricity, usually , does not match with terminals for power consumers, the values of voltage deviations, which should be maintained at this point, in general, differ from the above rules of the standard.

The actual values of voltage deviations at a specific point of delivery, is known, depend on the voltage levels supported by on the buses of 6-10 kV substation, and the voltage loss in elements of distribution network to the consumer. In other word, voltage losses in the distribution network depends on the load attached to it customers and the parameters of the network elements. Therefore, the voltage mode control in the distribution of electric network is reduced to two technical problems;

a) to provide the distribution network voltage loss is generally not exceeding the limits specified in standard ГОСТ 13109-97.

b) establish and maintain power in the center of this law regulation voltage, which satisfies the requirements of the most consumers connected to that network.

The level of voltage depend on technical power loss, arising as the transmission of electric power, and in its consumption. For example, load losses, i.e. losses in the longitudinal part of the substitution circuits of lines and transformers, are inversely proportional to the square of the voltage.

$$\Delta P_{tech.} = k^{2} \cdot \Delta P_{LOAD} \left(\frac{100}{100+\delta U}\right)^{2} + \Delta P_{NO-LOAD} \left(\frac{100+\delta U}{100}\right)^{2} \qquad (1.3)$$

Where ΔP_{LOAD}, $\Delta P_{NO-LOAD}$ - loss of load and no-load, at nominal voltage;

δU - voltage tolerance from nominal,%.

In general, the total of the losses can be represented by the following formula:

$$\Delta P = \Delta P_{tech.} + \Delta P_{com.} + \Delta P_{inst.} \qquad (1.4)$$

Where $\Delta Ptech.$- technical power loss,

$\Delta P_{com.}$- commercial losses;

$\Delta P_{inst.}$- instrumentals losses

It is clear ,which is more often seen in the dependence of technical power losses from network utilization. That means, the voltage losses in the seasonal maximum and minimum load modes allows to specify power losses and to identify areas with the maximum levels of network losses, does not allow quality electric power supply that meets the requirements of ГОСТ13109-97.

Evaluation of existing voltage losses in distribution networks 6 (10) and 0.38 kV can be produced by two methods: on the basis of the calculation operating modes of network or based on measurements of voltage losses.

Therefore, a more suitable method for calculating the modes in the distribution network on the basis of available information on loads and network parameters, although the error in determining the loss of voltage in this case can be higher.

The reliability calculation can be checked during the measurement operating parameters in specific points of an electrical network.

The input to the calculation of loss of voltage and the choice of parameters regulation are load data of substation load and network for at least of the two modes; Maximum and minimum daily loads of the substation in the characteristic annual period of time.

To determine the maximum and minimum daily load of the substation necessary to have daily load schedules, on the basis of which according to / 1 / can be defined 30 minutes of maximum and minimum loads, intervals of daily maximum and minimum loads, and power rating of these substation in the corresponding time intervals.

As for the load of network transformers, it is known that their measurement by performed twice per year. In this case moment of measuring the load may not match the time interval the largest loads of substation, that does not allow to determine with enough certainty necessary to select the regulation parameters data, i.e. load of network transformers in the modes of maximum and minimum load of substation.

Therefore to obtain loads of network transformers required day intervals using standard graphics load transformer substations.

Recent research on the development of standard schedules conducted in the late 70s - early 80s and are reflected in the technical literature. However, during the period of time since obtain of the standard schedules have been significant changes in the consumer loads. In this regard, for the calculation of losses in the voltage distribution networks is undertaken validation standard schedules. On the basis of the calculation mode in the distribution power supply of voltage regulation parameters selected in this network - the law regulating the voltage to the CPU and adjusting branch network transformers 6 (10) / 0.4 kV.

Experience shows that keeping of contract terms of tolerance of voltage between the power system and territorial electrical network, generally, hindered by the absence of counter of automatic of voltage regulation at the buses feeding centers. The absence of such regulation in the centers of power supply is against requirements of electrical networks rules .

In the power system is often operated by equipment has capable to provide not only automatic, but the station director voltage regulation, so the performance of contract terms require to replace obsolete equipment.

It is not always The requirements of electrical networks rules in the periodic measurements of (2 times per year) voltages and currents on the buses of 0.4 kV transformer substations each followed by analysis and selection, corresponding corrective measures.

As a result of work carried out by experts operating "NC LINVIT", it can be concluded that one of the most intractable issues in configuration mode voltage is to coordinate of work on counter-regulation of the voltage between the electrical network, is the center of power supply, and the electrical network, whose electrical networks, are connected to these centers of power supply and carry power end consumers.

To provide compatibility mode voltages in electrical networks electrical network must be different;

1- definition for reference points, set by the electrical network, acceptable ranges of voltage variation that provide in the end, fulfillment of the requirements standard for terminals for power consumers.
2- ensure coordinated work of the different regulating devices installed to keep range of voltage tolerance of electrical network.

It should also be noted that for optimal mode configuration for voltage in an electrical network in characteristic of periods of the annual maximum and minimum load necessary to establish system for collecting information and updating the calculated values. Obviously, that the commitment of each electrical network to maintain a certain range of voltage changes at the control points need to enter into contractual terms concluded by the parties.

1.3. Power and energy savings

The most obvious benefit of voltage regulation, and the one that is most advertised by suppliers, is energy saving. This benefit must be analyzed with caution, keeping in mind that voltage regulation has an immediate impact on power, not energy. In some cases the two are directly related, but in others the connection is not so obvious. Some preliminary estimates are made here, but this is certainly a topic that could be examined further. There are several classes of load with different power-energy relationships.

1.3.1. Incandescent lighting

The power consumption is proportional to voltage squared and the duty cycle is unaffected by the voltage. It should be noted that as the voltage is reduced, the efficacy (light output per watt) drops substantially (a disadvantage), and the lamp lifetime increases, which is an advantage. Decreasing light levels due to reduced voltage might prompt customers to increase lamp wattage or add lighting, negating some power savings. Incandescent lighting is assumed to make up 75% of residential lighting and 25% of commercial lighting.

1.3.2. Other lighting

This class includes fluorescent (linear or compact) and high intensity discharge lighting, which are assumed to make up 75% of commercial lighting, and 25% of residential. The power depends on the voltage,but the dependence is flatter than incandescent lighting.

Some newer or premium ballasts are regulated, so that the power consumption is unaffected by voltage, but for this study we will assume the power is proportional to voltage, and the duty cycle is unaffected by voltage.

1.3.3. Electric heating

This class includes space heaters, water heaters, and thermostatically controlled, electrically heated appliances such as ovens and clothes dryers. These loads consume peak power at a rate proportional to the voltage squared, but since they are controlled by thermostats the energy consumption is determined by the thermostat set point.

The duty cycle increases to make up for the reduced power, and the energy consumption is unaffected by voltage. For example, if the voltage is reduced 5% the heat output of an oven element is reduced about 10%, but it will be on 10% longer in each thermostat cycle to maintain the oven temperature. When averaged over the cycle time, voltage regulation has negligible impact on the average power or total energy consumption of these appliances.

1.3.4. Refrigeration

This category includes refrigerators, freezers and air conditioners. As with heaters, the average power and total energy consumption are determined by thermostats, and voltage control has little impact on the energy consumption. In this case, since the main load is a fully loaded compressor motor the peak power will also depend very little on the voltage, so we assume no impact on either peak power or energy with this type of load. One factor which we will not include is the defrost cycle of frost-free refrigerators. During this part of the cycle, a heater operates to melt frost, using additional power proportional to the square of the voltage. For this report the effect is neglected, but it may warrant further examination since it could have an impact on the dependence of load on voltage.

1.3.5. Motors

Aside from refrigeration loads, the most significant motors in the residential sector would be furnace fan motors, and in the commercial sector HVAC motors, typically small single phase or three phase induction motors. The dependence between voltage and power with these motors is complicated. At idle or minimum load, as the voltage is reduced the core losses are reduced with the square of the voltage while other losses are unchanged, resulting in a dependence between linear and quadratic. Near full load there are two effects. If the motor load and speed (and thus the power output) are held constant, the motor current must increase, resulting in higher resistive losses in the windings, decreased efficiency, and a power consumption that increases with decreasing voltage. In practice, the slip will increase slightly and the motor speed will decrease with decreasing voltage.

If the motor is driving a fan, the decrease in speed reduces the output power (with the cube of the speed) and the net result may be that the decreased efficiency is more than offset by the decreased output power, leading to a slight drop in electrical power consumption. An efficiency model for a 1 hp fan motor gives the following power changes for a 10% voltage drop: -0.5% at 75% load, -1% at 50% load, and –16% at no load. Assuming that most motors are loaded to at least half rated load, we will use the 50% load value for this study, i.e. 1% power reduction for 10% voltage reduction. The duty cycle is assumed to be unaffected by air flow rate or voltage.

Each of these load types has a load response of the form , where V is the voltage, $P \propto V^a$ and $P \propto E^b$ is the peak power consumption, and E is the total energy consumption over a longer time (hours or days). The coefficients a and b depend on the load type, and range from 0 (no change with voltage) to 2 (quadratic, which for small changes gives a power change twice the voltage change). When the components are combined in their typical proportions, the power and energy of the combined load have the same form, but the averaging produces average values of a and b that depend on the load composition. The power and energy coefficients for each type are illustrated in Figure 1, which shows the power and energy changes that will result from a 6% voltage reduction for each load type .

1.4. Reduced Distribution System Cost

Under some circumstances customer voltage regulation may be a cost-effective alternative to improving system voltage control. This is likely to be applicable primarily in cases where a small number of customers are affected by daily or seasonal variations in loading on a long line. When customer voltages begin to stray outside the accepted limits the normal practice would be to install fixed or switched capacitor banks to maintain acceptable voltage. The capacitor size and cost are determined by the total load and the line impedance. The cost of customer voltage regulation, on the other hand, is determined by the number and size of affected customers.

In a case where the variable load is large and very few customers are affected, the use of customer voltage regulation is likely to be a good alternative.

Whether the line upgrade is eliminated or deferred, the cost savings could justify direct purchase and installation of a number of customer voltage regulation units. In the event that the capacitors are later installed, the regulators could be removed and installed elsewhere as needed.

1.5. System Stability

Under normal circumstances, one of the factors that helps stabilize the system is the dependence of load on voltage. If the generating capacity is reduced by the loss of a generator or line, the voltage tends to drop, which reduces the connected load. Similarly, if the voltage on a distribution line drops, the natural load reduction helps compensate for the drop and reduce the impact. The widespread installation of customer voltage regulation on either a line or the system reduces this tendency, and could in principle reverse the feedback to the extent that the system becomes unstable. In a worst case scenario, if all customers on a line had regulators and a system event caused a momentary voltage reduction, the regulators would maintain constant power by increasing their current demand. Since system losses are largely current dependent, the load would actually increase, and the system voltage could eventually collapse or go into slow oscillation. In practice, it is unlikely that enough of the system would be on customer regulation to cause such problems, but if the technology is widely adopted within parts of the system, the impact on stability should be assessed.

1.6. Power Quality

Since current technology is relatively slow to respond, customer voltage regulation is unlikely to have much impact on most aspects of power quality. Transients would be largely unaffected, as would outages. Sags and surges of relatively long duration (seconds to minutes) might be corrected by these voltage regulators, with two consequences. Customers equipped with voltage regulators would see very little change, as the regulators would correct the voltage at their main panel. For other customers on the same line, however, the impact would be negative. If a 10% sag occurred on a line where half the customers had regulators, the regulated customers would draw10% more current to compensate for the reduced voltage, which would make the sag worse for other customers.

With normal system impedances this is unlikely to have a severe impact. Perhaps a more serious concern is the possibility of introducing frequent voltage changes that could result in light flicker. Depending on the step size and frequency, voltage regulators could introduce periodic voltage fluctuations that might cause flicker problems, especially if a situation occurs where different regulators interact with each other to cause ‘hunting’ or oscillation.

2.CONFIGURATION AND DESIGN OF POWER SUPPLY

The electrical power system of industrial region consists of electrical equipment intended for providing of consumers by electric energy. Electrical power supply carries out the process of transmission, distributing and consumption of electric power.

The characteristics of equipment of power supply ,for example rating of power , voltage ,current, and losses, determine by load which connected to these equipment. At the first step to design and select equipment of power supply ,will calculate apparent power and reactive power of loads at each workshop.

2.1 CALCULATION OF ELECTRICAL LOADS

2.1.1 Short characteristic of consumers of a district

Calculation of powers is executed in a complex form. Consumers` powers are expressed in complex form.

We make calculations for transformer workshop №1. Consumed total power in the peak mode, kVA;

$$S_1 = \frac{P_1}{\cos\varphi_1} = 1807/0.81 = 2230.86 \qquad (2.1)$$

Consumed reactive power in the peak mode, kVAr

$$Q_1 = \sqrt{S_1^2 - P_1^2} = (2230.86^2 - 1807^2)^{0.5} = 1308.25 \qquad (2.2)$$

Loads of transformer substations are chosen from source data and resulted in table 2.1

Powers of workshops Table 2.1

Work shop	Load in the peak mode,P+jQ,MVA			Total power S	p.f.	Secondary nominal voltage U_L,kV
WS-1	1807	+j	1308.25	2230.86	0.81	10
WS-2	602	+j	514.81	792.11	0.76	10
WS-3	1472	+j	1142.40	1863.29	0.79	10
WS-4	828	+j	577.95	1009.76	0.82	10
WS-5	636	+j	560.70	848.00	0.75	10
WS-6	1223	+j	1013.41	1588.31	0.77	10
WS-7	1527	+j	1265.32	1983.12	0.77	10
WS-8	1201	+j	900.75	1501.25	0.8	10
WS-9	1642	+j	1188.79	2027.16	0.81	10
WS-10	1912	+j	1284.87	2303.61	0.83	10

2.1.2 The Load Center

One of essential elements in distribution system planning is the location of the load center where the primary substation is situated. Establishment of load center or primary substation particularly in a densely populated area ,must be prepared in long-term plan , for example in 10 year plan. The outlets form the primary substation will then supply the required electrical energy to the nearby customer loads . Customer substations will then further transformer the distribution high voltage to low voltage.

Load center can be located through the equations :-

$$X_0 = \frac{\sum_{i=1}^{m} S_i \cdot X_i}{\sum_{i=1}^{m} S_i}; \; Y_0 = \frac{\sum_{i=1}^{m} S_i \cdot Y_i}{\sum_{i=1}^{m} S_i}, \qquad (2.3)$$

where S_i total power of load nodes , kVA;

$X_i, Y_i -$ coordinates of placing of load nodes on a plan, mm.

Coordinates of workshops Table 2.2

Number of workshop	S	X,	$S \times X$,	Y,	$S \times Y$,
	KVA	mm	KVA·mm	mm	KVA·mm
WS-1	2230.86	3080	6871049	1160	2587798
WS-2	792.11	3662	2900707	1160	918848
WS-3	1863.29	10826	20171978	1196	2228495
WS-4	1009.76	8902	8988884	2646	2671825
WS-5	848	10530	8929440	5780	4901440
WS-6	1588.31	7030	11165819	4426	7029860
WS-7	1983.12	3856	7646911	5130	10173406
WS-8	1501.25	4050	6080063	5404	8112755
WS-9	2027.16	4956	10046605	3140	6365282
WS-10	2303.61	1156	2662973	5898	13586692
Formula for a result	$\sum_{i=1}^{m} P_i$		$\sum_{i=1}^{m} P_i \cdot X_i$		$\sum_{i=1}^{m} P_i \cdot Y$
Result	16147.47		85464427		58576400

$$X_0 = \frac{\sum_{i=1}^{10} S_i \cdot X_i}{\sum_{i=1}^{m} S_i} = 85464427/16147.47 = 5293$$

$$Y_0 = \frac{\sum_{i=1}^{10} S_i \cdot Y_i}{\sum_{i=1}^{10} S_i} = 58576400/16147.47 = 3628$$

Center load located at coordinates (5293,3628).

At this coordinates will be located main substation (110/10) to feed the workshops.

2.1.3 The basic requirements to the circuit layout

The circuit layout must provide necessary reliability of power supply with the least expenses, necessary quality of supplied electrical energy, convenience and safety operation, possibility of further development of network and involvement of new consumers.

Absolutely no-break power supply of consumers is practically impossible. The interruptions of feed are possible at any amount of reserves lines. Additional expenses on backuping can considerably promote the prime price of electric power.

Minimum the necessary backuping concerns by the category of reliability of electro-receivers. Power supply of consumers of the I category must be providedby two independent sources.

Electro-receivers of the II category it is also recommended to provide electric power from two independent feed sources. For them we will assume an interruption in power supply in a time of including of reserve feed to the attendants of personnel or personnel of departure operative brigade.

Apply the method of variants for construction of rational network configuration. A few variants compare for the set location consumers and choose the best on the basis of techno-economic comparison.

For constructing of rational network configuration in project practice is used a variant method, in which several variants are chosen for specified placing of consumers. The best of them is chosen for the reason of techo-economic comparison. By the terms of reliability, it is allowed to connect into single electrically connected group 6-3 consumers with voltage 35-220 KV (the least number is related to the highest voltage).

For providing of necessary reliability of district supply with prevailing loads of I and II categories it is possible to use open-loop reserve networks (radial, backbone, backbone with submains, including the shortest connection network) or simple closed networks (with double-ended feeding or circled). An example of network configurations is given on figure 1.2, where under the feed source (SUB.) is meant a feed source or a tie-station.

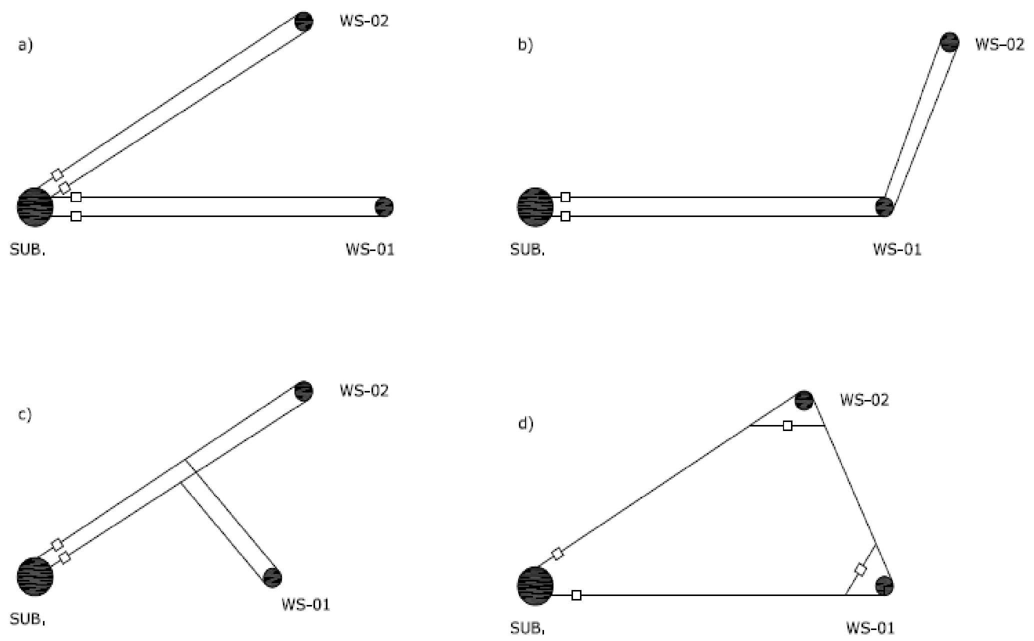


Fig 2.1- Possible schemes of consumers` feeding: a) radial, b) backbone,

c) backbone with submains, d) circled.

It is necessary to mention, that power lines with two-circuit towers don`t secure necessary reliability of power supply of consumers of I category in IV condition and special district on glaze, because of possibility of total interaption of supply by failure. That`s why power lines for supplying of such consumers are made from single-circuit towers.

Circuit layout to a considerable extent influenced on selection of scheme of distribution device of consumers` substations. For substations, which are feeded from closed networks, for distributing device, the “bridge” scheme is chosen:

-with breakers in transformers circuits (or lines), if projected network is placed in IV or special district on glaze;

-with automated disconnectors and short circuit (breakers optional) in others district on glaze.

In radial and backbone networks distribution devices of consumers` substations are made by scheme “block of line-transformer” with breakers or automated disconnectors and in short circuitors in transformer`s circuits, depend on district on glaze.

For searching of the most economical solution it is needed to make numbers of technically embodied variants of circuit layout, which are differ by technical and economical characteristics, answered the demands.

It is necessary to pass energy to the consumer on the most short way. For decreasing of variant`s quantity it is needed to divide consumers to several groups, in terms of their siting,

relative to feed source FS. Each group must be considered separately of other groups. It makes possible to plan limited quantity of variants and use the most easy and reliable schemes, that demands the least numbers of lines and substation devices for operation

If some load node, situated near power lines, connects feed source and tie-station TS, it is needed to separate it to independed group and feed it froma subcircuit of this power line or made power line of external supply after backbone scheme.

