Ministry of Education and Science of Ukraine
Ternopil Ivan Puluj National Technical University

Faculty of Applied Information Technology and Electrical Engineering
(full name of faculty)
Electrical Engineering
(full name of department)

QUALIFYING PAPER

For the degree of

bachelor
(degree name)

topic: **CALCULATION OF THE CARRYING CAPACITY OF UNDERGROUND CABLE POWER TRANSMISSION LINES**

Submitted by: fourth year student 4, group IEE-43
specialty 141 Electrical Power Engineering, Electrical Engineering and Electromechanics
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Ternopil
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Faculty Faculty of Applied Information Technology and Electrical Engineering
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Department Electrical Engineering
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« » 2023

ASSIGNMENT
FOR QUALIFYING PAPER

for the degree of Bachelor
(degree name)

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

student *Udogu Chukwudalu Paul*
(surname, name, patronymic)

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Paper supervisor *Nakonechniy Myroslav, Senior lecturer,Ph.D.*
(surname, name, patronymic, scientific degree, academic rank)

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2. Calculation and research section
3. Project designing section
4. Labour occupational safety and security in emergency situations

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

1 analysis of cable lines 2. Classification of power cables. 3. Mathematical model of electromagnetic processes 4. Mathematical model of thermal processes in underground cable lines 5. Calculation of cable parameters. 6. Electrical properties of the structural elements of the power cable. 7. Thermal properties of materials.

6. Advisors of paper chapters

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

7. Date of receiving the assignment *21.12.2022*

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LN	Paper stages	Paper stages deadlines	Notes
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	SECTION»		
3	Preparation of the «PROJECT DESIGNING SECTION»	09.01.23 – 14.01.23	
4	Preparation of the «LABOUR OCCUPATIONAL	14.01.23 – 18.01.23	
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6	Preparation, execution and printing graphic material of	19.01.23– 22.01.23	
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7	Getting feedback and review of master's thesis	23.01.23– 24.01.23	
	And drafting a report for the master's defense.		

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ABSTRACT

Chukwudalu Udogu Development of a model of wind power plant 141 - Electric power, electrical engineering and electromechanics; Ternopil Ivan Puluj National Technical University. Faculty of Applied Information Technologies and Electrical Engineering. Department of Electrical Engineering, IEE-43 group. - Ternopil: TNTU, 2023

Pages - 70 Illustrations - 22; Tables -5; References - 25.

In this qualification work, the classification of cable lines, their construction and electrical characteristics are considered. Methods of grounding cable lines are given; sources of energy loss are determined. A mathematical problem for calculating the load capacity of cable lines was established, and a mathematical model of electromagnetic and thermal processes was formed.

The cable parameters were calculated, a mathematical model was chosen that allows you to calculate the electrical parameters of cable grounding systems, and the requirements for screen grounding options were considered. A mathematical model was developed and the magnetic, electrical and thermal characteristics of the cable network were calculated. The influence of cable network laying methods on cable temperature is calculated.

Key words: power cable, temperature, losses, grounding.

CONTENTS

INTRODUCTION

Without a doubt, energy has become a necessity for human activities and living, as it has become a deciding factor for the development of many countries around the globe. In our own way we can say it is a space of economic activity, which is a sector for natural and artificial subsystems, which performs the action of transforming, distributing and the consumption of all kinds of energy resources. Energy as a sector consist of a large number of power plants, substations, electrical and heating networks linked and connected in a continuous production process. One of the important components of modern electrical systems is power lines. The high density of urban infrastructures in several conditions determines the method of electricity that will be used to transmit energy in the course of a new construction, cable lines are preferably used a lot more than air for building a reliable power supply system. It is relevant to note the issue of transferring part of overhead lines to cable lines.

Cable lines have high cost of construction, but there are difficulties in their design and operation, lower throughput per unit cross-section also occurs due to the temperature and limited insulation which has couple of advantages, such as; the compactness of the line, the absence of environmental impact on the line, and the decrease in maintenance and operation costs.