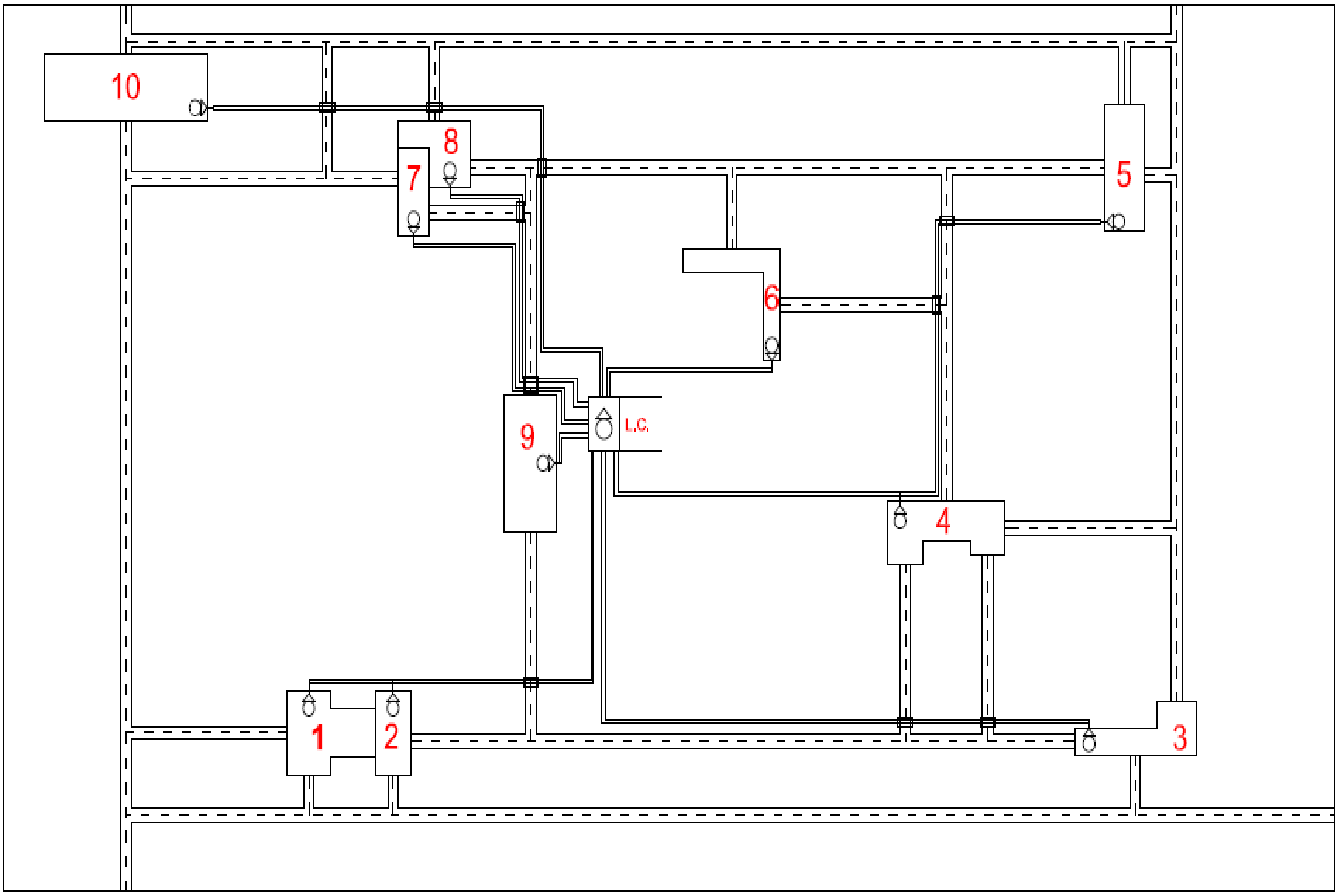


Fig.2.2- Plan of placing on locality of workshop and load center (LC)

2.2 Selection Power Transformer

2.2.1 Selection of transformer stations powers

Setting on substation two identical transformers provides minimum necessary reliability of electric supply of users (I and II category) and it's economic the most expedient decision. In case of setting off one transformer and second transformer is overload, with maximum of overload of 40%.Necessary power of transformers ($S_{TRANS.}$) is equal

$$S_{REQ.}=(0.65\ldots0.70)S_P \qquad (2.4)$$

where S_P - is apparent power workshop in the mode of the peak load.

Rated power of transformer at the substation according to (2.4) is determined, MVA:

$$S_{REQ.}=(0{,}65...0{,}7)S_P = 0{,}7\cdot 2230.86 = 1561{,}60 \text{ kVA}$$

Calculated power of transformers, obtained by the formula (1.4), is rounded to the nearest standard power $S_{TRANS.}$ on the scale of GOST 11920-85, GOST 12965-85, kVA: 25, 40, 63 100, 160, 250, 400, 630, 1000, 1600,1800

We select two transformers for WS-1 of workshop №1 the power of which is

$$S_{TRANS} = 1600 \text{ kVA}$$

In normal mode transformers will work with load factor:

$$L.F.=\frac{S_P}{2\cdot S_{TRANS.}} = 1561{,}60/(2\cdot 1600)=0.697<0.7 \qquad (2.5)$$

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

$$L.F.E.=\frac{S_P}{S_{TRANS.}} = 1561.60/1600=1.39<1.4 \qquad (2.6)$$

Preview selection of transformers' number and power of others workshops WS are similar and presented in the table form (2.6).

Selection of transformer Table 2.3

Work shop	Calculated load			Number of transformer	Required power of transformers, kVA	Nominal rating of transformer $S_{TRANS.}$ kVA	Transformer utilizations in nominal condition L.F.	Transformer utilizations in post emergency condition L.F.E.
	P_{load} kW	Q_{load} kVAR	S_P kVA					
WS-1	1807	1308.25	2230.86	2	1561.60	1600	0.697	1.39
WS-2	602	514.81	792.11	2	554.48	630	0.63	1.26
WS-3	1472	1142.40	1863.29	2	1304.30	1600	0.58	1.16
WS-4	828	577.95	1009.76	2	706.83	1000	0.51	1.02
WS-5	636	560.70	848	2	593.60	630	0.67	1.34
WS-6	1223	1013.41	1588.31	2	1111.82	1600	0.50	1.00
WS-7	1527	1265.32	1983.12	2	1388.18	1600	0.62	1.24
WS-8	1201	900.75	1501.25	2	1050.88	1600	0.47	0.92
WS-9	1642	1188.79	2027.16	2	1419.01	1600	0.63	1.26
WS-10	1912	1284.87	2303.61	2	1612.53	1800	0.64	1.28

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

We select transformers, passport data present in the table(2.4)

We accept:

for high-voltage side $U_H =$ 10 kV;

for low-voltage side $U_L =$ 0,4

Characteristics of transformers Table 2.4

Workshop number	Type	Nominal power, kV ·A	Nominal voltage of windings, kV		Losses, kW		Short-circuit voltage $U_к$, %	Idle current I_x in % from the nominal current
			HV	LV	non-working stroke ΔP_x	short circuit $\Delta P_к$		
WS-1	TM-1600	1600	10	0.4	4.3	16.5	5.5	1.3
WS-2	TM-630	630	10	0.4	2.27	7.6	5,5	2.0
WS-3	TM-1600	1600	10	0.4	4.3	16.5	5.5	1.3
WS-4	TM-1000	1000	10	0.4	3.8	12.7	5.5	1.6
WS-5	TM-630	630	10	0.4	2.27	7.6	5.5	2.0
WS-6	TM-1600	1600	10	0.4	4.3	16.5	5.5	1.3
WS-7	TM-1600	1600	10	0.4	4.3	16.5	5.5	1.3
WS-8	TM-1600	1600	10	0.4	4.3	16.5	5.5	1.3
WS-9	TM-1600	1600	10	0.4	4.3	16.5	5.5	1.3
WS-10	TM-1800	1800	10	0.4	8	24	5.5	4.5

2.2.2 Losses of transformers

Active power losses, kW:

$$\Delta P_{TRANS1.} = (\Delta P_{к1} \cdot L.F._{1}^{2} + \Delta P_{x1}) \cdot n_1 = (16.5 \cdot 0.697^2 + 4.3) \cdot 2 = 24.63, \quad (2.7)$$

Where n is the number of transformers in TS (transformer substation);

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

L.F. - is the transformer load factor in normal conditions.

Reactive power losses,kVAr:

$$\Delta Q_{TRANS1.} = (\frac{I_{x1}}{100} \cdot S_{TRANS1.} + L.F._1^2 \cdot \frac{U_{\kappa 1}}{100} \cdot S_{TRANS1.}) \cdot n_1 \quad (2.8)$$

$=(1,3/100 \cdot 1600+0.697^2 \cdot 5.5/100 \cdot 1600) \cdot 2=127.10$

Calculation of power losses in transformers of others workshop's TS is the same and presented in the table (1.5).

Power losses of transformers Table 2.5

Workshop number	Type	Losses, KW		Short-circuit voltage U_κ, %	Idle current I_x in % from the nominal current	Active power losses, ΔP_{TRANS}, KW	Reactive power losses, ΔQ_{TRANS}, KVAr
		non-load loss ΔP_x	short circuit ΔP_κ				
WS-1	TM-1600	4,3	16,5	5,5	1,3	24.63	127.10
WS-2	TM-630	2,27	7,6	5,5	2,0	10.57	52.71
WS-3	TM-1600	4,3	16,5	5,5	1,3	19.70	100.81
WS-4	TM-1000	3,8	12,7	5,5	1,6	14.21	60.61
WS-5	TM-630	2,27	7,6	5,5	2,0	11.36	56.31
WS-6	TM-1600	4,3	16,5	5,5	1,3	16.85	85.60
WS-7	TM-1600	4,3	16,5	5,5	1,3	21.29	109.25
WS-8	TM-1600	4,3	16,5	5,5	1,3	15.89	80.48
WS-9	TM-1600	4,3	16,5	5,5	1,3	21.70	111.45
WS-10	TM-1600	4,3	16,5	5,5	1,3	25.71	132.84

Imparted active power taking into account losses in transformers, kW:

$P_{WS1}=P_{load1}+\Delta P_{TRANS.1=}1807+24.63=1831.63$ (2.9)

Imparted reactive power taking into account losses in transformers, kVAr

$$Q_{WS1}=Q_{load1}+\Delta Q_{TRANS.1}=1308.25+127.10=1435.35 \quad (2.10)$$

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

$$S_{WS1}=S_{load1}+\Delta S_{TRANS.}=(P_{WS1}^{2}+Q_{WS1}^{2})^{0.5} \quad (2.11)$$

$$=(1831.63^{2}+1435.35^{2})^{0,5}=2327.04,$$

Calculation of powers taking into account losses in transformers of others workshop's WS is the same and presented in the table (1.6).

Calculation of powers with transformer losses Table 2.6

Number of substation	Active power losses, ΔP_{TRANS}, KW	Reactive power losses, ΔQ_{TRANS}, KVAr	Imparted active power, P_{WS}, KW	Imparted reactive power, Q_{WS}, KVAr	Imparted total power, S_{WS}, KVA
WS-1	24.63	127.10	1831.63	1435.35	2327.04
WS-2	10.57	52.71	612.57	567.52	835.06
WS-3	19.70	100.81	1491.70	1243.21	1941.84
WS-4	14.21	60.61	842.21	638.56	1056.92
WS-5	11.36	56.31	647.36	617.01	894.30
WS-6	16.85	85.60	1239.85	1099.01	1656.82
WS-7	21.29	109.25	1548.29	1374.57	2070.42
WS-8	15.89	80.48	1216.89	981.23	1563.21
WS-9	21.70	111.45	1663.70	1300.24	2111.52
WS-10	25.71	132.84	1937.71	1417.71	2400.96
Total:			13031.91	10674.41	16858.09

*Annotation. $$S_{total}=\Sigma S_{wsi}=\sqrt{\Sigma P_{wsi}^{2}+\Sigma Q_{wsi}^{2}} \quad . \quad (2.12)$$

$$=(13031.91^{2}+10674.41^{2})^{0,5}=16845.58\text{kVA}$$

2.3. Selection of the section of cable lines and energy loss

We carry out selection of the section of cable lines on the example of SUB-TS3 ,which according to the accepted scheme of power distribution supplies to radial scheme with reservation from SUB tires (figure 1.1), and SUB lines – TS01-TS04,which according to the accepted scheme of power distribution supplies to trunk scheme with reservation from SUB tires (figure 1.1) ,

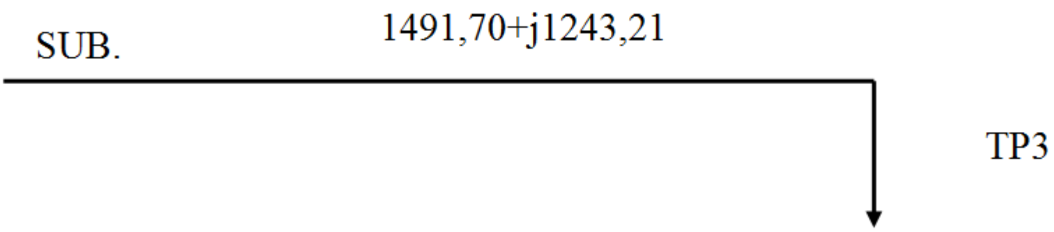


Fig. 2.3 - Feed circuit SUB – WS3

Operating current of line SUB – TP3 is equal to consumed current of work shop №3 I_3 , A:

$$I_3 = \frac{S_{TP3}}{n_{cable}\sqrt{3}\cdot V_{low}} = 1941.84/(2\cdot 1.73\cdot 10) = 56.12 \qquad (2.13)$$

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

Cross-section of the line, mm^2:

$$F_3 = \frac{I_3}{j_{ec}} = 56.12\ /1.20 = 46.77 \qquad (2.14)$$

where j_{ec} = 1.20 A/mm2 is economic current density for cables with aluminum core in [1].

We accept cross-section of cable by the table A5-A6,and choose 50 mm^2 cross-section.

Workshop 3

Permissible current of cable I=155 A.

Cable checking on heating:

- in normal mode, A:

Workshop 3 $I > I_P$ (2.15)

$$155 > 56.12$$

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

Workshop3 $I > 2 \cdot I_P$ (2.16)

$$155 > 2 \cdot 56.12 = 112.24$$

Conditions are satisfied.

Cable checking on voltage losses:

Workshop 3 $$\Delta U_{cable3} = \frac{P_3 \cdot l_{cable} \cdot r_{cable3} + Q_3 \cdot l_{cable3} \cdot x_{cable3}}{2 \cdot U^2_{nominal}} \% < 5\% ,$$ (2.17)

where r_{cable3}=0,620 , x_{cable3}= 0,090 ohm / Km - specific active and reactive resistance of cable;

l_{cable} is length of cable. We accept length (Km) of cable from substation (load center) to every workshop, For radial connection

SUB-TS3	SUB-TS6	SUB-TS7	SUB-TS8	SUB-TS9	SUB-TS10
6.54	1.72	3.2	2.86	0.46	5.4

$$\Delta U_{cable3} = (1491.70 \cdot 3.27 \cdot 0.62 + 1243.21 \cdot 3.27 \cdot 0{,}09)/(2 \cdot 10^2) = 3.4\% < 5\%$$

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

$$\Delta U_{emergency} = 2 \cdot \Delta U_{loss} = 2 \cdot 3.4 = 6.8\% < 10\%.$$ (2.18)

If the condition $\Delta U_{кабг3} < \Delta U_{max.}$ = 5% is not satisfied than we select cable with the nearest larger section than the selected, and again check according to voltage losses.

We determine the active power losses in cables, kW:

Workshop3

$$\Delta P_{cable} = \frac{S_{TP3}^2}{V_{low}^2}\frac{r_{cable3}}{2}10^{-3} = (1491.70^2 \cdot 0.62 \cdot 10^{-3})/(10^2 \cdot 2) = 11.67 \qquad (2.19)$$

We determine the reactive power losses in cables, KVAr:

$$\Delta Q_{cable} = \frac{S_{TP3}^2}{V_{low}^2}\frac{x_{cable3}}{2}10^{-3} = (1243.21^2 \cdot 0.09 \cdot 10^{-3})/(10^2 \cdot 2) = 1.7 \qquad (2.20)$$

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

$$\Delta E_{act} = \Delta P_{cable} \cdot \tau_a \qquad (2.21)$$

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

$$\tau_a = \left(0{,}124 + \frac{T_{ма}}{10000}\right)^2 8760 = (0{,}124 + 4355/10000)^2 \cdot 8760 = 2742 \qquad (2.22)$$

where $T_{ма}$ is number of hours per year of maximum active power usage (according to task for metal enterprises):-

$T_{ма}$ =4355 hours per year.

$$\Delta E_{act} = \Delta P_{c\,able} \cdot \tau_a = 11.67 \cdot 2742 = 31999$$

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

$$\Delta E_{rec} = \Delta Q_{cable} \cdot \tau_p \qquad (2.23)$$

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

$$\tau_p = \left(0{,}124 + \frac{T_{мр}}{10000}\right)^2 8760 = (0{,}124 + 5880/10000)^2 \cdot 8760 = 4441, \qquad (2.24)$$

where $T_{мр}$ is number of hours per year of maximum reactive power usage (according to task for metal enterprises):-

$$T_{мр} = 5880 \text{ hours per year.}$$

$$\Delta E_{rec} = \Delta Q_{cable} \cdot \tau_p = 1.7 \cdot 4441 = 7550$$

Selection of cable cross-section of other subcircuits is performed in the same way. Results of calculation of energy losses in cable lines are included in the table (2.7) and table (1.8).

Selection of cross section and voltage loss of radial connection Table 2.7

Subcircuit	Operating current, Ip, A Eq.(2.13)	Calculated cable cross-section, F, mm^2 Eq.(2.14)	Selected cable cross-section, F, mm^2	Permissible current of cable , I,A	Specific resistance of cable r_{cable} Ω/Km,	Specific reactance of cable x_{cable} Ω /Km	Voltage losses, ΔU_{loss}, % Eq.(2.17)
SUB-TP3	56.12	46.77	50	155	0.620	0.090	3.4
SUB-TP6	47.88	39.9	50	155	0.620	0.090	0.75
SUB-TP7	59.84	49.87	70	190	0.443	0.086	1.3
SUB-TP8	45.18	37.65	50	155	0.620	0.090	1.2
SUB-TP9	61.03	51	70	190	0.443	0.086	0.2
SUB -TP10	69.40	57.83	70	190	0.443	0.086	2.8

Power and energy losses Table 2.8

Subcircuit	Active power losses, ΔP_{cable}, KW, Eq.(2.19)	Reactive power losses, ΔQ_{cable} ,KVAr Eq.(2.20)	Active energy losses, ΔE_{act}, KW/year Eq.(2.21)	Reactive energy losses, ΔE_{rec}, KVAr/year Eq.(2.23)
SUB-TP3	11.67	1.7	31999	7550
SUB-TP6	8.51	1.24	23334	5486
SUB-TP7	9.50	1.84	26035	8186
SUB-TP8	7.58	1.10	20771	4884
SUB-TP9	9.88	1.92	27079	8514
SUB -TP10	12.77	2.48	35012	11008

-For back-bone connection

Operating current of line SUB - TP2 consist of (algebraically) currents consumed by shops number 2 and number 1 fig. (2.4), which is caused almost identical coefficients of load power plants after the reactive power compensation, A:

$$I_{21} = I_2 + I_1 .$$

-Distance for backbone connection

SUB-TS2	TS2-TS1	SUB-TS4	TS4-TS5
3.6	0.8	3.0	3.9

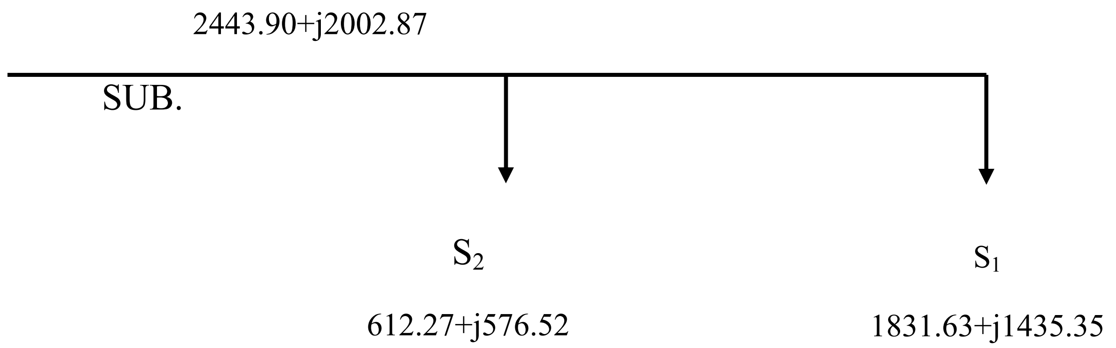


Fig.2.4- Power scheme SUB –WS2 – WS1

Selection of cable cross-section of other subcircuits is performed in the same way. Results of calculation of energy losses in cable lines are included in the table (2.9) and table (2.10).