The design of the cable lines is a very important duty in the case of power supply and this should be done taking into account the development of the network, the responsibility and purpose of the line, the method of laying and cable structures, the cooling conditions of the cable, the presence of approximations and cross-sections with underground communications.

In cases of cable lines with a voltage value of 6-20 kV, the main factor limiting throughput is the final magnitude of the current density, for cable lines at higher voltages, the operating temperature of the cable has a great influence.

1 ANALYTICAL SECTION

1.1 Purpose, classification and characteristics of cable lines

A cable power transmission (CL) is a line for transmitting electrical energy or its individual pulses. A cable line is a power line made by one or more cables laid directly in the ground, cable channels, pipes, cable structures, and water.

Cable structures include cable fittings, cable-supporting systems, and devices for attaching and supporting cables and fittings [1-3].

Compared to air, cable lines are much more expensive and have lower throughput per unit cross-sectional area (due to temperature restrictions of insulation). CLs are more time-consuming in construction and repair, require high consumption of materials and highly qualified staff. The advantages of cl include their stability to atmospheric influences (thunderstorms, ice), as well as the inaccessibility of the route for unauthorized persons. Cable lines are laid where the construction of overhead lines is impossible due to a limited area or is impractical from an architectural point of view, according to safety conditions and other requirements. CL is built on the territory of cities, industrial enterprises, through large water expanses, etc. the main elements of the LC are cables, cable couplings and cable structures.

The actual purpose of the cable line is the transfer of electrical energy from the installations that produce it (power plants), converting and distributive (electrical substations) to consumers. In general, we recall all electrical lines that are outside the listed electrical structures.

The following classification is also used:

-low voltage networks (up to 1 kV);

-medium voltage (6-35 kV);

-high voltage (110-220 kV);

-high (330-750 kW);

-ultrahigh (over 1000 kV).

1.2 Designs of power cables with a voltage of 10 kV.

Cables designed for the transmission and distribution of electrical energy are called power. They consist of the following main structural elements: conductive cores, insulation, shells and protective shells. In addition to the main elements, the design of power cables may include screens, zero cores, protective grounding conductors and aggregates. Conductive cores are used to pass electric current. They are basic and zero. The main cores are designed to perform the main function of the cable - the transmission of electricity. Zero conductors are used to flow the difference in phase currents, provided that they are unevenly loaded. They are connected to the neutral of the current source. Protective conductors Groundings are auxiliary cable conductors and are designed to connect non-metallic parts under operating voltage, electrical installations to which a cable with a protective grounding circuit of the current source is connected. Conductive cores are made of copper or aluminum. Paper, rubber, plastic are used as insulation of cores. The most common power cables with paper impregnated insulation, in which insulation is superimposed on top of each core, and on top of the insulated conductors - waistband. The advantages of impregnated paper insulation are low cost, high electrical strength and relatively high heat resistance. In cables for a voltage of 6 and 10 kV, a screen of semiconducting paper is applied over the waist insulation. When twisting insulated veins in the process of cable manufacturing, the gaps between the conductors with Complement with paper harnesses (fillers). For sealing, a shell is applied over the insulation. The sheaths of cables with paper insulation are made of lead or aluminum.

Lead is a soft metal with high corrosion resistance to many chemicals contained in the soil. A significant disadvantage of lead is poor resistance to vibrations, which can damage lead in the shell of cables laid on bridges, overpasses, etc. lead is destroyed in the soil rotting under the action of certain organic substances, solutions of lime and concrete.

Aluminum is currently widely used for protective shells, which has several advantages over lead: its strength is several times higher, its mass is 4.2 times less. Due to the small resistivity and (7 times less than that of lead), the aluminum shell is used as a zero wire in four wires of AC conductive networks. The disadvantages of aluminum shells include their susceptibility to corrosion, most especially in humid environments. To protect against corrosion and mechanical damage, protective coatings are applied to the cable sheaths.

Recently, cables with plastic insulation in a plastic sheath, which are manufactured for voltages from 1 to 35 kV for routes with an unlimited difference in gasket levels, have become widespread. Polyvinyl chloride or polyethylene is used as insulation in these cables. The shell is made of polyvinyl chloride. On the plastic insulation of cables with a voltage of 6 and 10 kV, screens made of metal tape (copper or aluminum foil) are applied, and in 10 kV cables there is also a screen on a core of polyethylene or polyvinyl chloride.

Classification features can be the type of insulation, design features, as well as the rated voltage for which they are designed. One of the classification options for power cables is presented in Fig.1.1

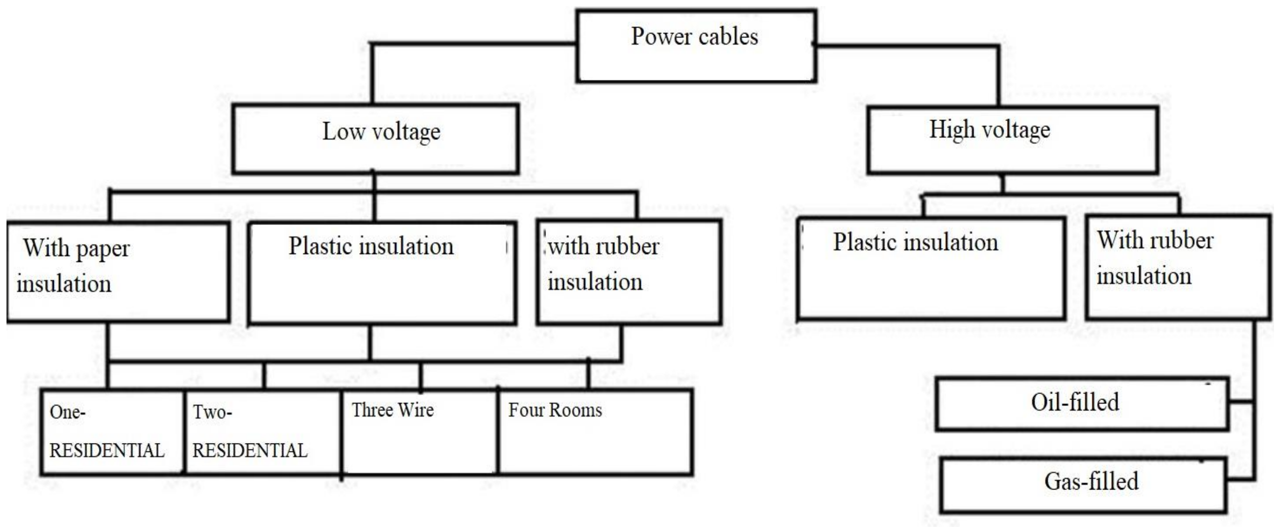


Figure 1.1. – Classification of power cables

In accordance to the rated operating voltage, power cables can be divided into two groups. The first group includes cables designed to work in electrical networks of alternating voltage 1; 3; 6; 10; 20 and 35 kV. Depending on the purpose, low voltage cables are available in single-core, two-core, three-core and four-core versions. Single-core and three-core cables are used in networks with a voltage of 1-35 kV. Two- and four-core cables are used in networks with voltage up to 1 kV.

Each cable design has its own designation and brand. The cable brand consists of the initial letters of the words describing the cable design (Fig.1.2).