Selection of cross section and voltage loss of back-bone connection Table 2.9

Subcircuit	Operating current, Ip, A Eq.(1.13)	Calculated cable cross-section, F, mm^2 Eq.(1.14)	Selected cable cross-section, F, mm2	Permissible current of cable , I,A	Specific resistance of cable r_{cable} Ω/Km,	Specific reactance of cable x_{cable} Ω /Km	Voltage losses, ΔU_{loss}, % Eq.(1.17)
SUB-TP2	91.39	76.16	95	225	0.326	0.083	1.7
TP2 -TP1	67.26	56.05	70	190	0.443	0.086	0.4
SUB-TP4	56.40	47	50	155	0.620	0.090	1.6
TP4 –TP5	25.85	21.54	25	105	1.24	0.099	1.7

Power and energy losses Table 2.10

Subcircuit	Active power losses, ΔP_{cable}, KW, Eq.(1.19)	Reactive power losses, ΔQ_{cable} ,KVAr Eq.(1.20)	Active energy losses, ΔE_{act}, KW/year Eq.(1.21)	Reactive energy losses, ΔE_{rec}, KVAr/year Eq.(1.23)
SUB-TP2	16.30	4.20	44695	18652
TP2 -TP1	12.00	2.33	32904	10348
SUB-TP4	11.80	1.70	32356	7550
TP4 –TP5	2.60	0.20	7129	888

2.4. Selection Of The Main Diagram Of Electrical Connections

The main diagram of electrical connections defines main qualities of electrical stations and substations: reliability, efficiency, maintainability, security of service, ease of use, ease of placement of electrical equipment, the possibility of further expansion, etc.

You can see the block diagram of electrical system with the substation and transformers which have splitting of secondary windings on figure (1.4).

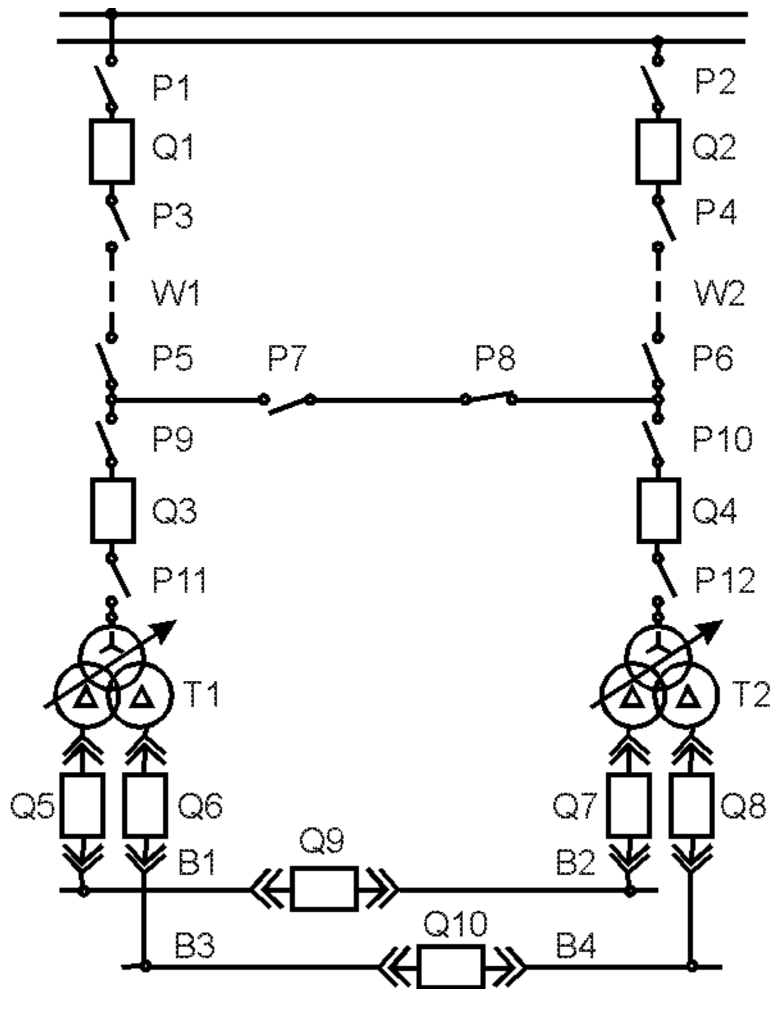


Fig. 2.5- Block diagram of the substation with two transformers

The diagram with 2 blocks "line – transformer" with switches in circuits of transformers and non-automatic jumper from the lines (fig.1.4) is used at the high voltage side with the condition that there are 2 transformer and 2 outgoing lines for one-ended substations. The diagram is economical because there are 2 switches used for 4 connections. The diagram is reliable, when the line W1 from the first block is cut off by the switch Q1, T1 block's transformer is cut off together with it. The non-automatic jumper with disconnecting devices P7 and P8 are applied to the resuming of operation of the undamaged transformer T1. One of these disconnecting devices is normally joined, another one is cut off. If line W1 is damaged, switches Q1 and Q3 are cut off. Damaged line goes out of use in repair by linear disconnectors P3 and P5. Cut off disconnector of jumper is turned on in dead time (no-current condition). Then the switch Q3 is turned on. Power supply of transformer T1 is restored through the line W2 and non-automatic jumper. If transformer T1is damaged switches Q5, Q6, Q3 and Q1 are cut off, that is, a whole unit (block) will be cut off. But it is impossible to restore an operation of the undamaged line W1 because the jumper doesn't have a switch which is a drawback of block diagram. But this drawback is not very significant, because damages of the transformer, compared with damage of the line, are rare. Units (blocks) operate separately in the normal condition at high and low voltage.

Diagram with 2 isolated switchable busbars by switches Q9 and Q10 (fig. 1.4) is used according to [2] on the side of low voltage substations. On the side of low voltage transformers operate separately. The diagram is economical and reliable. Reliability of electricity supply of consumers is provided with different sections of low voltage B1 and B2. If one section is damaged, all joining of this section will be deactivated.

2.4.1. Calculation And Plotting Of Annual Load Diagram

Several daily diagrams that characterize the operation of the consumer in different seasons and different days of the week are given in reference literature. The winter daily-load diagram of working day is the main thing.

The task of course design is specified daily load enterprises for delivery of a substation design . There is a diagram on the fig. 1.5.

According to the task the maximum load of substation in winter is P_{max} = 13 MW.

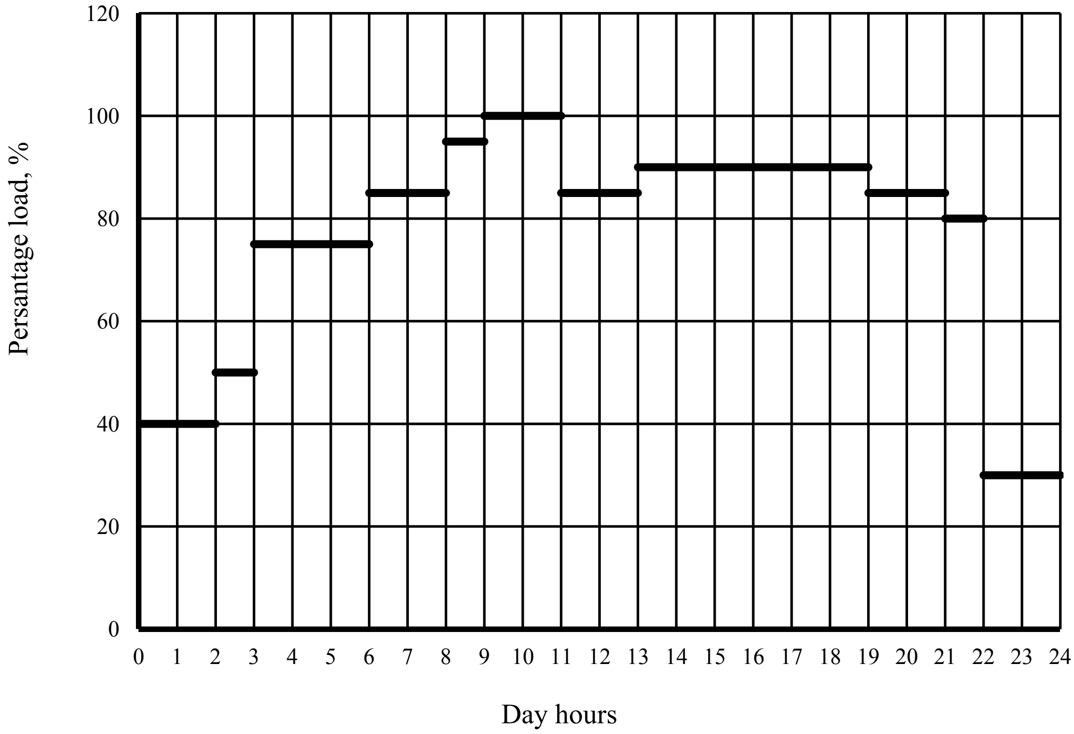


Fig.2.6- Daily diagram of active load substation

Let us assume that the substation's maximum load is P_{max} = 13 MW (as it is stated in the task). It is typical of winter and equals 100% according to the daily-load diagram. Thus the winter daily-load diagram of working day is calculated according to the following formula:

$$P_{iw} = \frac{n_i\%}{100} \cdot P_{max} , \qquad (2.25)$$

where P_{iw} (i winter) is the power on the i-stage of the winter daily-load diagram, MW;

ni is an ordinate of daily diagram's respective stage, %;

P_{max} -is the substations maximum load that is stated in the task, MW.

The winter daily-load diagram changed into the summer daily-load diagram with the help of multiplying ordinates by constant coefficient Ks :

$$P_{is} = \frac{K_s \cdot P_{iw}}{100}, \quad (2.26)$$

P_{is} -(i summer) is the power on the i-stage of the summer daily-load diagram, MW;

Where K_s- is summer load of substation in percentage of the winter load, %; Let us assume that power factor of enterprise is constant, i.e. independent of how large the load is on every stage of load diagram

$$\cos\varphi_i = const. \quad (2.27)$$

Then the total power of the substation on the i-stage of the daily load is calculated according to the following formula:

$$S_i = \frac{P_i}{\cos\varphi}, \quad (2.28)$$

where $\cos\varphi$ =0,8 is the power factor, which is given in the task to the project. Calculation of load diagrams is given in table(2.13).

Load diagrams Table2.13

Time interval, t, hours	Ordinate of daily diagram's respective stage,%	Power on the i-stage of the winter daily-load diagram ,P_{iw}, MW	Power on the i-stage of the summer daily-load diagram ,P_{is}, MW	Total winter power of the load ,S_{iw},MWA	Total summer power of the load ,S_{is},MWA	$P_{iw}\cdot t_i$, MVA·hous	$P_{is}\cdot t_i$, MVA·hours	$S^2_{iw}\cdot t_i$, $(MVA)^2\cdot$year
0-1	40	5.2	4.16	6.5	5.2	5.2	4.16	42.25
1-2	40	5.2	4.16	6.5	5.2	5.2	4.16	42.25
2-3	50	6.5	5.2	8.125	6.5	6.5	5.2	66.02
3-4	75	9.75	7.8	12.1875	9.75	9.75	7.8	148.54
4-5	75	9.75	7.8	12.1875	9.75	9.75	7.8	148.54
5-6	75	9.75	7.8	12.1875	9.75	9.75	7.8	148.54
6-7	85	11.05	8.84	13.8125	11.05	11.05	8.84	190.79
7-8	85	11.05	8.84	13.8125	11.05	11.05	8.84	190.79
8-9	95	12.35	9.88	15.4375	12.35	12.35	9.88	238.32
9-10	100	13	10.4	16.25	13	13	10.4	264.06
10-11	100	13	10.4	16.25	13	13	10.4	264.06
11-12	85	11.05	8.84	13.8125	11.05	11.05	8.84	190.79
12-13	85	11.05	8.84	13.8125	11.05	11.05	8.84	190.79
13-14	90	11.7	9.36	14.625	11.7	11.7	9.36	213.89
14-15	90	11.7	9.36	14.625	11.7	11.7	9.36	213.89
15-16	90	11.7	9.36	14.625	11.7	11.7	9.36	213.89
16-17	90	11.7	9.36	14.625	11.7	11.7	9.36	213.89
17-18	90	11.7	9.36	14.625	11.7	11.7	9.36	213.89
18-19	90	11.7	9.36	14.625	11.7	11.7	9.36	213.89
19-20	85	11.05	8.84	13.8125	11.05	11.05	8.84	190.79
20-21	85	11.05	8.84	13.8125	11.05	11.05	8.84	190.79
21-22	80	10.4	8.32	13	10.4	10.4	8.32	169
22-23	30	3.9	3.12	4.875	3.9	3.9	3.12	23.77
23-24	30	3.9	3.12	4.875	3.9	3.9	3.12	23.77
$\sum$						239.2	191.36	4007.15

With the help of daily diagram of load from table (2.13) you can determine:

1) daily consumption of electricity in winter, MW • h:

$$W_{dw} = \sum_{i=0}^{24} P_{iw} \cdot t_i = 239.2, \qquad (2.29)$$

where t_i is the duration of i-stage of the daily diagram, hour ;

2) daily consumption of electricity in summer, MW • h:

$$W_{ds} = \sum_{i=0}^{24} P_{is} \cdot t_i = 191.36, \qquad (2.30)$$

3) average daily load in winter, MW:

$$P_{a\,\text{var}\,w} = \frac{W_{dw}}{t_d} = 239.2/24 = 9.97 \qquad (2.31)$$

Where t_d is the duration of the day - 24 hours

4) average daily load in summer, MW:

$$P_{a\,\text{var}\,s} = \frac{W_{dw}}{t_d} = 191.36/24 = 7.97 \qquad (2.32)$$

5) load factor in winter, which shows the irregularity degree of diagram of ent

$$K_{lfw} = \frac{P_{a\,\text{var}\,w}}{P_{\max}} = 9.97/13 = 0.77 \qquad (2.33)$$

load factor in summer:

$$K_{lfs} = \frac{P_{a\,\text{var}\,w}}{P_{\max}} = 7.97/13 = 0.61 \qquad (2.34)$$

Annual consumption of electricity, MW • h:

$$W_a = W_{dw} \cdot n_w + W_{ds} \cdot n_s = 239.2 \cdot (365 - 120) + 191.36 \cdot 120 = 81567.2$$

where n_w is number of days in the winter;

n_s is number of days in the summer;

$$n_w = n_{annual} - n_s$$

where n_{annual} is number of days per year, n_{annual}=365

6) duration of maximum load, $T_{\max}$ hours:

$$T_{\max} = \frac{W_{annual}}{P_{\max}} = 81567.2/13 = 6274 \quad (2.35)$$

2.4.2. Selection of transformers

We determine the rated power of transformer on the main t the main step-down substation according to formula (1.36), MVA:

$$S_{TRANS}=(0{,}65...0{,}7)S_{total}=0.7\cdot16845.58\cdot10^{-3}=11.79 \quad (2.36)$$

S_{total} maximum apparent power consumed by workshops,from formula (2.12)

Estimated power of transformers, obtained by the formula (2.36), rounded to the nearest standard power on a scale of GOST 11920-85, GOST 12965-85, MVA: 2,5, 6.3, 10, 16, 25, 40, 63.

We choose for SUB two transformers with capacity = 16 MVA.

If one of the selected transformer cutting off in emergency mode, then overload of the second selected transformer, which remains in the work, should not exceed 40%. Adherence to specification (2.21) allows you to save a working time of transformer isolation within the regulatory.

Characteristics of selected transformers are represented in the table(2.14).

Table 2.14

Transformer	Rated capacity, MVA	Average nominal voltage, kV	ΔU_K, %	ΔP_K, kW	ΔP_x kW	I_x, %	Estimated cost	R_T, Ω	X_T, Ω	ΔQ_x, kVAr	Voltage control limits,%
ТДН-16000/110	16	115/6,6;11	10,5	85	19	0,7	315	4,38	86,7	112	± 9 × 1,78 %

$$\Delta S = \frac{S_{\max} - S_{TRANS.}}{S_{TRANS.}} = 16.85 - 16/16 = 5.31\%. \qquad (2.37)$$

ΔS = 5.31% - the magnitude of the transformer's overload in operating emergency conditions.

The selected transformer is checked for emergency overload according to GOST 14209-97;

$$S_{TRANS.} \cdot K_2 \geq S_{\max}, \qquad (2.38)$$

Where K_2 is a coefficient of emergency overload in the case of cutting of one of the transformers during the accident which is determined by [4]. It depends on the initial load factor (K1), overload duration (h), temperature of cooling medium during the accident (T_{cool}) and the transformer's cooling system. If the temperature of cooling medium or magnitude of factor K1 is situated between the two tabulated values of [4], then you should take the biggest coefficient K_2 , and perform interpolation between the two closest values.

Initial load factor K1 is determined by;

$$K_1 = \frac{S_{m.sq.}}{n \cdot S_{TRANS.}} \qquad (2.39)$$

where n is the number of transformers n=2

$S_{m.sq}$ is the mean-square load which is calculated according to the daily load diagram, MWA;

$$S_{m.sq.} = \sqrt{\frac{1}{T}\int_0^T S_i^2 dt} \qquad (2.40)$$

Where T is the duration of diagram, hours.

Let us transform mathematical formula 2.40 to the calculated one

$$S_{m.sq.}=\sqrt{\frac{S_1{}^2\cdot t_1+S_2{}^2\cdot t_2+S_3{}^2\cdot t_3+S_4{}^2\cdot t_4+S_5{}^2\cdot t_5+...+S_i{}^2\cdot t_i}{24}}$$

Where t_i is the duration of i-stage of the daily load diagram (1 hour, tab. 2.13).

S_i is the total power of i-stage of the daily load diagram.

Mean-square load in winter, MVA, is;

$$S_{m.sq.w}=\sqrt{\frac{\Sigma S_{iз}^2\cdot t_i}{24}}=(4007.15/24)^{0,5}=12.92$$

Initial load factor in winter is;

$$K_{1w}=\frac{S_{m.sq.w}.}{n\cdot S_{ntr}}=12.92/(2\cdot 16)=0.4$$

Mean-square load in summer, MWA, is;

$$S_{m.sq.s.}=\sqrt{\frac{\Sigma S_{is}^2\cdot t_i}{24}}=\kappa_s\cdot S_{cm.sq.w.}=0.8\cdot 12.92=10.34$$

Initial load factor in summer is;

$$K_{1s}=\frac{S_{m.sq.s.}}{n\cdot S_{TRANS.}}=10.34/(2\cdot 16)=0.32$$

Calculated daily duration of emergency overload h is accepted according to the technological design standards: 4-hour single-shift work, 8-hour two-shift work, 12-24-hour three-shift work. For two-shift work we accept h= 8 hours.

The equivalent temperature of cooling air is calculated according to the many years meteorological observations of air temperature. Therefore, the equivalent summer temperature in Luhansk region is T_{cool} = 21.2 ^{0}C, and for winter it is Tcool = -5,9 ^{0}C.

According to the table 1.36 [2] or table A K_1 = 0.32 and h=8 hours, environmental temperatures in winter in Luhansk region T_{cool} = -5.9 ^{0}C and method of transformer cooling is D (name of transformer) we determine the allowable winter load emergency:K_{2w}= 1.56.

But according to [2] when value designed you cannot take more than 1,4 for power transformers with capacity less than 100 MVA and more than 1.3 for transformers with capacity more than 100 MVA. So let's accept;

$$K_{2w}=1.4$$

The selected transformer is checked for emergency overload by GOST 14209-97 for winter load substations.

$$S_{TRANS.} \cdot K_{2w} \geq S_{\max}$$

$$16 \cdot 1.4 \geq 16.85$$

$$22.4 \geq 16.85$$

The selected transformer meets the requirements of the emergency overload in winter.

For K_1=0.4 and h=8 hours, environmental temperature for Luhansk region in summer T= 21.2 0C and method of transformer cooling D (name of transformer) we determine the allowable summer load emergency ;

$$K_{2l}=1.3$$

The selected transformer is checked for emergency overload by GOST 14209-97 for summer load substations

$$S_{TRANS.} \cdot K_{2l} \geq S_{\max} \cdot \frac{K_l\%}{100}$$

$$16 \cdot 1.3 \geq 16.85 \cdot \frac{80\%}{100}$$

$$20.8 \geq 13.48$$

2.4.3. Losses in transformer

At calculation losses of power in transformers is necessary to rate loss of active-power in iron (MW);

$$\Delta P_{iron} = n_{TRANS.} \cdot P_x \cdot 10^{-3} = 2 \bullet 21 \bullet 10^{-3} = 0.042 \qquad (2.41)$$

where n_{TRANS} - is amount of the same types of transformers on substation, pcs. In our example $n_{TRANS.}$=2.

P_{x1} - are nominal losses no-load running of transformer for a substation (references data), kW, from table. (2.14).

Losses of active-power in copper of transformer, MW

$$\Delta P_{copper} = n_{TRANS.} \cdot L.F.^2 \cdot P_\kappa \cdot 10^{-3} = 2 \bullet 0.53^2 \bullet 85.0 \bullet 10^{-3} = 0.048 \qquad (2.42)$$

where $P_{\kappa 1}$ - are nominal losses of short circuit in transformer (references data), kW, from table(2.140

Total losses in transformer,MW;

$$\Delta P_{TRANS.} = \Delta P_{iron} + \Delta P_{copper} = 0.042 + 0.048 = 0.090 \qquad (1.43)$$

The losses of electric power in transformers of separate substation rate, MW*year :

$$\Delta W_{TRANS.} = \Delta W_{iron} + \Delta W_{copper} = \Delta P_{iron} \cdot T + \Delta P_{copper} \cdot \tau \qquad (1.44)$$

where T- is work time of transformers in a year, 8760 hours;

τ - is time of maximal losses, hours

$$\tau = (0{,}124 + \frac{T_{max.}}{10000})^2 \cdot 8760 = (0{,}124 + 6274/10000)^2 .8760 = 4946 \qquad (1.45)$$

where $T_{max.}$ - is duration use of maximal loading of users, in project

$T_{max.}$ =6274 hour/year from (2.35).