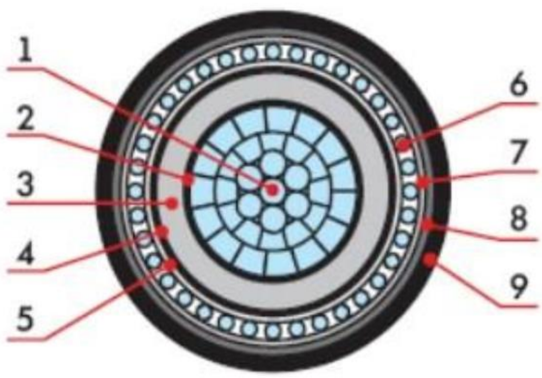


Figure1.2. – Design of single-core APVP cable for voltage 10-35 kV: 1 – conductive core ; 2 - extruded semiconductor layer of cross-linked polyethylene; 3 -insulation; 4 – extruded semiconductor layer made of cross-linked polyethylene; 5 – insulation screen;6 -screen made of copper wires, on top of which copper tape is superimposed; 7 -separation layer of cable paper or rubberized fabric; 8 – aluminopolymer tape; 9-shell - polyethylene of high hardness.

1.2.1 Current-carrying wires.

The basis of the cable design are conductive cores. The cores are designed to direct the flow of electrical energy in the cable and it is with the production of cores that the cable formation process begins.

Traditional metals for conductive cores are copper or aluminum [5]. The electrical conductivity of aluminum is comparable to the electrical conductivity of copper, and the density is 3.3 times less than the density of copper, this makes it possible to obtain aluminum cores 2 times lighter than copper with the same electrical resistance. Depending on the conditions of installation and operation, copper and aluminum cores are made: veins or multi-wire; round, sector or segment. For greater flexibility, if necessary, the cores are made not from one conductor, but from several, twisted together - from elements of the same diameter (conductor of regular twisting) or unequal diameter (conductor of irregular twisting). The cross-sectional area of the cores determines the amount of power losses for heating from the current flowing through them. Cables with sector cores have the shape of a segment with rounded corners and edges, the diameter is 20-25% smaller than cables with round conductors of equivalent cross-section, which gives a great economic effect.

The core can be compacted or not compacted. Due to the compaction of the core, a decrease in the size and gaps between the wires is obtained, and this saves insulation materials. When compacted, the round conductive core is affected by the surface effect and the effect of proximity. Under the action of the surface effect in the core, an increase in electrical resistance is observed, and the proximity effect is manifested in the distribution of currents in the conductor.

Cables can be single-core (the cross section consists of one conductor) and two-, three- and stranded (the cross section is formed by two, three, four or five cores) versions. In fact, single-core cables are more widely used due to economic superiority, smaller outer diameter, longer construction lengths and ease of laying and operation.

We give the nominal cross-sections of cores defined by the standard: 1.5, 2.5, 4, 6, 10, 16, 25, 35, 50, 70, 95, 120, 150, 185, 240, 300, 400, 500, 625, 800 [mm^2].

Table 1.1 Nominal intersections of cores

Conductive core material	Single Wire	Multi-wire
Copper	up to 16 mm^2	25 mm^2 and more
Aluminium	up to 120 mm^2	150 mm^2 and more