Losses of electric power in transformers of substation, MW*year

$$\Delta W_{mp1} = \Delta W_{iron} + \Delta W_{copper} = \Delta P_{iron} \cdot T + \Delta P_{copper} \cdot \tau = 0.042 \cdot 8760 + 0.048 \cdot 4946 = 605$$

2.4.4. Selection section of feed line for 110 kV

We determine the operating current of line of outdoor power, A:

$$I_{line} = \frac{S_{\max}}{n_{line}\sqrt{3}U_H}=8595{,}3/(2\cdot 1{,}73\cdot 35)=70{,}98;$$

where n_{line} is the number of parallel chains of the line, let us assume that n_{line}=2 for consumers of first and second categories.

The section selection of feed line is performed by economic current density, followed by heating checking. For two-shift schedule of enterprise $T_{ма}$ = 4355 hours per year, $J_{ек}$=1,1A/mm^2, where $T_{ма}$ is the number of hours per year of usage of maximum active power.

We determine the effective line section of outdoor electric power supply, mm^2.

$$F_{еф} = \frac{I_p}{J_{ек}}=70{,}98/1{,}1=64{,}524.$$

Obtained section is rounded to the nearest standard value , but you must remember that in terms of corona discharge minimal sections, which are recommended [5] are the following: if U_H = 110 KV than we take 70 mm^2; if U_H = 150 KV than we take 120 mm^2; if U_H = 220 KV than we take 240 mm^2. Based on the received value $F_{еф}$ and conditions of the minimum section we select the section F_{line} = 70 mm^2.

We select AS-grade of wire with the following parameters.

Table 2.15

Grade of wire	Admissible continuous current, $I_{прип}$ A	Resistance of 20^oC to 1 Km, Ohm, r_o	Reactance at 1Km, Ohm, x_o	Capacitive susceptance at 1Km, $b_0\cdot 10^{-6}$ cm	Charging capacity to 1Km, q_0, MVA
AS-70/11	265	0,428	0,444	2,55	0,034

3. CALCULATIONS OF VOLTAGE REGULATION METHODS

In this chapter we will calculate and analyze the loss of power and voltage at each node, and after then, we will modify the application of voltage regulation and analysis of all the ways to get to the method of choice for working out.

3.1. Formulation equations to calculate the power losses and voltage of load at the winter

Before calculating the voltage change caused by change load according to of daily load diagram , it is necessary to determine the impedance (r+jx) of transmission lines for each path in suggestion site plan site of enterprise . This is done by means of the following calculations:

For WS1: r=0.443 Ω/Km & x=0.086 Ω/Km from table (2.9)

Total resistance of cable SUB-WS1:

$$r_1=r\cdot L_{2-1}=0.443\cdot 0.8=$$

L_{2-1}:length of cable between workshops 1&2.

Total reactance of cable SUB-WS1:

$$x_1=x\cdot L_{2-1}=0.086\cdot 0.8=$$

Results of calculation of resistance and reactance of other cables are included in the table 3.1.

Table 3.1

Path of cable	Resistance of cable for 1Km ,r	Reactance of cable for 1Km ,x	Distance of cables L,Km	Total resistance		Total reactance	
				1-cable	2-cable	1-cable	2-cable
TP2-TP1	0.443	0.086	0.8	0.354	0.177	0.069	0.035
SUB-TP2	0.326	0.083	3.6	1.174	0.587	0.299	0.159
SUB-TP3	0.620	0.090	6.54	4.055	2.028	0.589	0.295

SUB-TP4	0.620	0.090	3.0	1.860	0.930	0.270	0.135
TP4-TP5	1.24	0.099	3.9	4.836	2.418	0.386	0.193
SUB-TP6	0.620	0.090	1.72	1.066	0.533	0.155	0.078
SUB-TP7	0.443	0.086	3.2	1.418	0.709	0.275	0.138
SUB-TP8	0.620	0.090	2.86	1.773	0.887	0.257	0.129
SUB-TP9	0.443	0.086	0.46	0.204	0.102	0.040	0.020
SUB-TP10	0.443	0.086	5.74	2.543	1.272	0.494	0.247

By using data from table 2.6, which represents the loads calculated from scheme of substation.

Calculation of the open-loop network is performed by two stages;

I stage. Accepted voltage at all nodes of the network $U_{nom.}$ and calculations are got out on each section of the network by the formulas, which made conditions for default mode parameters at the end of the site.

The purpose of stage I is to determine the power losses in power lines and at the beginning of each workshops. The calculation is carried out in from last workshop to substation;

$$S_{Eij}=S_{pj} \tag{3.1}$$

$$\Delta S_{ij} = \frac{(P_{Eij})^2 + (Q_{Eij})^2}{U_н^2} \times (r_{ij} + jx_{ij}) \tag{3.2}$$

$$S_{Bij} = S_{Eij} + \Delta S_{ij} = P_{Eij} + \Delta P_{ij} + j(Q_{Eij} + \Delta Q_{ij} - \frac{Q_{lij}}{2}), \tag{3.3}$$

Where S_{Eij} , P_{Eij},Q_{Eij} - apparent power, active and reactive power at the end of the line of j-th workshop (far from substation).

S_{Bij} , P_{Bij},Q_{Bij} - apparent power, active and reactive power at the beginning of the line of j-th workshop (near at substation).

ΔS_{ij},ΔP_{ij},ΔQ_{ij} - apparent power, active and reactive power along line between i-th and of j-th workshop .

Q_{lij} - reactive power generated by line

r_{ij},x_{ij} – resistance and reactance along line between i-th and of j-th workshop .

In the calculations at the load accept voltage source,kV ;

$$U_{soure}=110\cdot 1.05=115.5 \qquad (3.4)$$

We accepted for the first calculation

$$U_{1j}=U_{soure} \qquad (3.5)$$

II stage. Calculation of each network site is performed by the formulas which made conditions for default mode parameters at the beginning of the workshop.

Calculation is starting from main substation i and continue towards the workshops

ΔU_{Bij} - voltage drop along cable line

σ U_{Bij} - transverse component of the voltage drop across the site of line,kV.

U_i - voltage at the beginning of the line (for i-th workshop),kV.

U_j - voltage at the end of the line (for j-th workshop),kV.

For network with $U_{nominal}$ < 110 kV , we can assume that σ UBij ≈ 0. Then

$$U_j=U_i- \Delta U_{Bij} \qquad (3.6)$$

The calculation in two stages is the first iteration of approximate calculation. The further iterations distinguished by ,that 1stage receiving voltage substation buses, energy levels, obtained in an earlier iteration.

Following table include the first and forth(last) iterations of calculation of voltage and power losses in power supply elements for assumption site and for interval (23-24) of diagram load according to first and second stages. Table are including example how it can calculate only for four workshops (1,2,3,6,10) and main substations. Full method of calculations and results will be placed in appendix ().

First iteration Table 3.1

Parameter section	Sections				
	SUB-WS10	SUB-WS3	WS2-WS1	SUB-WS2	FS-SUB
S_{Pi} ,MVA	0.679+j0.497	0.373+j0.31	0.4575+j0.36	0.153+j0.143	3.884+j3.18
$r_{ij}+jx_{ij}$,Ω	1.272+j0.247	2.028+j0.295	0.177+j0.035	0.587+j0.159	24.42+j23.54
SE10,MVA	0.679+j0.497				
U_{1j},kV	10.5	10.5	10.5	10.5	115
ΔS_{SUB-10},MVA	$(8.2+j1.6)\times10^{-3}$				
S_{B10},MVA	0.687+j0.495				
S_{E3},MVA		0.373+j0.31			
ΔS_{SUB-3},MVA		$(4.3+j0.63)\times10^{-3}$			
S_{B3},MVA		0.377+j0.309			
S_{E1},MVA			0.4575+j0.36		
ΔS_{SUB-1},MVA			$(0.54+j0.11)\times10^{-3}$		
S_{B1},MVA			0.458+j0.3599		
S_{E2},MVA				0.611+j0.502	
ΔS_{SUB-2},MVA				$(3.33+j0.\ 9)\times10^{-3}$	
S_{B2},MVA				0.614+j0.501	
S_{ESUB},MVA					7.817+j6.34
ΔS_{SUB-FS},MVA	0.0978	0.08399	0.00924	0.04321	0.187+j0.18
S_{BSUB},MVA	0.0785	0.07251	0.00786	0.03848	8.004+j6.16
ΔUB_{ij},kV					2.96145
$\sigma\ U_{BSUB-FS}$,kV					2.94733
U_{SUB},kV					112.037
U_1,kV			10.1338		

U_2,kV				10.1421	
U_3,kV		10.101			
U_{10},kV	10.087				

Forth(last) iteration Table 3.2

Parameter section	sections				
	SUB-WS10	SUB-WS3	WS2-WS1	SUB-WS2	FS-SUB
S_{Pi},MVA	0.679+j0.497	0.373+j0.31	0.4575+j0.36	0.153+j0.143	3.884+j3.176
$r_{ij}+jx_{ij}$,Ω	1.272+j0.247	2.028+j0.295	0.177+j0.035	0.587+j0.159	24.42+j23.54
SE_{10},MVA	0.679+j0.497				
U_{1j},kV	10.087	10.101	10.133	10.142	112.037
ΔS_{SUB-10},MVA	$(8.9+j1.7)\times10^{-3}$				
S_{B10},MVA	0.688+j0.495				
S_{E3},MVA		0.373+j0.31			
ΔS_{SUB-3},MVA		$(4.7+j0.68)\times10^{-3}$			
S_{B3},MVA		0.377+j0.309			
S_{E1},MVA			0.4575+j0.36		
ΔS_{SUB-1},MVA			$(0.561+j0.099)\times10^{-3}$		
S_{B1},MVA			0.458+j0.3599		
S_{E2},MVA				0.611+j0.502	
ΔS_{SUB-2},MVA				$(3.59+j0.91)\times10^{-3}$	
S_{B2},MVA				0.614+j0.501	
S_{ESUB},MVA					7.82+j6.34
ΔS_{SUB-FS},MVA					0.197+j0.190
S_{BSUB},MVA					8.017+j6.154
ΔU_{Bij},kV	0.09791	0.08406			2.96212
$\sigma\ U_{BSUB-FS}$,kV	0.07853	0.07251			2.94785
U_{SUB},kV					112.038

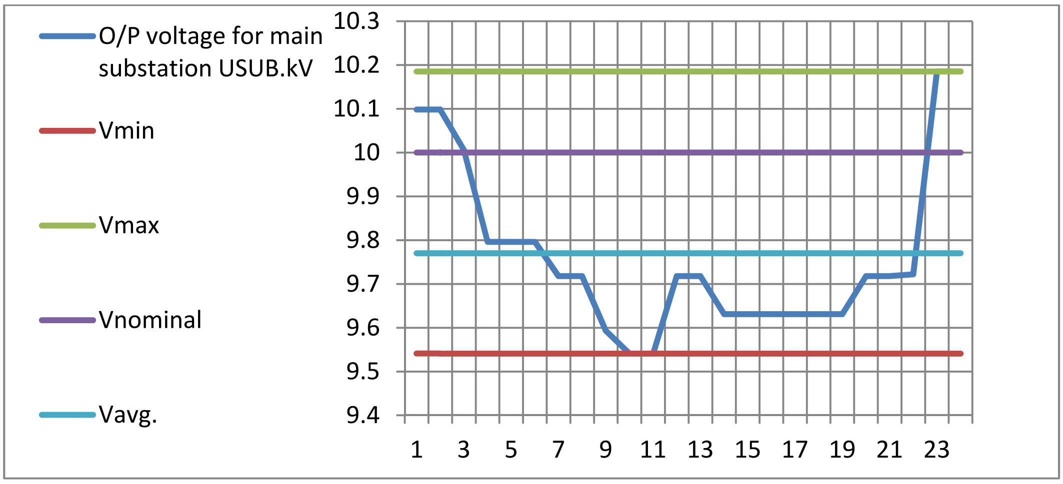
U_1,kV			10.134		
U_2,kV				10.1421	
U_3,kV		10.098			
U_{10},kV	10.089				

Results of calculation of power losses and revived voltage at workshops and substation for the last (forth) iteration are included in the table 3.3.

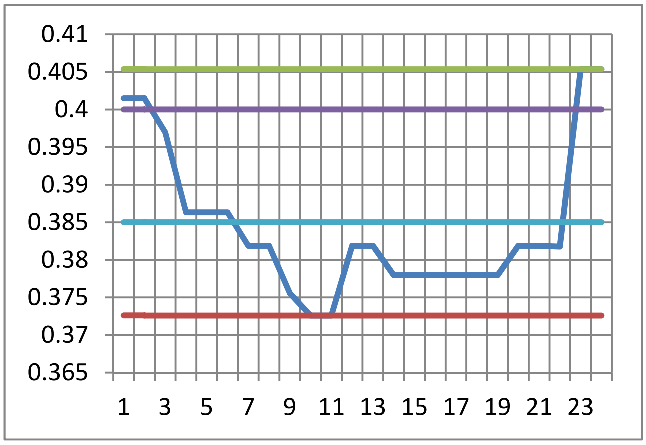
Output voltage at high side of transformers Table 3.3

Time interval,t, hours	SUB	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
0-1	10.098	10.037	10.048	9.974	10.006	9.887	10.068	10.06	10.055	10.089	9.959
1-2	10.098	10.037	10.048	9.974	10.006	9.887	10.068	10.06	10.055	10.089	9.959
2-3	10.006	9.924	9.938	9.845	9.895	9.752	9.969	9.956	9.951	9.996	9.838
3-4	9.796	9.658	9.682	9.537	9.633	9.42	9.739	9.712	9.721	9.783	9.55
4-5	9.796	9.658	9.682	9.537	9.633	9.42	9.739	9.712	9.721	9.783	9.55
5-6	9.796	9.658	9.682	9.537	9.633	9.42	9.739	9.712	9.721	9.783	9.55
6-7	9.718	9.547	9.575	9.418	9.538	9.308	9.653	9.613	9.63	9.703	9.5
7-8	9.718	9.547	9.575	9.418	9.538	9.308	9.653	9.613	9.63	9.703	9.5
8-9	9.593	9.389	9.423	9.248	9.405	9.171	9.514	9.466	9.477	9.574	9.31
9-10	9.541	9.315	9.354	9.153	9.352	9.116	9.462	9.406	9.411	9.52	9.241
10-11	9.541	9.315	9.354	9.153	9.352	9.116	9.462	9.406	9.411	9.52	9.241
11-12	9.718	9.547	9.575	9.418	9.538	9.308	9.653	9.613	9.63	9.703	9.5
12-13	9.718	9.547	9.575	9.418	9.538	9.308	9.653	9.613	9.63	9.703	9.5
13-14	9.631	9.449	9.479	9.288	9.471	9.281	9.561	9.505	9.516	9.612	9.35
14-15	9.631	9.449	9.479	9.288	9.471	9.281	9.561	9.505	9.516	9.612	9.35
15-16	9.631	9.449	9.479	9.288	9.471	9.281	9.561	9.505	9.516	9.612	9.35
16-17	9.631	9.449	9.479	9.288	9.471	9.281	9.561	9.505	9.516	9.612	9.35
17-18	9.631	9.449	9.479	9.288	9.471	9.281	9.561	9.505	9.516	9.612	9.35

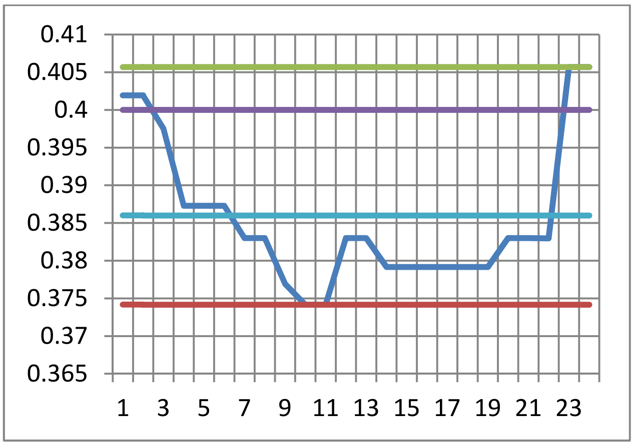
18-19	9.631	9.449	9.479	9.288	9.471	9.281	9.561	9.505	9.516	9.612	9.35
19-20	9.718	9.547	9.575	9.418	9.538	9.308	9.653	9.613	9.63	9.703	9.5
20-21	9.718	9.547	9.575	9.418	9.538	9.308	9.653	9.613	9.63	9.703	9.5
21-22	9.722	9.544	9.574	9.442	9.589	9.44	9.665	9.617	9.615	9.706	9.474
22-23	10.185	10.133	10.142	10.101	10.129	10.065	10.163	10.147	10.15	10.18	10.09
23-24	10.185	10.133	10.142	10.101	10.129	10.065	10.163	10.147	10.15	10.18	10.09



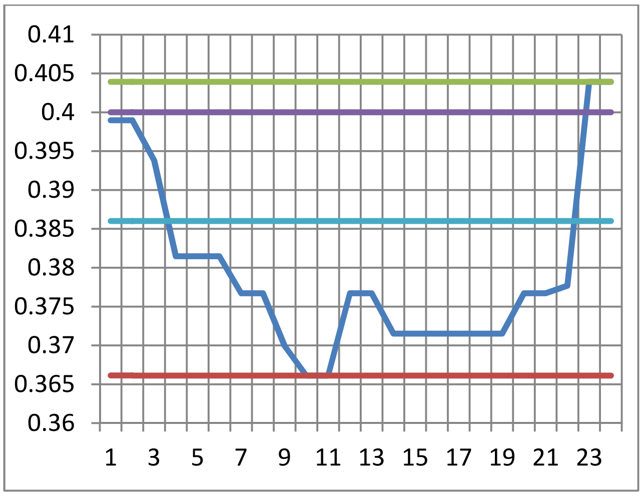
a) Output voltage of main substation 110/10 kV



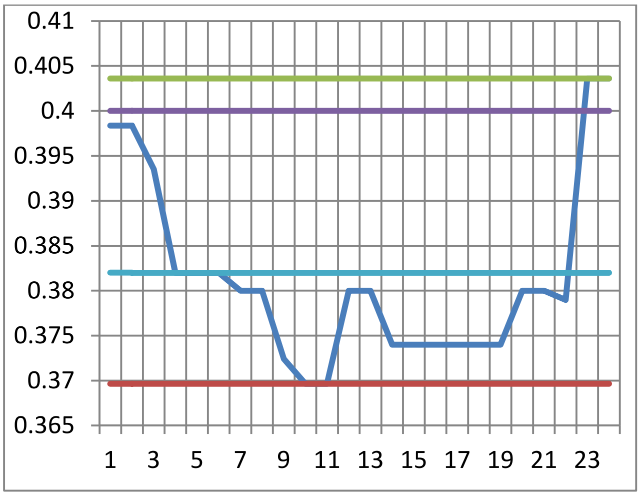
b) Output voltage of WS1 10/0.4 kV



c) Output voltage of WS2 10/0.4 kV



d) Output voltage of WS3 10/0.4 kV



e) Output voltage of WS10 10/0.4 kV

Fig 3.1 Voltage curves of power supply

Average, maximum, minimum voltage of workshops Table 3.4

substation	SUB	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
$U_{max.}$	10.185	10.134	10.142	10.098	10.129	10.065	10.163	10.148	10.149	10.180	10.090
$U_{min.}$	9.541	9.315	9.354	9.153	9.352	9.116	9.462	9.406	9.411	9.520	9.241
$U_{average}$	9.769	9.616	9.641	9.493	9.617	9.429	9.710	9.671	9.680	9.754	9.54

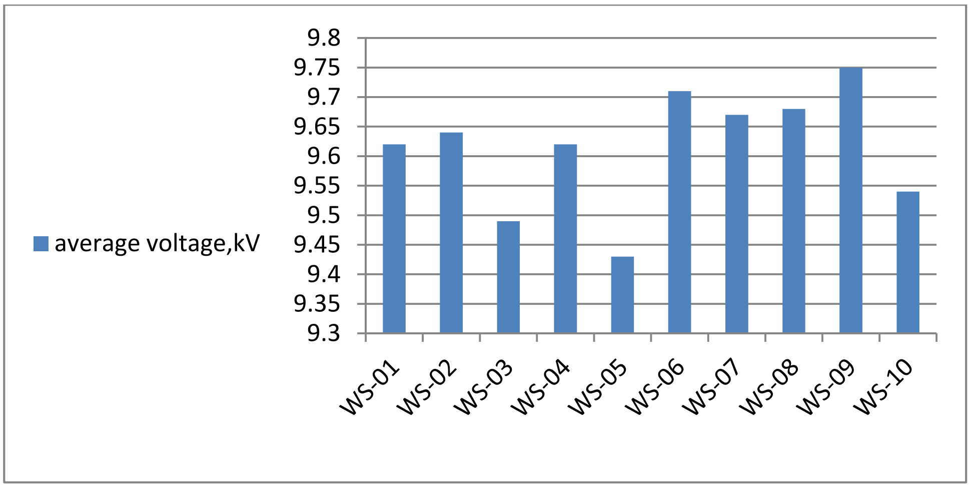


Fig 3.2- Average voltage for workshops

3.2. Adjusting The Voltage At Main Substation

The capability of adjusting the turns ratio of a transformer is oftentimes desirable to compensate for variations in voltage that occur due to loading cycles, and there are several means by which the task can be accomplished. There is a significant difference in a transformer that is capable of changing the ratio while the unit is on-line, referred to as a Load Tap Changing (LTC) transformer, and one that must be taken off-line, or de-energized, to perform a tap change.

In this section counter adjusting of voltage is used on loading. We doing the calculation of adjusting of voltage on main substation (110/10 kV).

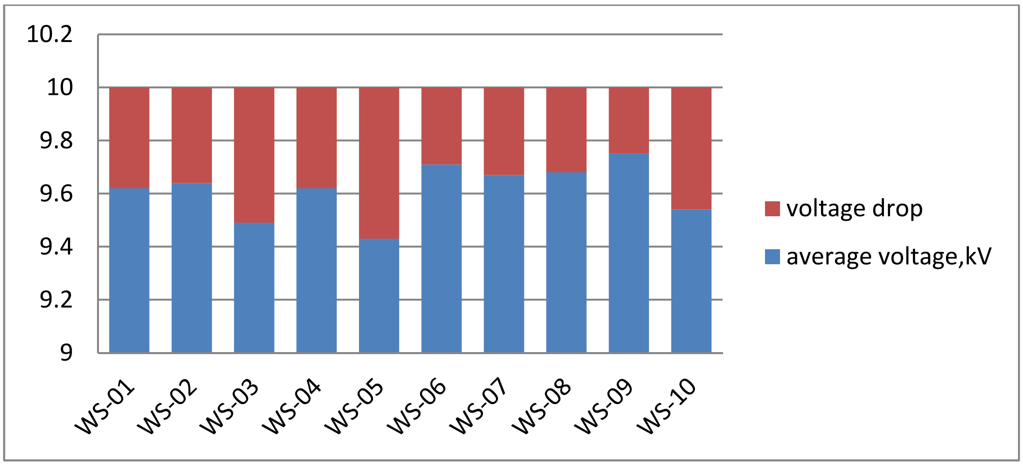


Fig 3.3-Voltage average and voltage drop at workshops

The desired levels of voltage on the side of low voltage rate for maximal mode of loading;

$$U_{desired}=1.05 \cdot U_{L.S} =10 \cdot 1.05 =10.5 \qquad (3.7)$$

Where $U_{L.S}$- rating voltage for low side of transformer.

For main substation rating voltage for low side U_{SUB}=10 kV.

For adjusting of actual voltages to level of desired, we carry out tap-changing of working arm of regulation winding in a transformer, for that we expect percent of change of coils of this winding, %,:

$$\Delta W\,\% = \frac{U_{actual} - U_{desired}}{U_{Lnom.}} \cdot 100\% = \frac{9.75 - 10.5}{10} \cdot 100\% = -7.5 \qquad (3.8)$$

U_{actual}= $U_{average9}$=9.75 kV from table 3.4.

For the choice standard branches we make the table of standard branches on the set chart of adjusting. The system of adjusting System of adjusting 9×1,78%.

We adopt the change of voltage of one level of branches

$k_{level.1}$=1.78 %.

We determine a number and sign of levels of branches of the system of adjusting of PПH (adjusting position of voltage);

$$\pm n_{level} = \frac{\pm \Delta W\,\%}{k_{level}} = \frac{-7.5}{1.78} = -4.21 \qquad (3.9)$$

Adopt standard number and sign of levels of branches of the system of PПH

$n_{stan.1}$=-4

We determine real voltage on a high side at chosen position of PПH, kV:

$$U_{actualH.S} = U_{no\min al} \cdot (1 + \frac{n_{s\tan.1} \cdot k_{level}}{100}) = 110 \cdot (1 - \frac{4 \cdot 1.78}{100}) = 102.17 \qquad (3.10)$$

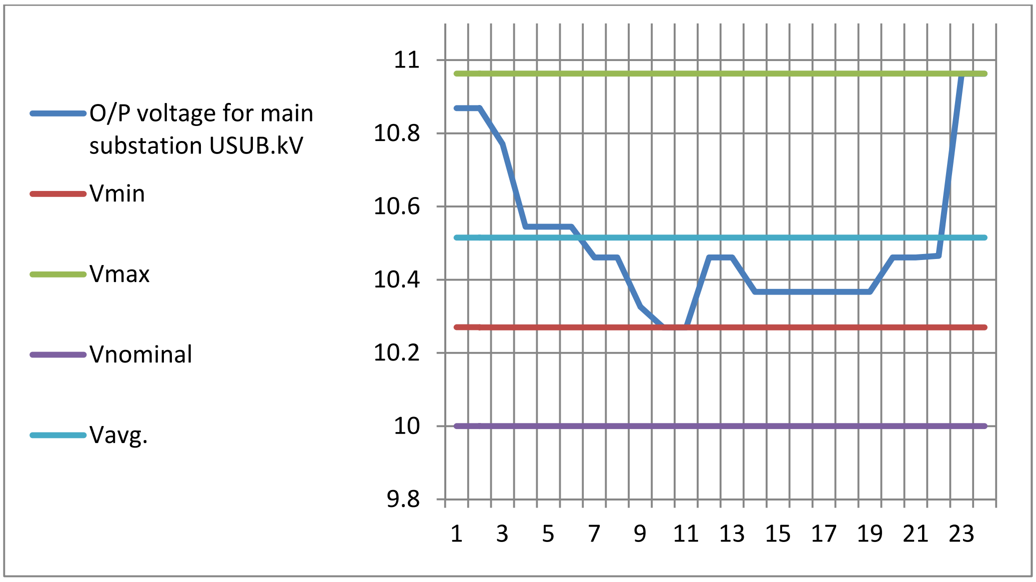
Now, we need new coefficient of transfer voltage in a transformer for main substation :

$$k = \frac{U_{H.S}}{U_{L.S}} = \frac{102.17}{10} = 10.22 \qquad (3.11)$$

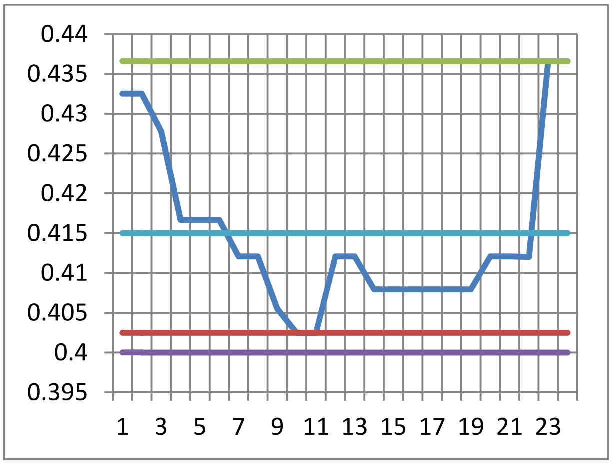
We will repeat calculation of power losses and voltage with actual coefficient (ratio) transformer as in section (3.1).Results of calculation of power losses and revived voltage at workshops and substation for the last (forth) iteration are included in the table 3.5.

Output voltage at high side of transformers Table 3.5

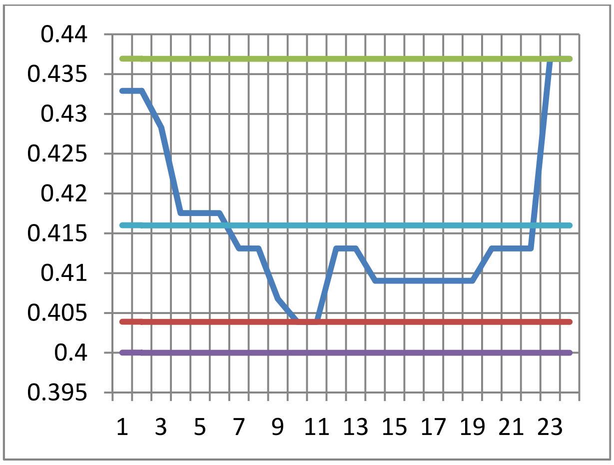
Time interval,t, hours	SUB	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
0-1	10.869	10.812	10.822	10.754	10.784	10.675	10.841	10.834	10.829	10.861	10.740
1-2	10.869	10.812	10.822	10.754	10.784	10.675	10.841	10.834	10.829	10.861	10.740
2-3	10.770	10.694	10.707	10.621	10.668	10.537	10.736	10.723	10.719	10.761	10.614
3-4	10.545	10.416	10.438	10.305	10.395	10.200	10.492	10.466	10.475	10.532	10.317
4-5	10.545	10.416	10.438	10.305	10.395	10.200	10.492	10.466	10.475	10.532	10.317
5-6	10.545	10.416	10.438	10.305	10.395	10.200	10.492	10.466	10.475	10.532	10.317
6-7	10.461	10.302	10.328	10.184	10.296	10.086	10.340	10.363	10.379	10.446	10.259
7-8	10.461	10.302	10.328	10.184	10.296	10.086	10.340	10.363	10.379	10.446	10.259
8-9	10.326	10.138	10.169	10.008	10.154	9.941	10.253	10.208	10.219	10.308	10.064
9-10	10.270	10.062	10.097	9.9130	10.097	9.882	10.197	10.145	10.150	10.251	9.993
10-11	10.270	10.062	10.097	9.9130	10.097	9.882	10.197	10.145	10.150	10.251	9.993
11-12	10.461	10.302	10.328	10.184	10.296	10.086	10.340	10.363	10.379	10.446	10.259
12-13	10.461	10.302	10.328	10.184	10.296	10.086	10.340	10.363	10.379	10.446	10.259
13-14	10.367	10.198	10.226	10.051	10.220	10.046	10.302	10.250	10.260	10.349	10.107
14-15	10.367	10.198	10.226	10.051	10.220	10.046	10.302	10.250	10.260	10.349	10.107
15-16	10.367	10.198	10.226	10.051	10.220	10.046	10.302	10.250	10.260	10.349	10.107
16-17	10.367	10.198	10.226	10.051	10.220	10.046	10.302	10.250	10.260	10.349	10.107
17-18	10.367	10.198	10.226	10.051	10.220	10.046	10.302	10.250	10.260	10.349	10.107
18-19	10.367	10.198	10.226	10.051	10.220	10.046	10.302	10.250	10.260	10.349	10.107
19-20	10.461	10.302	10.328	10.184	10.296	10.086	10.340	10.363	10.379	10.446	10.259
20-21	10.461	10.302	10.328	10.184	10.296	10.086	10.340	10.363	10.379	10.446	10.259
21-22	10.465	10.300	10.328	10.206	10.342	10.206	10.411	10.368	10.365	10.450	10.235
22-23	10.963	10.915	10.923	10.882	10.911	10.852	10.942	10.928	10.929	10.957	10.874
23-24	10.963	10.915	10.923	10.882	10.911	10.852	10.942	10.928	10.929	10.957	10.874



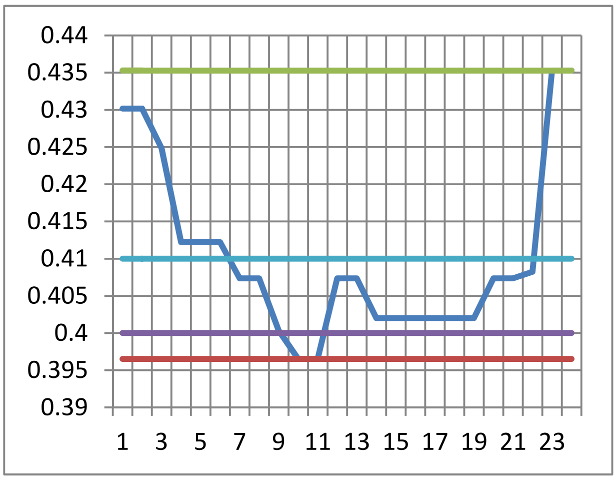
a) Output voltage of main substation (110/10)



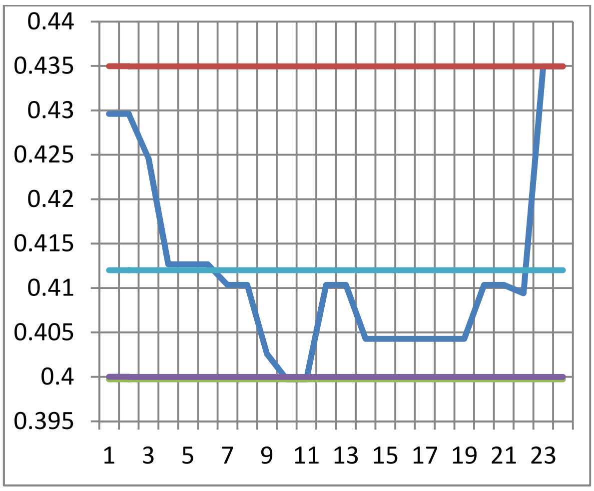
b) Output voltage of WS1 10/0.4 kV



c) Output voltage of WS2 10/0.4 kV



d) Output voltage of WS3 10/0.4 kV



e) Output voltage of WS10 10/0.4 kV

Fig 3.4 Voltage curves of power supply after adjusting the voltage at main substation

3.3. Adjusting The Voltage At Main Substation And Workshops

In this section , we will use the same method in section(3.2) and use the results in pervious section to calculations power loss and voltage . We doing the calculation of adjusting of voltage on substation №1 (as an example) for the mode of the maximal loading. Calculations for other substations are resulted at table 6.1.

For adjusting of actual voltages to level of desired, we carry out tap-changing of working arm of regulation winding in a transformer, for that we expect percent of change of coils of this winding, %,:

$$\Delta W\% = \frac{U_{actual} - U_{desired}}{U_{Lnom}} \cdot 100\% = \frac{10.915 - 10.5}{10} \cdot 100\% = 4.15. \quad \text{from (3.8)}$$

For the choice standard branches we make the table of standard branches on the set chart of adjusting. The system of adjusting we choice from table 2.6. System of adjusting 2 ×2,5%.

We adopt the change of voltage of one level of branches

$k_{level.1}$=2,5 %.

We determine a number and sign of levels of branches of the system of adjusting of РПН (adjusting position of voltage);

$$\pm n_{level} = \frac{\pm \Delta W\,\%}{k_{level}} = \frac{4.15}{2.5} = 1.66 \quad \text{from (3.9)}$$

Adopt standard number and sign of levels of branches of the system of РПН

$n_{stan.1}$=2

We determine real voltage on a high side at chosen position of РПН, kV:

$$U_{actualH.S} = U_{nominal} \cdot (1 + \frac{n_{stan.1} \cdot k_{level}}{100}) = 10 \cdot (1 + \frac{2 \cdot 2.5}{100}) = 10.5 \quad \text{from (3.10)}$$

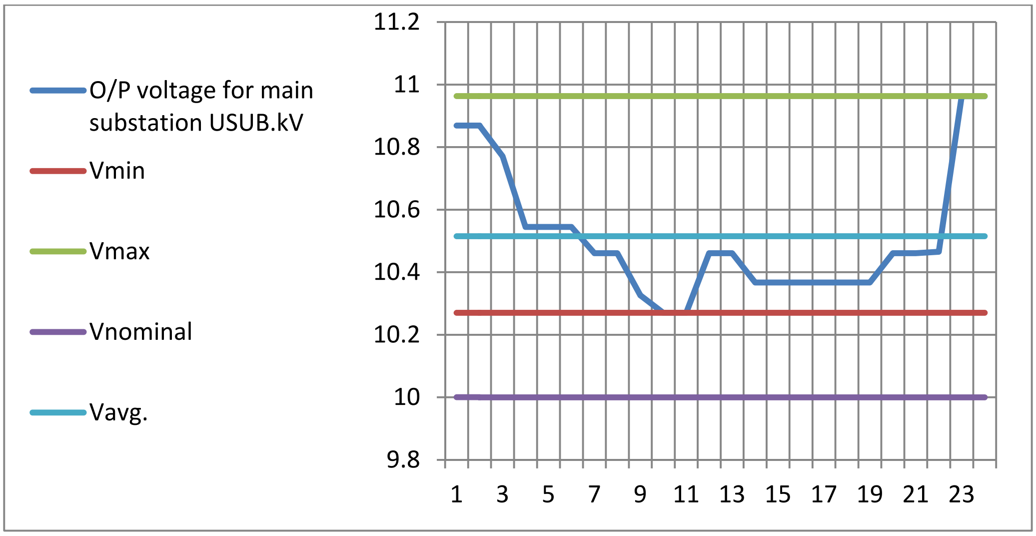
Now, we need new coefficient of transfer voltage in a transformer for main substation :

$$k_{level} = \frac{U_{HV}}{U_{LV}} = \frac{10.5}{0.4} = 26.25 \qquad \text{from(3.11)}$$

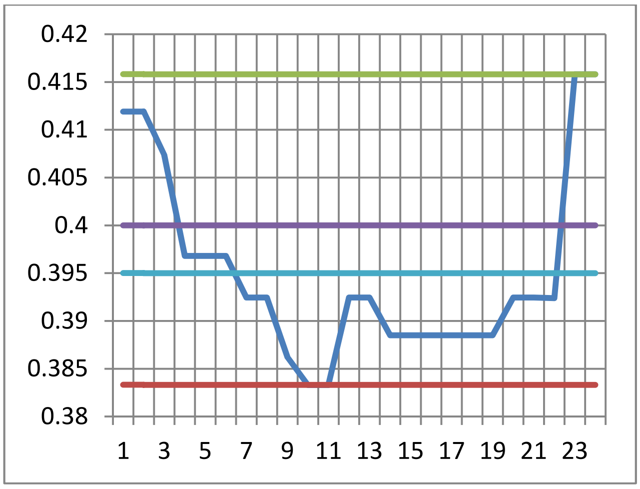
Results of calculation of adjusting voltage at other workshops are include in table 3.6.

Adjusting the voltage at workshops Table 3.6

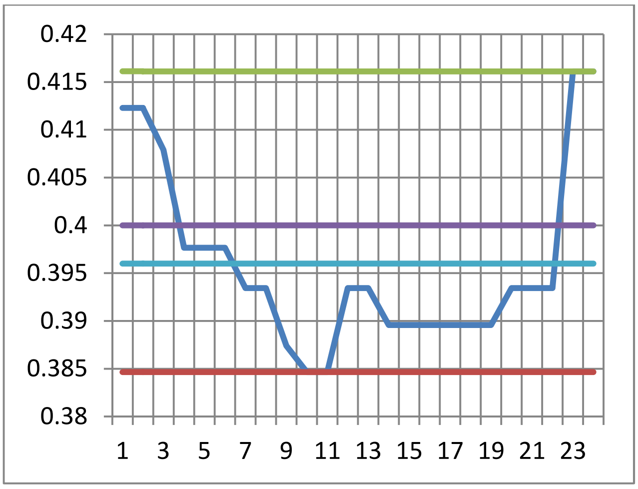
Actual Coefficient of transformations of transformer	26.25	26.25	26.25	26.25	25.625	26.25	26.25	26.25	26.25	25.625
Actual voltage on a low side at chosen position of РПН,$U_{real.H.S.}$, kV, (6.7)	10.5	10.5	10.5	10.5	10.25	10.5	10.5	10.5	10.5	10.25
Standard number and sign of stages of branch of the system of adjusting of РПН,n_{stan}	2	2	2	2	1	2	2	2	2	1
Number and sign of stages of branch of the system of adjusting of РПН,n_{level} ,(4.19)	1.66	1.69	1.53	1.64	1.41	1.77	1.71	1.72	1.83	1.49
Coefficient of stage of branch k_{level}%, (table 2.6(	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Percent of change of coils of regulation winding ΔWi%, (a.a)	4.15	4.23	3.82	4.11	3.52	4.42	4.28	4.29	4.57	3.74
Desired level of voltage on the side of low voltage,$U_{desired}$, kV (6.2)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
Voltage, consumed by a knot on the output of substation (voltage on the lower side of transformers, resulted to the higher),U , kV (table 4.7)	10.915	10.923	10.882	10.911	10.852	10.942	10.928	10.929	10.957	10.874
Workshop	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10



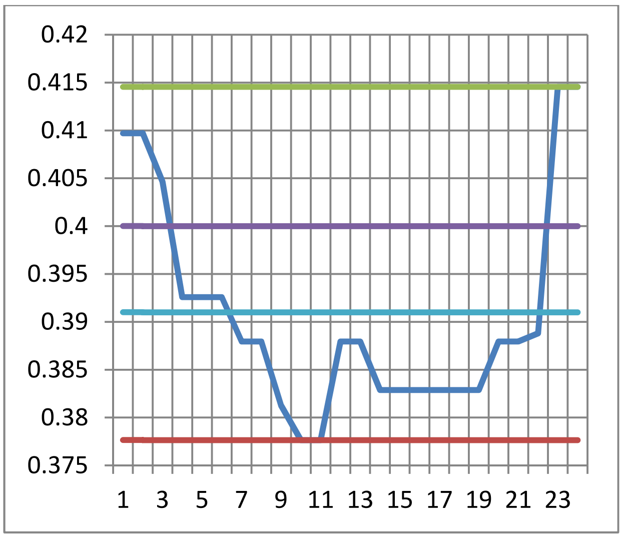
a) Output voltage of main substation 110/10 kV



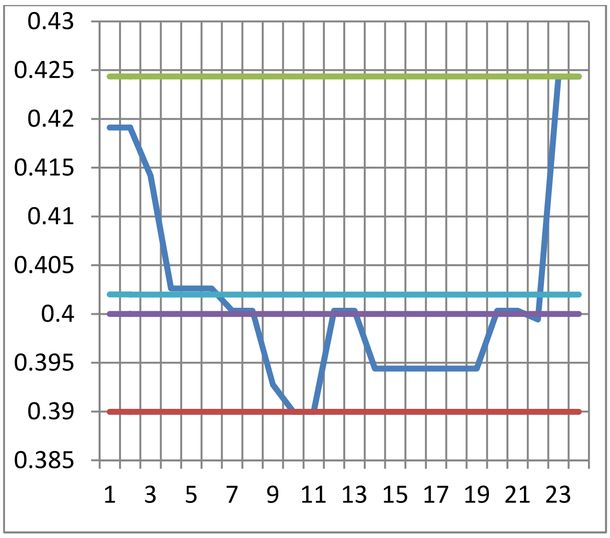
b) Output voltage of WS1 10/0.4 kV



c) Output voltage of WS2 10/0.4 kV



d) Output voltage of WS3 10/0.4 kV



e) Output voltage of WS10 10/0.4 kV

Fig 3.5 Voltage curves of power supply after adjusting the voltage at main substation and workshops

3.4 Adjusting The Voltage By Compensating Reactive Power Of Power Supply

After calculated the load daigram of the winter, carried specification capacity compensating devices CD. Assuming, that the installed capacity of power generators sufficient to cover designed needs of the active power for the network, are P_G. Thus, the calculated active power consumption of substations ,P_S, is taken from table (2.6),power losses in cable lines P_L, which feeds the substation, for which compensation device is calculated .