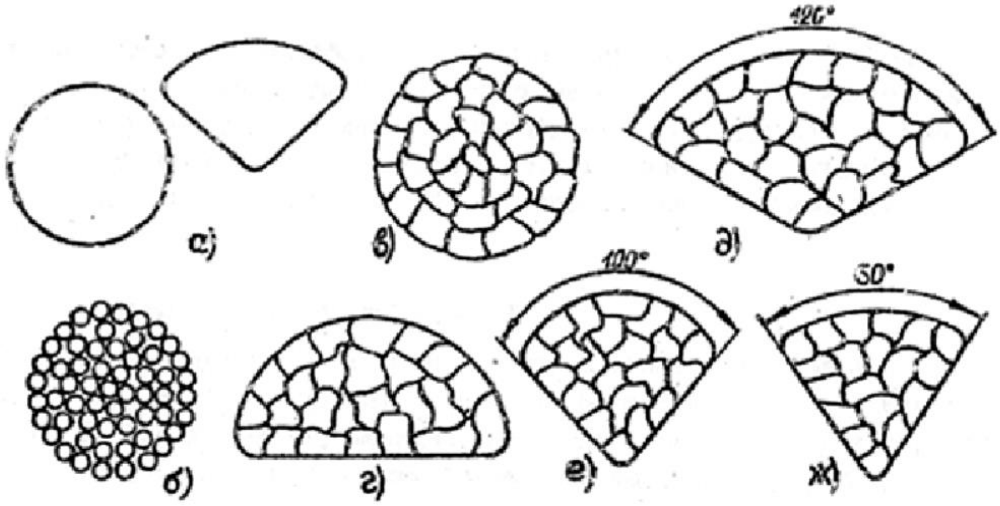


Figure 1.3 – Types of cross-sections of conductive cable cores:
a - round and sector solid core; b - round twisted unsealed core; c - round twisted compacted core; g - segment twisted compacted core; d - sectoral twisted sealed core for three-core cables; e, f - sectoral twisted sealed core for four-core cables.

1.2.2 Isolation.

Insulation serves to separate the conductive cores from each other and from the outer shell, if any. Insulation counteracts the forces of the electric field between the conductors and the cable sheath, which seek to create a leakage current or breakdown in the cables, so it must have high mechanical and electrical strength in order to withstand the listed effects in stationary and transient modes. The state of strength of the insulation is one of the determining factors of cable reliability.

Paper-insulated cables are made of thick paper impregnated with a special cable mass. Depending on the viscosity of the impregnating composition, paper-insulated cables are made with a viscous, depleted and non-leaking impregnating composition.

A cable with a viscous impregnating composition is a cable with paper insulation impregnated with an oil and oil composition or a warehouse with the same viscosity.

Depleted-impregnated insulation in the cable is formed by partial or complete removal of the free part of the impregnating composition in the cable, that is, paper insulation is freed from an excess of impregnating composition. Such cables are designed for vertical and inclined tracks with a limited level difference (up to 100 m).

Cables with this type of insulation are available for a voltage not exceeding 6 kV due to reduced electrical strength.

A cable with a non-leaking impregnating composition is a paper insulated cable impregnated with an insulating composition, the viscosity of which is such that at the operating temperatures of the cable the composition is not capable of draining. These cables have no restrictions when laying on vertical and inclined sections of the route.

Impregnated paper insulation of cable cores has good electrical characteristics, long service life, relatively high allowable temperature, relatively low cost. To increase the electrical strength of paper and impregnated insulation , it is possible to use gas cables that exclude the appearance of gas inclusions by filling voids with gas with increased electrical strength.

Rubber insulation is made of synthetic or natural rubber and is flexible and non-hydroscopic. Its disadvantages are rapid aging, changes in the chemical properties of the material, relatively high cost and relatively low heating temperature, which leads to a decrease in the permissible current load of the cable. Plastic insulation is made mainly of polyvinyl chloride and polyethylene.

Cables with insulation made of polyvinyl chloride plastic are used mainly for voltages up to 1000 V, The disadvantage of this plasticis its thermoplastic and wt. Heating the core with load currents can cause softening of the insulation and displacement of the core from the central position to the periphery of the insulating layer. In addition, the electrical strength of the insulation from polyvinyl chloride plastic depends on the time spent under AC voltage.

Polyethylene is a synthetic polymer that has the greatest use and promising widespread use as cable insulation. Polyethylene has good mechanical properties in a wide temperature range, resistance to acids, alkalis, moisture and has high electrical insulation characteristics. Initially, the insulation consisted of stress-stabilized polyethylene (PE), today cross-linked polyethylene is used. The creation of cable insulation from cross-linked polyethylene is currently carried out using two main manufacturing technologies, depending on the reagent. With the help of a reagent, the crosslinking process takes place: peroxide cross-linked (in a neutral gas medium with organic peroxides or hydroperaxids, which are derivatives of hydrogen peroxide) and silylated (with organic silanides, which are compounds of silicon with organic radicals).