For example, substation WS1 most economical consumption of reactive power

$$Q_{econ.4} = P_{ni} \cdot tg\varphi_G \qquad (3.12)$$

$tg\varphi_G$ -the tangent value

$$tg\varphi_G = 0.395$$

For value $tg\varphi_G$ in the network, that designed, need to install compensating devices (CD) near to consumers on the side of low voltage. Reactive power compensating devices (CD,) determined by the formula;

$$Q_{CD.} = (Q_{SUB} - \frac{Q_c}{2}) - Q_G \qquad (3.13)$$

Where $(Q_{SUB} - \frac{Q_c}{2})$ - the maximum value of reactive power load knot, taking into account charging power lines, Q_p and $\frac{Q_c}{2}$.

Obviously, if $(Q_{SUB} - \frac{Q_c}{2}) \le Q_G$, we do not need to install compensating devices in substation.

Batteries in the form of complete systems such as CU are mostly used at the consuming substations for compensating devices. According to [5] their power levels are;

for the secondary (low) voltage $U_{L.S.}$ = 6 kV – 0.3, 0.4, 0.45, 0.675, 0.9, 1.125, 1.35, 1.8, 2.7 MVAr.

for the secondary (low) voltage $U_{L.S.}$ = 10 kV – 0.4,0.45, 0.675, 0.9, 1.125, 1.35, 1.8, 2.7 MVAr.

Having determined the calculated value of power compensation devices Q_{CD} , you should select condensing plants (CP) for its implementation or determine the number of individual capacitors, with the help of which the calculated power of compensation devices (CD) can be realized. The substation is provided with 2 transformers, when complete devices are chosen, you should remember that they must be separated at the substation into two busbar sections of low voltage 6-10 kV, i.e., their number should be divisible by two. When determing the number of individual capacitors their number should be divisible by 6 because they are uniformly separated by phases and by busbar sections.

Thus, the power of compensation devices is equally (CD) divided to each of these busbars 6-10 kV of the substation, it means that the number of similar CD should be divisible by 2, with triple-wound transformers or double-wound or autotransformer, which are installed at the substation (for example, there are types such as TM, NTM, TDN, TDTN, ATDTSTN) and divisible by 4 - for the transformers with split low-voltage windings (type TRDN).

The following calculations should take into account not calculated power compensating devices $Q_{кпі}$, and established $Q_{кпні}$.

Power of consumers after the reactive power compensation in the load center is defined as, MVA:

$$S_{крп} = P_i + j(Q_{кпні} - Q_г) \qquad (3.14)$$

Source [5], select the compensating device with capacitor batteries.

Reactive power of compensating device Table 3.7

Number of workshop	The active power at maximum load ,P,MW	Reactive power at maximum load, Q , MVAr	The economic value of tangent, tgφ$_{ec.}$	Economic reactive power of the load , Q_{ec}, MVA	Reactive power compensating devices, Qкроз= Qфакт,MVAr
WS1	1831.63	1435.35	0.395	723.49	711.86
WS2	612.57	567.52	0.395	241.97	325.55
WS3	1491.7	1243.21	0.395	589.22	653.99
WS4	842.21	638.56	0.395	332.67	305.89
WS5	647.36	617.01	0.395	255.71	361.30
WS6	1239.85	1099.01	0.395	489.74	609.27
WS7	1548.29	1374.57	0.395	611.57	763
WS8	1216.89	981.23	0.395	480.67	500.56
WS9	1663.7	1300.24	0.395	657.16	643.08
WS10	1937.71	1417.71	0.395	765.4	652.31

The final selection of compensating devices that doskladayutsya to capacitor devices in Table 3.8.

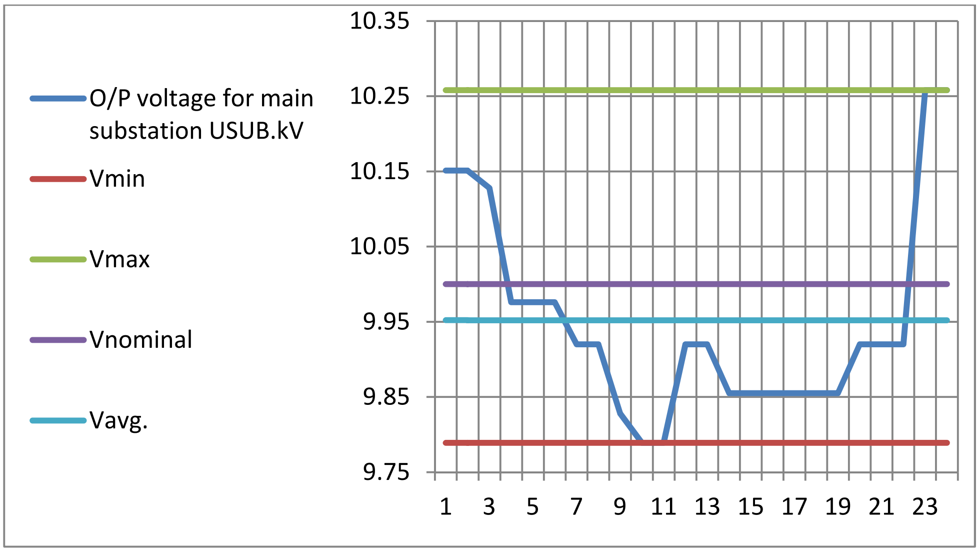
Selecting of compensating device Table 3.8

Number of workshop	Required power of compensating devices, Qкроз,MVAr	Multiplicity	Number of compensating devices, n_{CD}, pieces	Type of compensating device	Nominal rating power of compensating device, MVAr	Total power of compensating devices	Active and reactive power at maximum load,P+jQкрп,MVA		
WS1	711.86	2	2	УКМ 58-0.4-402	402	804	1831.63	+j	631.35
WS2	325.55	2	2	УКМ 58-0.4-200	200	400	612.57	+j	167.52
WS3	653.99	2	2	УКМ 58-0.4-402	402	804	1491.70	+j	439.21
WS4	305.89	2	2	УКМ 58-0.4-200	200	400	842.21	+j	238.56
WS5	361.3	2	2	УКМ 58-0.4-200	200	400	647.36	+j	217.01
WS6	609.27	2	2	УКМ 58-0.4-402	402	804	1239.85	+j	295.01
WS7	763	2	2	УКМ 58-0.4-402	402	804	1548.29	+j	570.57
WS8	500.56	2	2	УКМ 58-0.4-256	256	512	1216.89	+j	469.23
WS9	643.08	2	2	УКМ 58-0.4-402	402	804	1663.70	+j	496.24
WS10	652.31	2	2	УКМ 58-0.4-402	402	804	1937.71	+j	613.71

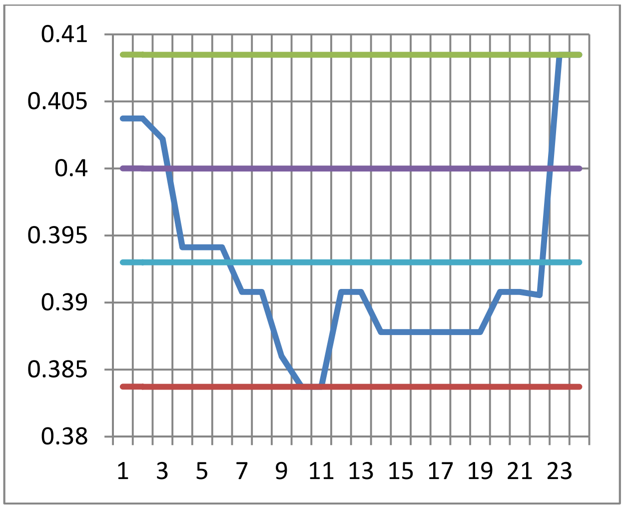
We will repeat calculation of power losses and voltage with new reactive power for each workshops transformer as in section (3.1).Results of calculation of power losses and revived voltage at workshops and substation for the last (forth) iteration are included in the table 3.9.

Output voltage at high side of transformers Table 3.9

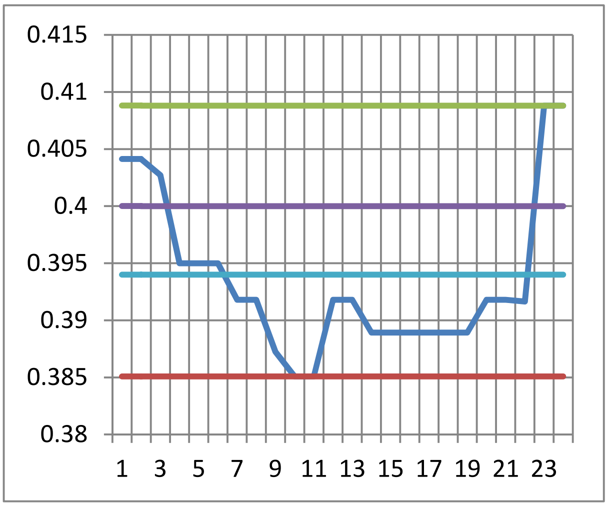
Time interval,t, hours	SUB	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
1-0	10.151	10.093	10.103	10.028	10.063	9.945	10.122	10.114	10.109	10.143	10.013
2-1	10.151	10.093	10.103	10.028	10.063	9.945	10.122	10.114	10.109	10.143	10.013
3-2	10.128	10.055	10.068	9.981	10.03	9.904	10.094	10.082	10.077	10.118	9.974
4-3	9.976	9.853	9.875	9.741	9.834	9.652	9.924	9.9	9.906	9.963	9.753
5-4	9.976	9.853	9.875	9.741	9.834	9.652	9.924	9.9	9.906	9.963	9.753
6-5	9.976	9.853	9.875	9.741	9.834	9.652	9.924	9.9	9.906	9.963	9.753
7-6	9.92	9.77	9.795	9.65	9.765	9.57	9.862	9.827	9.839	9.906	9.723
8-7	9.92	9.77	9.795	9.65	9.765	9.57	9.862	9.827	9.839	9.906	9.723
9-8	9.828	9.65	9.681	9.52	9.667	9.47	9.758	9.716	9.722	9.811	9.574
10-9	9.789	9.593	9.627	9.444	9.627	9.43	9.719	9.671	9.671	9.771	9.521
11-10	9.789	9.593	9.627	9.444	9.627	9.43	9.719	9.671	9.671	9.771	9.521
12-11	9.92	9.77	9.795	9.65	9.765	9.57	9.862	9.827	9.839	9.906	9.723
13-12	9.92	9.77	9.795	9.65	9.765	9.57	9.862	9.827	9.839	9.906	9.723
14-13	9.855	9.695	9.723	9.548	9.716	9.553	9.792	9.743	9.749	9.838	9.6
15-14	9.855	9.695	9.723	9.548	9.716	9.553	9.792	9.743	9.749	9.838	9.6
16-15	9.855	9.695	9.723	9.548	9.716	9.553	9.792	9.743	9.749	9.838	9.6
17-16	9.855	9.695	9.723	9.548	9.716	9.553	9.792	9.743	9.749	9.838	9.6
18-17	9.855	9.695	9.723	9.548	9.716	9.553	9.792	9.743	9.749	9.838	9.6
19-18	9.855	9.695	9.723	9.548	9.716	9.553	9.792	9.743	9.749	9.838	9.6
20-19	9.92	9.77	9.795	9.65	9.765	9.57	9.862	9.827	9.839	9.906	9.723
21-20	9.92	9.77	9.795	9.65	9.765	9.57	9.862	9.827	9.839	9.906	9.723
22-21	9.92	9.764	9.791	9.668	9.803	9.674	9.869	9.827	9.821	9.905	9.696
23-22	10.258	10.212	10.22	10.178	10.207	10.149	10.238	10.224	10.224	10.253	10.17
24-23	10.258	10.212	10.22	10.178	10.207	10.149	10.238	10.224	10.224	10.253	10.17



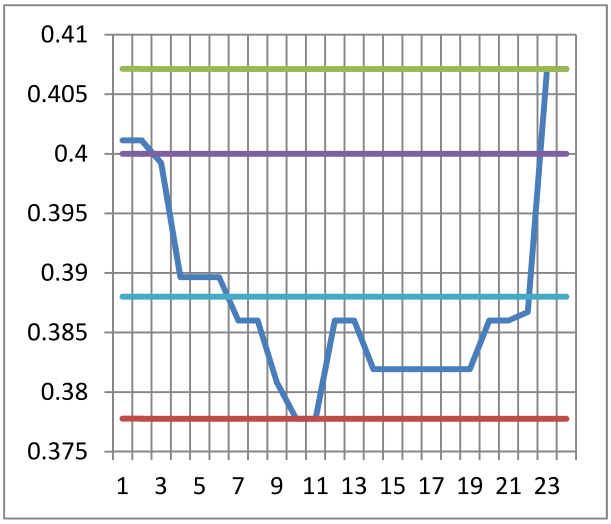
a) Output voltage of main substation 110/10 kV



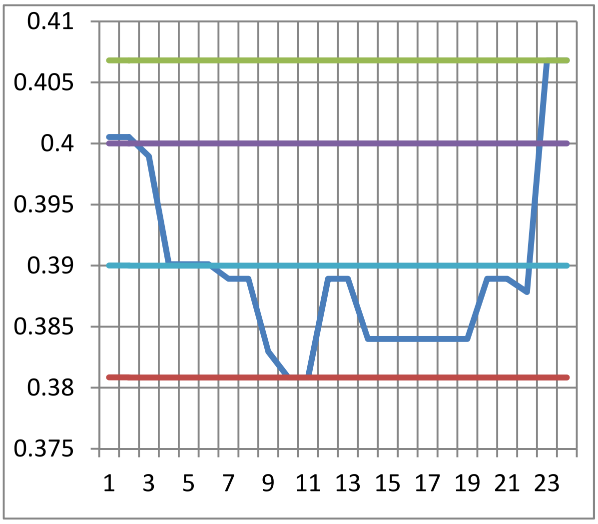
b) Output voltage of WS1 10/0.4 kV



c) Output voltage of WS2 10/0.4



d) Output voltage of WS3 10/0.4 kV



e) Output voltage of WS10 10/0.4 kV

Fig 3.6 Voltage curves of power supply with use compensating device

3.5.Voltage regulation by change cable line parameter

Voltage drop occurs in transmission line by passing current through impedance of line. In radial connection , two cables which they work in parallel and therefore the equivalent resistance will be divide by two and also for reactance ,therefore the voltage drop at the smallest possible value.

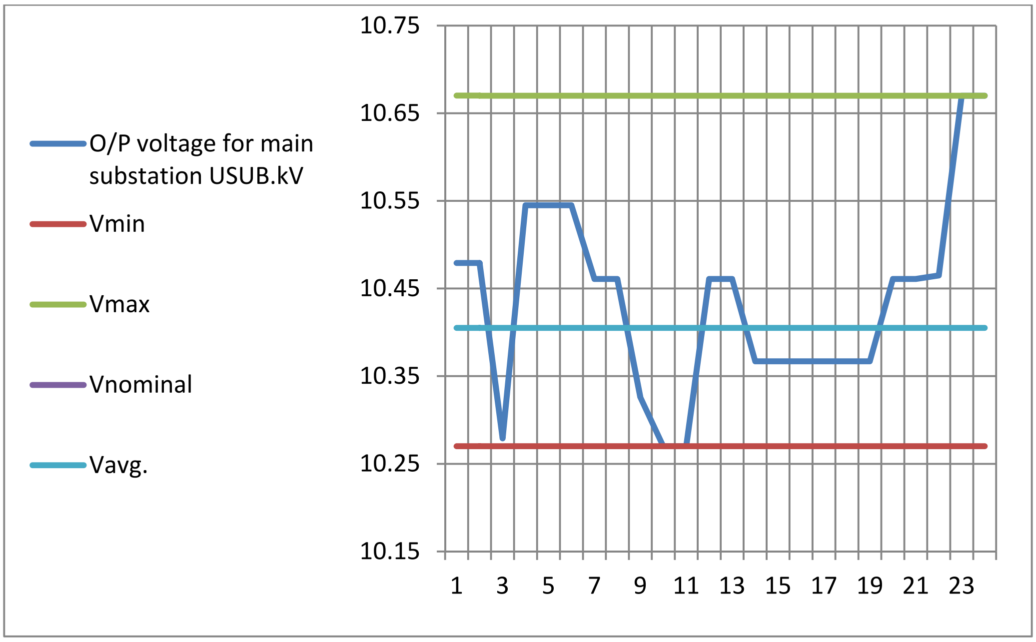
When workshop works at minimum load , the current will pass in cables at minimum. Over voltage may be occur and exceed the permissible limits of voltage, therefore two cable do not need to work together ,one of these cable will turn off by switches. Impedance of cable are multiplied twice. In other word, one circuit will transmit from substation to consumer.

By applying as stated above in our calculations, and will obtain results of calculation of power losses and revived voltage at workshops and substation for the last (forth) iteration are included in the table 3.10.