Methods of peroxide and silane crosslinking according to the method of exposure are a chemical method of crosslinking polyethylene. Stitching is the creation of a mesh structure at the molecular level due to the formation of longitudinally transverse volumetric bonds between polymer macromolecules, thus, the linear structure passes into the spatial one, providing good electrical and mechanical characteristics of the material.

The insulation of a multicore cable superimposed on top of insulated twisted or parallel laid is called belt insulation (the insulation of each conductive core is called phase insulation).

To give the cables the desired shape, special flagella are inserted between the individual conductors - jute fillers. The space between the veins, depending on the type of insulation, is filled with harnesses made of paper, rubber, or yarn impregnated with antiseptic, polyvinyl chloride or polyethylene.

1.2.3 Protective shells and coverings.

Designed to prevent the insulating layer of the cable from external influences, moisture and mechanical damage. Different shells differ in their mechanical strength, corrosion resistance, moisture resistance. Depending on the design of the cable, the protective coatings include a pillow, armor cover and outer covers. Depending on the design of the cable, one or two of the specified elements of the protective cover may be absent.

For cable sheaths with paper insulation in terms of tightness and moisture resistance, aluminum and lead are considered the best materials. The strength of lead shells is 2-2.5 times lower than aluminum. Due to the good mechanical strength of aluminum, cables in an aluminum sheath can be operated unarmed.

For cables with plastic insulation, a metal shell is not required, a plastic sheath is used. plastic -PVC and polyethylene - shells differ from the insulating mixture and the appropriate selection of plasticizers and stabilizers that provide increased resistance to global aging. Polyethylene and PVC shells are more resistant to aggressive media compared to aluminum and lead shells.

PVC shells do not spread combustion, have moisture resistance, but at negative temperatures they become brittle. Polyethylene shells have even greater moisture resistance and resistance to aggressive media, incombustibility.

The element of the polymer outer shell is also a halo-freematerial that does not propagate combustion and an electrically conductive layer applied over the shell to test its strength.

At the request of the customer, it is allowed to apply an electrically conductive layer to the shell, and it is also possible to create longitudinal stiffeners.

The pillow is part of the protective cover applied to the shell and designed to prevent the shell from damage by armor.

To protect against mechanical stress, the cable is covered with armor made of metal tape or wires. For cables, combined armor can also be made of several layers.

On top of the armor and between the metal sheath of the cable and the armor, jute covers are superimposed, impregnated with anti-corrosion compounds.

1.3. Electrical characteristics of cables.

When designing, manufacturing, testing, installing and further operating power cables, their characteristics should be taken into account [16].

Electrical resistance of cores;

Taking into account the effect of temperature, electrical resistance can be determined by the formula

$$R = R\left(1 + aT\right)$$

in terms of length 1 km and a cross section of 1 mm^2, where is the temperature coefficient of resistivity at a temperature of 20 ° C.

Insulation resistance

The value of the insulation resistance establishes the correctness of the drying and impregnation process of paper insulation, as well as the degree of its humidity.

Measuring the cable insulation resistance is a mandatory step when starting and installing a cable line. The cable insulation resistance is a particley from dividing the applied constant voltage by the current passing a minute after switching on the voltage: *U*

$$R_{i з} = \frac{U}{I_{\min}}.$$

The cable is considered to have withstood the test, if there was no breakdown, there were no sliding discharges and shocks of current, the leakage of its increase after it reached a constant value.

Capacity;

The capacitance value is not regulated by standards, but the capacitive current is necessary for the correct configuration of network devices.

The value of the capacitive current is according to the empirical formula,

$$I_c = 0.1 \cdot U \cdot l$$

where the voltage U is set to kilovolts, and the length is set in kilometers. l

Electric field strength;

The reliability of the cable insulation during operation is determined by its electrical strength and compliance with the accepted value of the electric field strength with its maximum permissible value. The electric field strength E at any point of insulation located at a distance from the axis of the core under voltage U is determined by the equation r_x

$$E = \frac{U}{r_x \ln \frac{R}{r}}$$

U is the operating voltage between the lifeloyu and the metal sheath of the cable, kV; R is the outer radius of insulation, mm; r is the inner radius of insulation, mm.

To equalize the electric field and better use the insulating material, the insulating layer with a larger dielectric constant is placed closer to the core, since the value of the maximum electric field strengths in different layers of insulation is inversely proportional to their dielectric constant.

Characteristics of the magnetic field.

The magnetic field in the cable occurs when electrical energy is transmitted over the cable (at alternating current). The emergence of a magnetic field affects the increase in the electrical resistance of the jet conductors and the effect of proximity. The metal components of the cable have power losses, electrodynamic forces appear that act on the cable cores and cause vibration.

Electrodynamic forces also act in DC cables.

In normal cable operation, these forces are small, but with a short circuit on the cable, electrodynamic forces pose a risk of mechanical damage to the cables.

The increase in electrical resistance is described by the equation for sinusoidal alternating current for a conductive medium:

$$\nabla^2 F = j\mu\mu_0\omega\gamma F$$

where is the F-vector of electric or magnetic field strength;

μ_0 - magnetic permeability of vacuum,

μ - relative permeability of the environment;

γ - specific conductivity of the medium.

The propagation of the current in thep lead depends on the parameter $R = \sqrt{j\omega\mu\mu_0\gamma}$,

Which is inversely proportional to the value of the penetration of the field into the conductor.

1.4. Cable marking.

The conditional lettering of power cables contains data on the material from which the core, insulation, sheath and type of protective cover are made. The alphanumeric and digital marking of cables reflects the features of its design. When installing cable lines, each line must be marked, have its own number or name. Marking is applied to the outer shell of the cable product [17].

Indomestic markings and cables, the first letter characterizes the material of conductive cores: copper cores are marked, the letter A is used to designate aluminum.

The following letter of the cable brand indicates the insulation material: paper impregnated insulation has no letter designation, paper insulation with a non-flowing composition based on ceresin or another composition - C; polyethylene insulation - P; PVC (PVC compound) - B; rubber - P; insulation from the vulcanized polyethylene - B; Insulation from self-extinguishing polyethylene - C.

The type of protective sheath is characterized by the following letter: A- aluminum, C - lead, P - polyethylene, B - from polyvinyl chloride; P - rubber; ST - corrugated steel, H - rubber oil-resistant, does not spread combustion.

The type of protective cover is set in the last letters of the marking: B - armor cover made of flat tapes; BG - bare (in the absence of external jute coating); K - armored cover made of steel round wires; P - armored covermade of steel flat wires.

The lowercase letters "in" and "y" after the designation of armor mean a reinforced coating and a particularly reinforced coating of the shell, respectively.

The outer one is a protective cover of a polyvinyl chloride hose denoted by the seam, from a polyethylene hose - Shp. The letter "n" indicates the non-combustible outer cover, the absence of a protective cover - "b", on the reinforced pillow at the protective cover - "l", on a particularly reinforced one - "ll".

For cables intended for vertical gaskets, the letter "U" is indicated in the marking.

Gas-filled cables in the designation have the letter G, oil is filled with cables the letter M.

After the letter designation of the brand of the cable follows a digital designation indicating the number and cross section of the current-conducting wires.

Depending on the corrosion activity of the soil, different brands of cables are recommended for laying in the ground (trenches). So the cables in an aluminum sheath with plastic insulation are not recommended for laying on routes with high corrosion activity and the presence of stray currents. Corrosion adversely affects cable lines and leads to a deterioration in the stability and condition of insulating materials. Corrosion activity is determined by the value soil resistance, and this is a necessary measure for engineering work related to the design and laying of not only cables, but also gas pipelines, pipelines, underground structures and tanks. GOST 9.602-89 and GOST 9.602-2005 determine the method of work on measuring soil resistance[18-20].