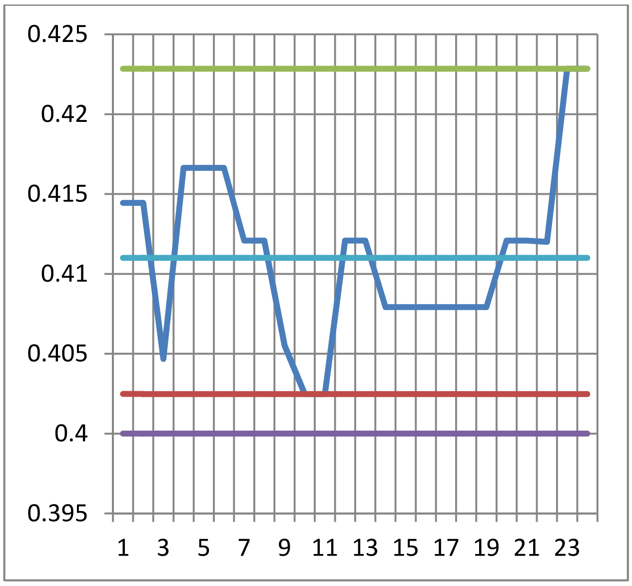
Output voltage at high side of transformers Table 3.10

Time interval,t , hours	SUB	WS1	WS2	WS3	WS4	WS5	WS6	WS7	WS8	WS9	WS10
1-0	10.479	10.361	10.382	10.246	10.288	10.025	10.421	10.404	10.397	10.462	10.201
2-1	10.479	10.361	10.382	10.246	10.288	10.025	10.421	10.404	10.397	10.462	10.201
3-2	10.279	10.117	10.146	9.97	10.042	9.712	10.206	10.177	10.172	10.258	9.937
4-3	10.545	10.416	10.438	10.305	10.395	10.2	10.492	10.466	10.475	10.532	10.317
5-4	10.545	10.416	10.438	10.305	10.395	10.2	10.492	10.466	10.475	10.532	10.317
6-5	10.545	10.416	10.438	10.305	10.395	10.2	10.492	10.466	10.475	10.532	10.317
7-6	10.461	10.302	10.328	10.184	10.296	10.086	10.4	10.363	10.379	10.446	10.259
8-7	10.461	10.302	10.328	10.184	10.296	10.086	10.4	10.363	10.379	10.446	10.259
9-8	10.326	10.138	10.169	10.008	10.154	9.941	10.253	10.208	10.219	10.308	10.065
10-9	10.27	10.062	10.097	9.913	10.097	9.882	10.197	10.145	10.15	10.251	9.993
11-10	10.27	10.062	10.097	9.913	10.097	9.882	10.197	10.145	10.15	10.251	9.993

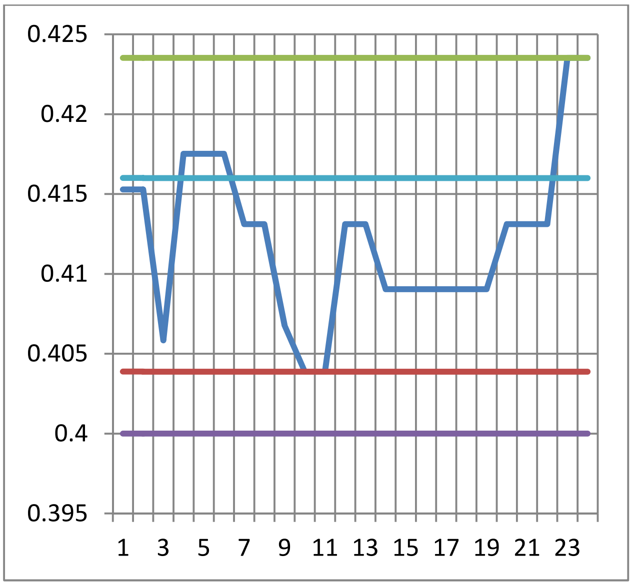
12-11	10.461	10.302	10.328	10.184	10.296	10.086	10.4	10.363	10.379	10.446	10.259
13-12	10.461	10.302	10.328	10.184	10.296	10.086	10.4	10.363	10.379	10.446	10.259
14-13	10.367	10.198	10.226	10.051	10.22	10.046	10.302	10.25	10.26	10.349	10.107
15-14	10.367	10.198	10.226	10.051	10.22	10.046	10.302	10.25	10.26	10.349	10.107
16-15	10.367	10.198	10.226	10.051	10.22	10.046	10.302	10.25	10.26	10.349	10.107
17-16	10.367	10.198	10.226	10.051	10.22	10.046	10.302	10.25	10.26	10.349	10.107
18-17	10.367	10.198	10.226	10.051	10.22	10.046	10.302	10.25	10.26	10.349	10.107
19-18	10.367	10.198	10.226	10.051	10.22	10.046	10.302	10.25	10.26	10.349	10.107
20-19	10.461	10.302	10.328	10.184	10.296	10.086	10.4	10.363	10.379	10.446	10.259
21-20	10.461	10.302	10.328	10.184	10.296	10.086	10.4	10.363	10.379	10.446	10.259
22-21	10.465	10.3	10.328	10.206	10.342	10.206	10.411	10.368	10.365	10.445	10.235
23-22	10.479	10.571	10.588	10.509	10.559	10.426	10.628	10.597	10.602	10.659	10.482
24-23	10.479	10.571	10.588	10.509	10.559	10.426	10.628	10.597	10.602	10.659	10.482



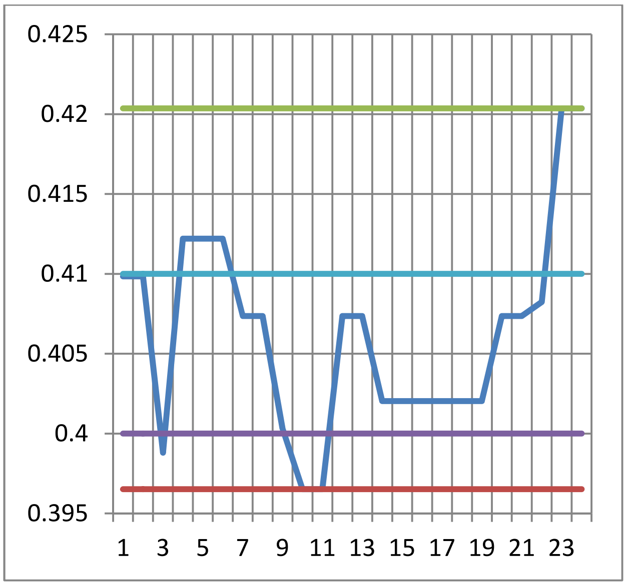
a) Output voltage of main substation 110/10 kV



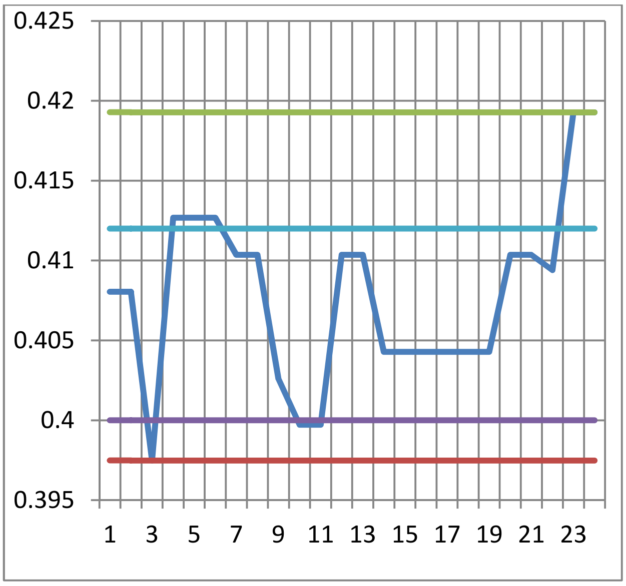
b) Output voltage of WS1 10/0.4 kV



c) Output voltage of WS2 10/0.4 kV



d) Output voltage of WS3 10/0.4 kV



e) Output voltage of WS10 10/0.4 kV

Fig 3.6 Voltage curves of power supply change parameter of transmission line

4. LABOR SAFETY

4.1. 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 km^2 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 and more
Average number of lightning strikes in 1 km of surface	1	3	6	9	12

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.

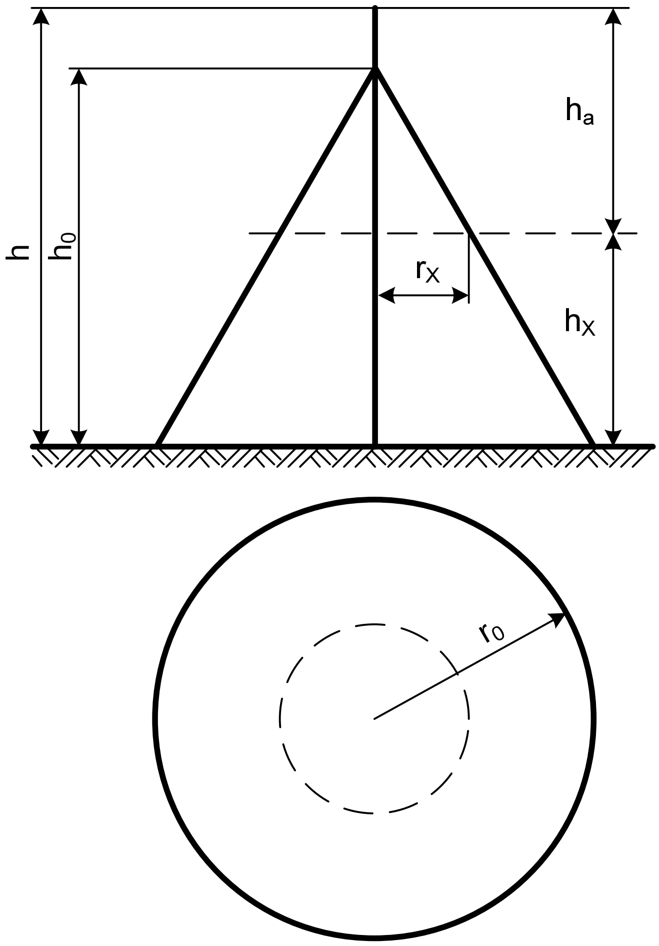


Fig. 4.1 Protection zone of single lightning rod

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. 4.2.

Dimensions substation and installation of lightning rod

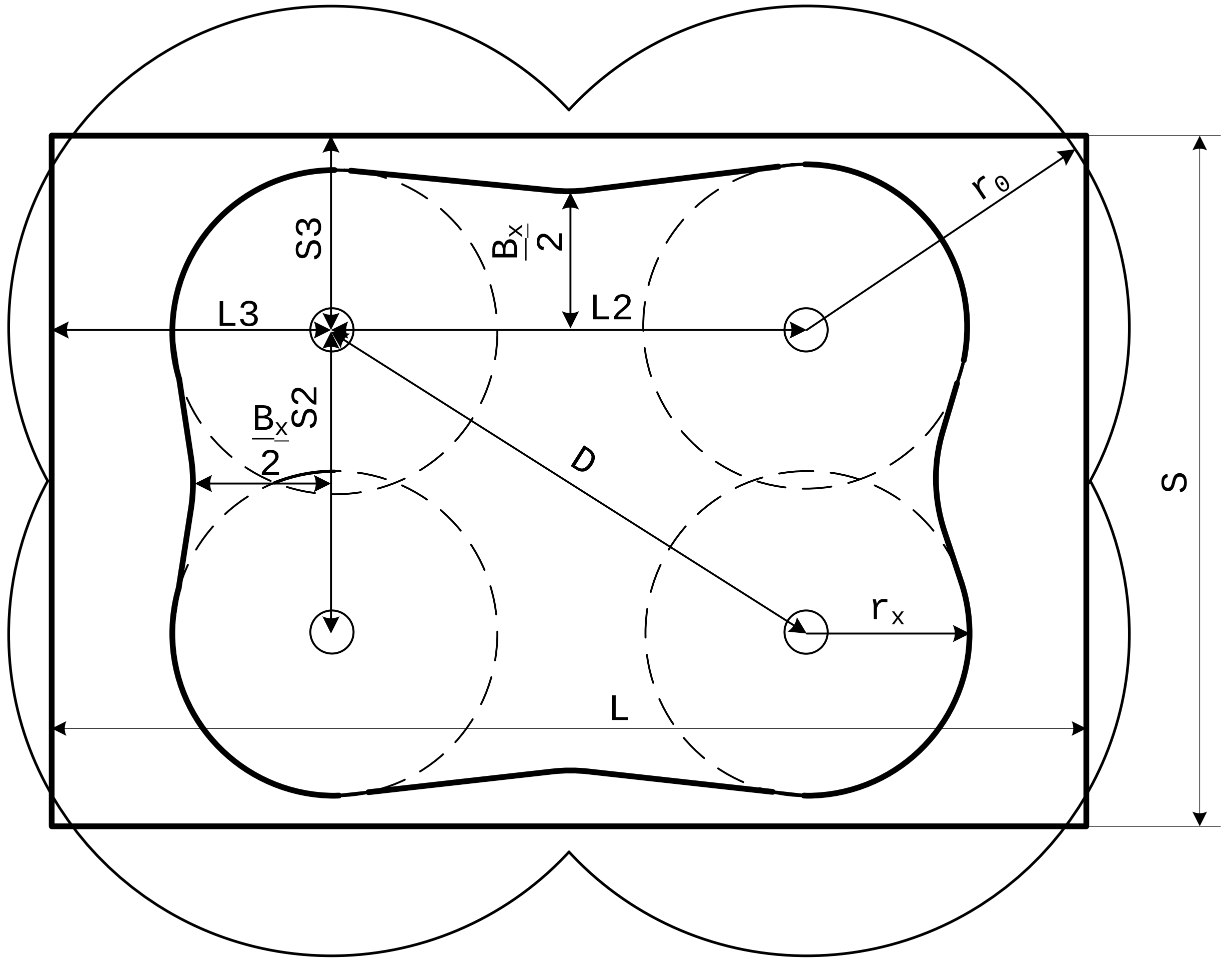


Fig. 4.2- Zone of substation lightning protection

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:

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

$$36 \leq 8 \cdot 12;$$

$$36 \leq 96$$

Lightning protection is calculated correctly

4.2. Calculation of substation earthing device

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

$$\rho_{расч} = K_1 \cdot \rho_{изм2} \qquad (4.1)$$

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

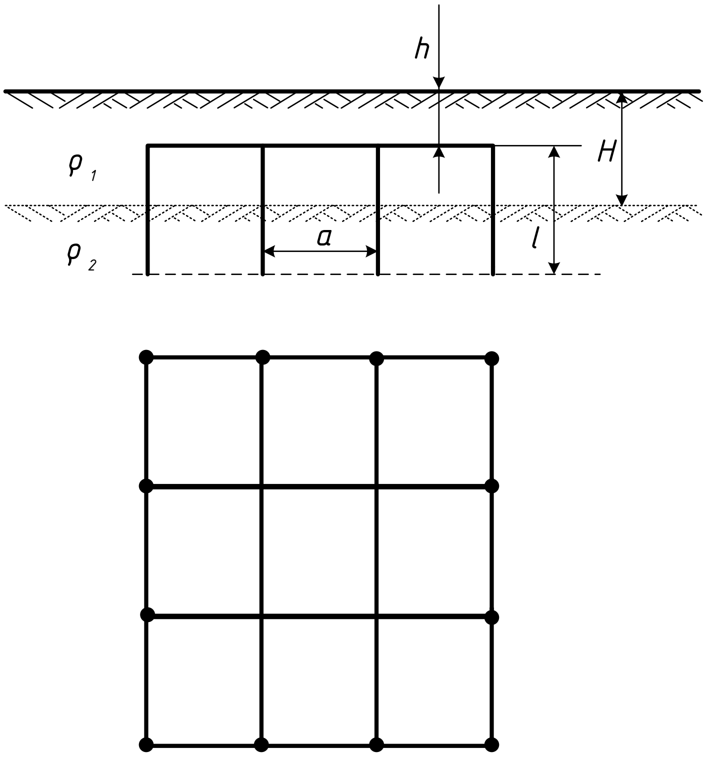


Fig. 4.3 Location of grounding

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 (**Error! Reference source not found.**.1) find

$\rho_{расч}$=1,15·210 =241,5 (Ом·м)

Define artificial grounding resistance by the formula

$$R_u = \frac{R_{\in} \cdot R_3}{R_{\in} + R_3} \qquad (4.2)$$

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 (4.2) we obtain

$$R_u = (2,1\cdot 0,5)/(2,1+0,5) = 0,4$$

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

$$R_n = \frac{\rho_{расч}}{2\pi l}\cdot Ig\frac{2l^2}{b\cdot h} \qquad (4.3)$$

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

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

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

$$R_{n\sum} = \frac{R_n}{n\cdot \eta_n} \qquad (4.4)$$

where n – quantity accept n= 4 bands;

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

accept η = 0,36

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

$$R_{n1\sum} = 3,708/(4\cdot 0,36) = 2,58$$

Similarly to formulas (4.3) and (8.4) we find the spreading resistance of a cross-band and equivalent resistance of the transverse bands

ln(546750)= 5,51

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

accept n_2= 5

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

The total resistance of equal grid of horizontal bands

$$R_c = \frac{R_{n1\sum} \cdot R_{n2\sum}}{R_{n1\sum} + R_{n2\sum}} \cdot \frac{1}{\eta} \qquad (4.5)$$

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

$$R_{cm} = \frac{R_c \cdot R_н}{R_c - R_н} \qquad (4.6)$$

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

$$r_в = \frac{0.366\rho}{le}\left(\lg\frac{2le}{0{,}95bx} + \frac{1}{2}\lg\frac{4l_t + le}{4l_t - le}\right) \qquad (4.7)$$

where *le* – length of 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)))=33,22 Ом.

Determine the required number of vertical grounding by formula

$$n_e = \frac{r_в}{R_{cm} \cdot \eta_6} \qquad (4.9)$$

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.

$$S_m = I_p \cdot \frac{\sqrt{tn}}{K_m} \quad (4.10)$$

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;

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

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

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

CONCLUSION

In carrying out master's work following results were obtained:

1. The calculation of power system industry with the ability of the iterative calculation of changes in voltage drops in the system when changing load of the consumers.

2. Suggested optimum operating mode of the industrial complex when changing load in fixed daily period, due to installation of a voltage regulator principal down substation in position -4 (one position during the season, calculated), and missing to the nominal voltage rises due to consumer regulators in workshops (also one position for the entire season).

3. We obtain a smoothed graph voltage variations during the day through the effective use of reactive power compensators.

4. Suggested in the night-time to regulate the voltage level by changing the parameters of a network is exactly off one of the parallel cable lines.

ЗАКЛЮЧЕНИЕ

При выполнении магистерской работы были получены следующие результаты:

1. Произведен расчет системы электроснабжения промышленного комплекса с возможностью итерационного расчета изменений потерь напряжения в системе при изменении загруженности потребителей.
2. Предложено оптимальный режим работы промышленного комплекса при изменении загруженности в основной дневной период за счет установки регулятора напряжения главной понизительной подстанции в положение -4 (одно положение в течении рассчитанного сезона), а недостающее до номинального значения напряжение потребителя поднимается за счет регуляторов в цеховых подстанциях(тоже одно положение на весь сезон).
3. Получен сглаженный график изменения напряжения в течении суток за счет эффективного использования компенсаторов реактивной мощности.
4. Предложено в ночное время регулировать уровень напряжения за счет изменения параметров сети в точности отключением одной из параллельных кабельных линий.

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Appendix

Calculations of power losses and voltage drop in power supply elements of main substation and workshops for interval (23-24) according to section () in chapter three

First iteration

	SUB-WS10	SUB-WS9	SUB-WS8	SUB-WS7	SUB-WS6	SUB-WS3	WS4-WS5	SUB-WS4	WS2-WS1	SUB-WS2	FS-SUB	
P,MW	0.679	0.498	0.366	0.465	0.372	0.3725	0.2275	0.294	0.4575	0.1525	3.884	
Q,MVAr	0.497	0.39	0.294	0.411	0.33	0.31	0.217	0.224	0.36	0.1425	3.1755	
r,Ω	1.272	0.102	0.887	0.709	0.533	2.028	2.418	0.93	0.177	0.587	24.42	
x,Ω	0.247	0.02	0.129	0.138	0.078	0.295	0.193	0.135	0.035	0.159	23.54	
Pe10,MW	0.679											
Qe10,MVAr	0.497											
U1j,kV	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	115	10.45455*
ΔP10,MW	0.00817											
ΔQ10,MVAr	0.00159											
Pb10,MW	0.68717											
Qb10,MVAr	0.49541											
Pe9,MW		0.498										
Qe9,MVAr		0.39										

ΔP9,MW	0.00037			
ΔQ9,MVAr	7.25E-05			
Pb9,MVAr	0.49837			
Qb9,MVAr	0.38993			
Pe8,MW		0.366		
Qe8,MVAr		0.294		
ΔP8,MW		0.00177		
ΔQ8,MVAr		0.00026		
Pb8,MW		0.36777		
Qb8,MVAr		0.29374		
Pe7,MW			0.465	
Qe7,MVAr			0.411	
ΔP7,MW			0.002477	
ΔQ7,MVAr			0.000482	
Pb7,MW			0.467477	
Qb7,MVAr			0.410518	
Pe6,MW				0.372
Qe6,MVAr				0.33
ΔP6,MW				0.001196
ΔQ6,MVAr				0.000175

Pb6,MW	0.373196			
Qb6,MVAr	0.329825			
Pe3,MW		0.3725		
Qe3,MVAr		0.31		
ΔP3,MW		0.00432		
ΔQ3,MVAr		0.000628		
Pb3,MW		0.37682		
Qb3,MVAr		0.309372		
Pe5,MW			0.2275	
Qe5,MVAr			0.217	
ΔP5-4,MW			0.02276	
ΔQ5-4,MVAr			0.00182	
Pb5,MW			0.25026	
Qb5,MVAr			0.21518	
Pe4,MW				0.54426
Qe4,MVAr				0.43918
ΔP4,MW				0.004123
ΔQ4,MVAr				0.000599
Pb4,MW				0.54839
Qb4,MVAr				0.43858

Pe1,MW									0.4575			
Qe1,MVAr									0.36			
ΔP1-2,MW									0.000544			
ΔQ1-2,MVAr									0.000108			
Pb1,MW									0.45804			
Qb1,MVAr									0.35989			
Pe2,MW										0.61054		
Qe2,MVAr										0.50239		
ΔP2,MW										0.00333		
ΔQ2,MVAr										0.0009		
Pb2,MW										0.61387		
Qb2,MVAr										0.50149		
PeSUB,MW											7.8171	
QeSUB,MVAr											6.3444	
ΔP2,MW											0.18716	
ΔQ2,MVAr											0.18041	
PbSUB,MW											8.0042	
QbSUB,MVAr											6.16396	
ΔUBij,kV	0.09783	0.00576	0.03575	0.0381	0.02206	0.083989	0.06384	0.05589	0.00924	0.04321	2.961415	
σ USUB-FS	0.07853	0.00488	0.03024	0.03491	0.02012	0.07252	0.05613	0.04731	0.00786	0.03849	2.947333	
USUB,kV											112.0386	10.18533

U2,kV										10.14212
U1,kV									10.13288	
U4,kV								10.12944		
U5,kV							10.0656			
U3,kV						10.10134				
U6,kV					10.16327					
U7,kV				10.14722						
U8,kV			10.14958							
U9,kV		10.17957								
U10,kV	10.0875									

* Low (secondary) voltage of main transformer = high (primary) voltage of transformer / coefficient (ratio) of transformer

Second iteration

	SUB-WS10	SUB-WS9	SUB-WS8	SUB-WS7	SUB-WS6	SUB-WS3	WS4-WS5	SUB-WS4	WS2-WS1	SUB-WS2	FS-SUB
P,MW	0.679	0.498	0.366	0.465	0.372	0.3725	0.2275	0.294	0.4575	0.1525	3.884
Q,MVAr	0.497	0.39	0.294	0.411	0.33	0.31	0.217	0.224	0.36	0.1425	3.1755
r,Ω	1.272	0.102	0.887	0.709	0.533	2.028	2.418	0.93	0.177	0.587	24.42
x,Ω	0.247	0.02	0.129	0.138	0.078	0.295	0.193	0.135	0.035	0.159	23.54
Pe10,MW	0.679										
Qe10,MVAr	0.497										

U1j,kV	10.0875	10.1796	10.1496	10.1472	10.1633	10.1013	10.0656	10.1294	10.44	10.1421	112.0385	10.18533
ΔP10,MW	0.00885											
ΔQ10,MVAr	0.00172											
Pb10,MW	0.68785											
Qb10,MVAr	0.49528											
Pe9,MW		0.498										
Qe9,MVAr		0.39										
ΔP9,MW		0.00039										
ΔQ9,MVAr		7.72E-05										
Pb9,MVAr		0.49839										
Qb9,MVAr		0.38992										
Pe8,MW			0.366									
Qe8,MVAr			0.294									
ΔP8,MW			0.001898									
ΔQ8,MVAr			0.00028									
Pb8,MW			0.367898									
Qb8,MVAr			0.2937									
Pe7,MW				0.465								
Qe7,MVAr				0.411								
ΔP7,MW				0.002477								

ΔQ7,MVAr	0.000482			
Pb7,MW	0.467477			
Qb7,MVAr	0.410518			
Pe6,MW		0.372		
Qe6,MVAr		0.33		
ΔP6,MW		0.001196		
ΔQ6,MVAr		0.000175		
Pb6,MW		0.373196		
Qb6,MVAr		0.32983		
Pe3,MW			0.3725	
Qe3,MVAr			0.31	
ΔP3,MW			0.00432	
ΔQ3,MVAr			0.000628	
Pb3,MW			0.37682	
Qb3,MVAr			0.309372	
Pe5,MW				0.2275
Qe5,MVAr				0.217
ΔP5-4,MW				0.02276
ΔQ5-4,MVAr				0.00182
Pb5,MW				0.25026

Qb5,MVAr	0.21518				
Pe4,MW		0.54426			
Qe4,MVAr		0.43918			
ΔP4,MW		0.004126			
ΔQ4,MVAr		0.000599			
Pb4,MW		0.548388			
Qb4,MVAr		0.43858			
Pe1,MW			0.4575		
Qe1,MVAr			0.36		
ΔP1-2,MW			0.00054		
ΔQ1-2,MVAr			0.000108		
Pb1,MW			0.45804		
Qb1,MVAr			0.35989		
Pe2,MW				0.61054	
Qe2,MVAr				0.50239	
ΔP2,MW				0.00333	
ΔQ2,MVAr				0.000902	
Pb2,MW				0.61387	
Qb2,MVAr				0.50149	
PeSUB,MW					7.843527

QeSUB,MVAr											6.496988	
ΔP2,MW											0.2018	
ΔQ2,MVAr											0.194528	
PbSUB,MW											8.045328	
QbSUB,MVAr											6.30246	
ΔUBij,kV	0.09795	0.00578	0.03577	0.03813	0.02207	0.08408	0.07228	0.0602	0.00924	0.04323	2.99851	
σ USUB-FS	0.07856	0.00489	0.03025	0.03492	0.02012	0.07254	0.09321	0.06162	0.00786	0.0385	2.98517	
USUB,kV											112.00149	10.18195
U2,kV										10.13872		
U1,kV									10.1295			
U4,kV								10.1218				
U5,kV							10.0495					
U3,kV						10.0979						
U6,kV					10.1599							
U7,kV				10.1438								
U8,kV			10.1462									
U9,kV		10.1762										
U10,kV	10.084											

Third iteration

	SUB-WS10	SUB-WS9	SUB-WS8	SUB-WS7	SUB-WS6	SUB-WS3	WS4-WS5	SUB-WS4	WS2-WS1	SUB-WS2	FS-SUB	
P,MW	0.679	0.498	0.366	0.465	0.372	0.3725	0.2275	0.294	0.4575	0.1525	3.884	
Q,MVAr	0.497	0.39	0.294	0.411	0.33	0.31	0.217	0.224	0.36	0.1425	3.1755	
r,Ω	1.272	0.102	0.887	0.709	0.533	2.028	2.418	0.93	0.177	0.587	24.42	
x,Ω	0.247	0.02	0.129	0.138	0.078	0.295	0.193	0.135	0.035	0.159	23.54	
Pe10,MW	0.679											
Qe10,MVAr	0.497											
U1j,kV	10.084	10.1762	10.1462	10.1438	10.1599	10.0979	10.0495	10.12175	10.12948	10.1387	112.0015	10.18195
ΔP10,MW	0.00886											
ΔQ10,MVAr	0.00172											
Pb10,MW	0.68786											
Qb10,MVAr	0.49528											
Pe9,MW		0.498										
Qe9,MVAr		0.39										
ΔP9,MW		0.000394										
ΔQ9,MVAr		7.73E-05										
Pb9,MVAr		0.498394										
Qb9,MVAr		0.389923										
Pe8,MW			0.366									
Qe8,MVAr			0.294									

ΔP8,MW	0.0019			
ΔQ8,MVAr	0.00028			
Pb8,MW	0.3679			
Qb8,MVAr	0.29372			
Pe7,MW		0.465		
Qe7,MVAr		0.411		
ΔP7,MW		0.0027		
ΔQ7,MVAr		0.00052		
Pb7,MW		0.4677		
Qb7,MVAr		0.41048		
Pe6,MW			0.372	
Qe6,MVAr			0.33	
ΔP6,MW			0.00128	
ΔQ6,MVAr			0.00019	
Pb6,MW			0.37328	
Qb6,MVAr			0.32981	
Pe3,MW				0.3725
Qe3,MVAr				0.31
ΔP3,MW				0.00467
ΔQ3,MVAr				0.00068

Pb3,MW	0.37717			
Qb3,MVAr	0.30932			
Pe5,MW		0.2275		
Qe5,MVAr		0.217		
ΔP5-4,MW		0.0238		
ΔQ5-4,MVAr		0.0019		
Pb5,MW		0.2513		
Qb5,MVAr		0.2151		
Pe4,MW			0.54528	
Qe4,MVAr			0.43910	
ΔP4,MW			0.00445	
ΔQ4,MVAr			0.00065	
Pb4,MW			0.54973	
Qb4,MVAr			0.43846	
Pe1,MW				0.4575
Qe1,MVAr				0.36
ΔP1-2,MW				0.00058
ΔQ1-2,MVAr				0.000116
Pb1,MW				0.458085
Qb1,MVAr				0.35988

Pe2,MW										0.61058		
Qe2,MVAr										0.5024		
ΔP2,MW										0.00357		
ΔQ2,MVAr										0.00097		
Pb2,MW										0.61415		
Qb2,MVAr										0.50142		
PeSUB,MW											7.8201	
QeSUB,MVAr											6.3439	
ΔP2,MW											0.1973	
ΔQ2,MVAr											0.1903	
PbSUB,MW											8.0175	
QbSUB,MVAr											6.1536	
ΔUBij,kV	0.09791	0.005757	0.03576	0.03812	0.02206	0.08406	0.06406	0.05601	0.00924	0.04322	2.9621	
σ USUB-FS	0.07853	0.00488	0.03024	0.03491	0.02012	0.07251	0.05612	0.04732	0.00786	0.03849	2.9479	
USUB,kV											112.0379	10.18526
U2,kV										10.142		
U1,kV									10.1328			
U4,kV								10.12925				
U5,kV							10.0652					
U3,kV						10.1012						

U6,kV					10.1632
U7,kV				10.1471	
U8,kV			10.1495		
U9,kV		10.1795			
U10,kV	10.087				

Forth iteration

	SUB-WS10	SUB-WS9	SUB-WS8	SUB-WS7	SUB-WS6	SUB-WS3	WS4-WS5	SUB-WS4	WS2-WS1	SUB-WS2	FS-SUB
P,MW	0.679	0.498	0.366	0.465	0.372	0.3725	0.2275	0.294	0.4575	0.1525	3.884
Q,MVAr	0.497	0.39	0.294	0.411	0.33	0.31	0.217	0.224	0.36	0.1425	3.1755
r,Ω	1.272	0.102	0.887	0.709	0.533	2.028	2.418	0.93	0.177	0.587	24.42
x,Ω	0.247	0.02	0.129	0.138	0.078	0.295	0.193	0.135	0.035	0.159	23.54
Pe10,MW	0.679										
Qe10,MVAr	0.497										
U1j,kV	10.0873	10.1795	10.149502	10.147146	10.163202	10.1012	10.0652	10.1293	10.1328	10.14204	112.0379
ΔP10,MW	0.00885										10.18526
ΔQ10,MVAr	0.00172										
Pb10,MW	0.68785										
Qb10,MVAr	0.49528										

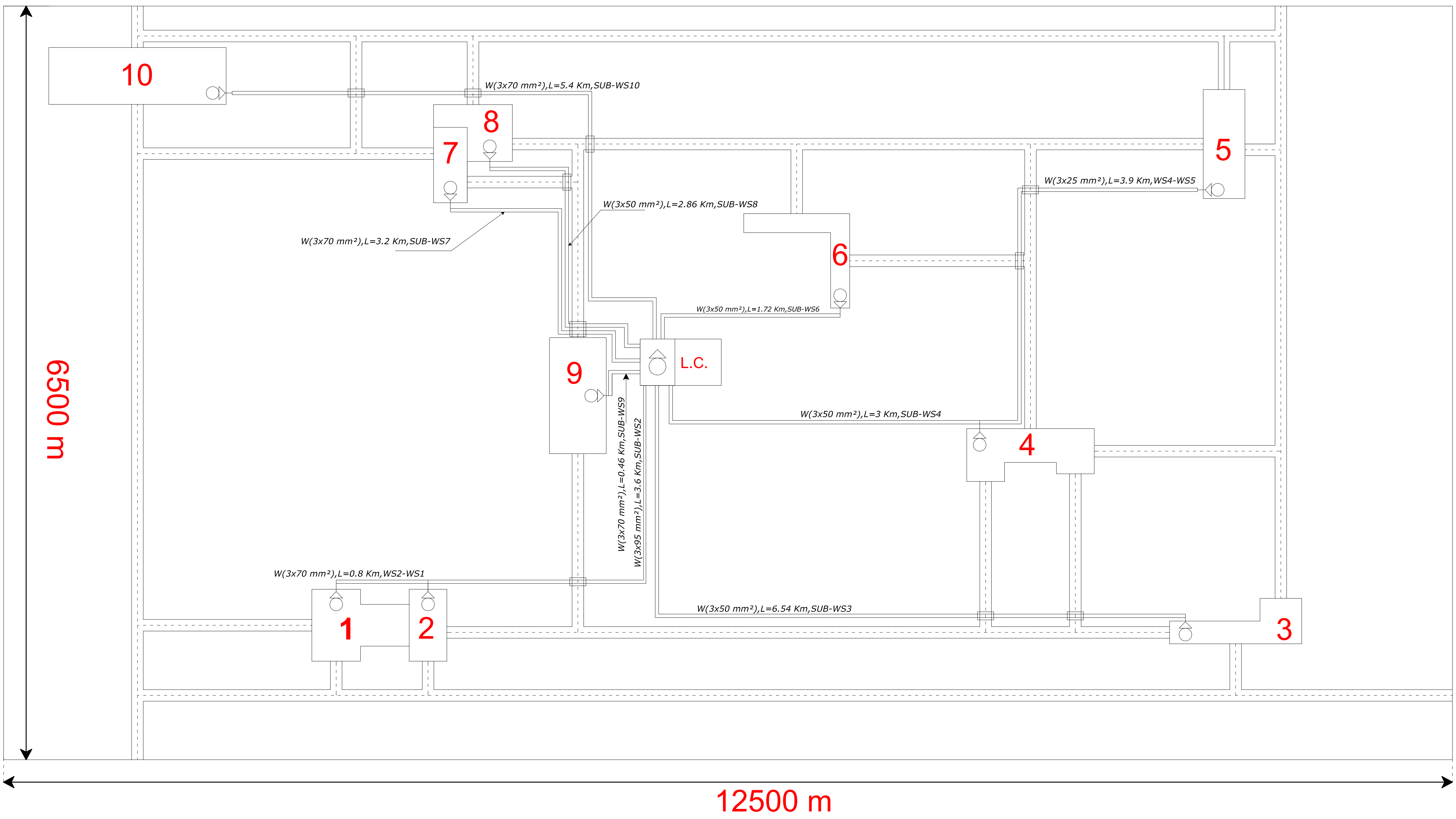
Pe9,MW	0.498			
Qe9,MVAr	0.39			
ΔP9,MW	0.00039			
ΔQ9,MVAr	7.72E-05			
Pb9,MVAr	0.49839			
Qb9,MVAr	0.38992			
Pe8,MW		0.366		
Qe8,MVAr		0.294		
ΔP8,MW		0.0018977		
ΔQ8,MVAr		0.000276		
Pb8,MW		0.3678977		
Qb8,MVAr		0.293724		
Pe7,MW			0.465	
Qe7,MVAr			0.411	
ΔP7,MW			0.0026521	
ΔQ7,MVAr			0.0005162	
Pb7,MW			0.4676521	
Qb7,MVAr			0.4104838	
Pe6,MW				0.372
Qe6,MVAr				0.33

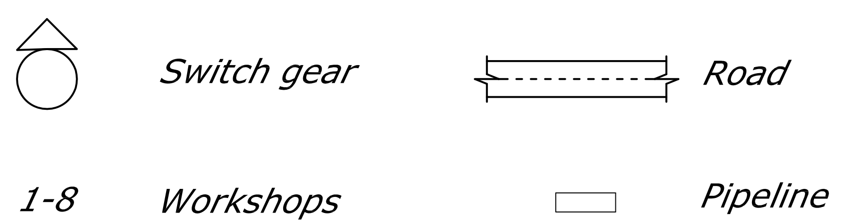
ΔP6,MW	0.001276			
ΔQ6,MVAr	0.0001867			
Pb6,MW	0.373276			
Qb6,MVAr	0.3298133			
Pe3,MW		0.3725		
Qe3,MVAr		0.31		
ΔP3,MW		0.0046679		
ΔQ3,MVAr		0.000679		
Pb3,MW		0.3771679		
Qb3,MVAr		0.309321		
Pe5,MW			0.2275	
Qe5,MVAr			0.217	
ΔP5-4,MW			0.023746	
ΔQ5-4,MVAr			0.0018954	
Pb5,MW			0.251246	
Qb5,MVAr			0.2151046	
Pe4,MW				0.545246
Qe4,MVAr				0.4391046
ΔP4,MW				0.0044424
ΔQ4,MVAr				0.0006449

Pb4,MW	0.5496884			
Qb4,MVAr	0.4384598			
Pe1,MW		0.4575		
Qe1,MVAr		0.36		
ΔP1-2,MW		0.0005842		
ΔQ1-2,MVAr		0.0001155		
Pb1,MW		0.4580842		
Qb1,MVAr		0.3598845		
Pe2,MW			0.6105842	
Qe2,MVAr			0.5023845	
ΔP2,MW			0.0035679	
ΔQ2,MVAr			0.0009664	
Pb2,MW			0.6141521	
Qb2,MVAr			0.501418	
PeSUB,MW				7.8200792
QeSUB,MVAr				6.3439239
ΔP2,MW				0.1972648
ΔQ2,MVAr				0.1901562
PbSUB,MW				8.017344
QbSUB,MVAr				6.1537677

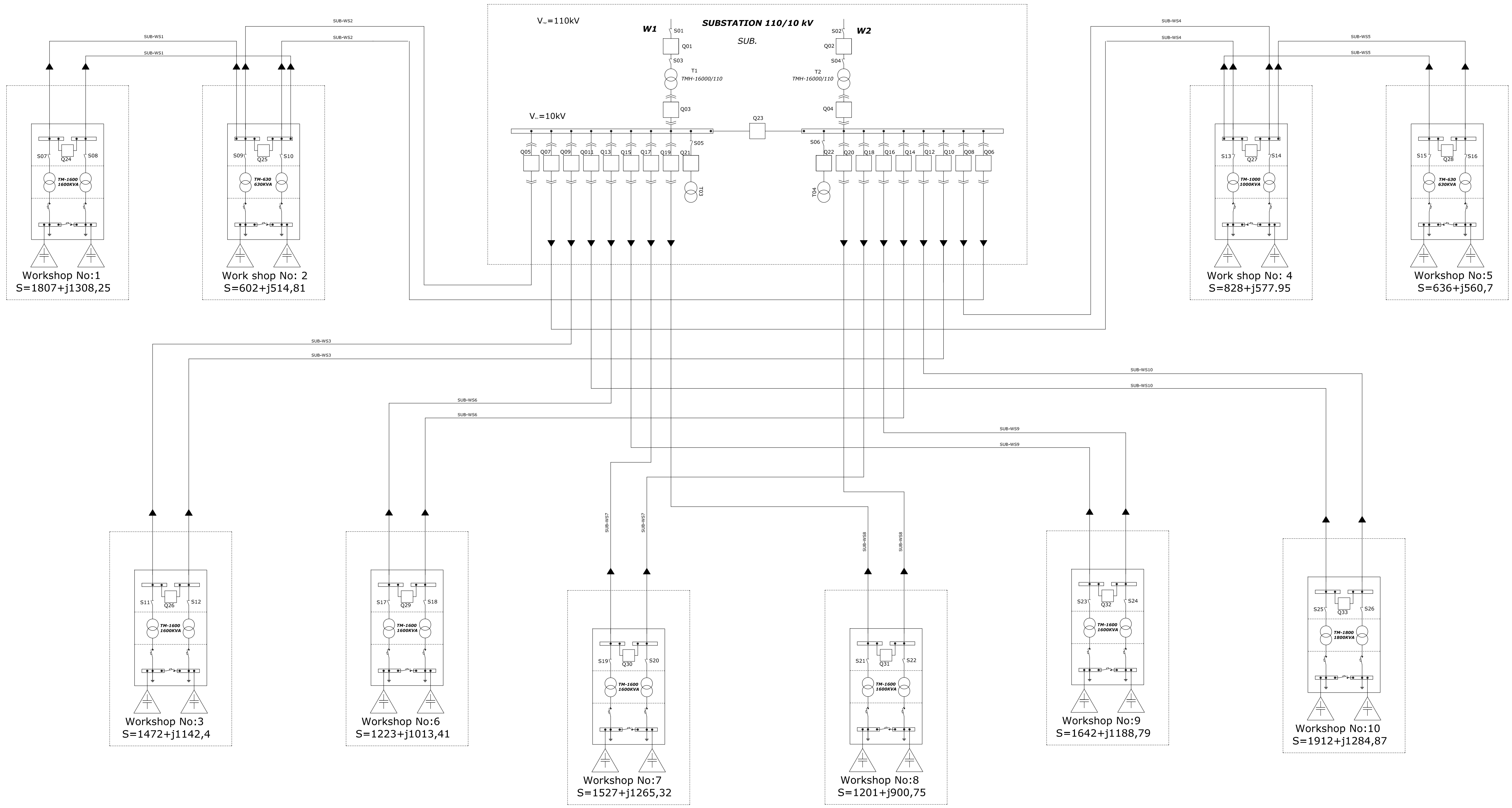
ΔUBij,kV	0.0979141	0.0057568	0.0357591	0.0381151	0.0220595	0.0840574	0.0640746	0.0560027	0.0092365	0.0432225	2.9621151
σ USUB-FS	0.0785347	0.0048835	0.030239	0.0349101	0.0201179	0.0725134	0.0561357	0.0473209	0.0078616	0.0384853	2.9478547
USUB,kV											112.03788
U2,kV										10.14204	10.18526
U1,kV									10.132803		
U4,kV								10.12926			
U5,kV							10.065185				
U3,kV						10.101205					
U6,kV					10.163203						
U7,kV				10.147147							
U8,kV			10.149503								
U9,kV		10.179505									
U10,kV	10.087348										
1	2	3	4	5	6	7	8	9	10	HV	LV
10.132803	10.14204	10.101205	10.12926	10.065185	10.163203	10.147147	10.149503	10.179505	10.087348	112.03788	10.18526

PM 101.104.000 EN





Change	List	Document No.	Signature	Data	PM 101.104.000 EN			
Developed		Al-Nussairi			Suggestions side plan of enterprise	Lit. M T	Mass	Scale
Checked		Zaharchuk A.S.				Sheet No: /		Sheets: /
No. count						ENU.Dep.ESOPC.		
Aproved		Zaharchuk A.S.						



PM 101.104.000 EN

Change	List	Document No.	Signature	Data	PM 101.104.000 EN			
Developed		Al-Nussairi			One line principle circuit scheme of power supply	Lit.	Mass	Scale
Checked		Zaharchuk A.S.				MT		
						Sheet No: /	Sheets: /	
No. count						ENU.Dep.ESOPC.		
Aproved		Zaharchuk A.S.						