The method is based on the measurement of the resistance that is given with the help of electrodes, its subsequent calculation and determination of the corrosion aggressiveness of the soil according to the table. Of particular danger are stray currents in the ground, where the earth acts as a conductive medium, and the occurrence of stray currents is associated with leakage currents from grounded devices of installations, from transmission lines. Stray currents despite their small current values are characterized by electrochemical activity and can lead to accelerated corrosion of underground metal structures.

1.5 Grounding of cable line screens.

According to the results of the experience gained by specialists in operation, research and testing, it was found that the efficiency and safety of the cable line is influenced by the connection and grounding schemes of the screens - Fig. 1.4 [13]. As a result of the use of an intermediate metal electrically conductive layer on the cable cores, we obtain the uniformity of the electric field, the elimination of the electric field on the cable surface. The size of the cross-section of the screens is determined from the preliminary calculations, it is less than the cross section of the conductive core. To reduce the voltage on the cable screens, it is necessary to ground it at one or more of its points.

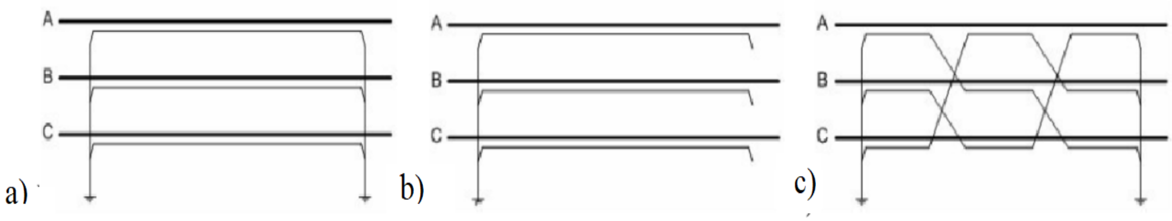


Figure.1.4. – The main schemes of connection and grounding of screens:
a - grounding on both sides, b - grounding on one side, c - transposition of screens.

The method of grounding the screens affects the loss of power, heat dissipation, the longitudinal resistances of the cable, the amount of voltage on the screen relative to the ground. Significant currents flowing in the screens cause additional heating. In some cases, the wrong choice of grounding method can lead to damage to cables due to uncalculated thermal conditions.

To reduce the currents in the screens with a three-phase group of single-phase cables, transposition of screens or their sectioning can be used. One-way grounding of the screens does not compensate for the magnetic field of the cable conductor, but the longitudinal induced current in the screen is zero. With double-sided grounding and screen, a current arises, which creates a magnetic field that compensates for the field of the core. The current in the screen-to-ground circuit with perfect transposition and double-sided grounding does not flow.

1.6 Sources of energy loss in cable lines

When transmitting electrical energy in each element of the electrical network, losses occur. To study the components of losses in various elements of the network and assess the need for a particular event aimed at reducing losses, an analysis of the structure of electricity losses is carried out [20]. Actual (reporting) losses of electricity are defined as the difference between electricity received in the network and electricity supplied from the network to consumers. These losses include components of different nature: losses in network elements having a purely physical nature, the consumption of electrical equipment installed at substations and ensuring the transmission of electricity, errors in fixing electricity by metering devices and, finally, theft of electricity, non-payment or incomplete payment of meter readings, etc. The division of losses into components can be carried out according to various criteria: the nature of losses (constant, variable), voltage classes, groups of elements, production units, etc. Given the physical nature and the specifics of the methods for determining the quantitative values of actual losses, they can be divided into four components:

1) technical losses of electricity caused by physical processes in wires and electrical equipment that occur during the transmission of electricity over electrical networks;

2) electricity consumption for substations' own needs, necessary to ensure the operation of technological equipment of substations and the vital activity of service personnel, which is determined by the readings of meters installed on transformers of substations' own needs;

3) loss of electricity caused by instrumental errors in their measurement (instrumental losses);

4) commercial losses caused by theft of electricity, inconsistency of meter readings with payment for electricity by household consumers and other reasons in the field of organization of control over energy consumption.

The first three components of the loss structure are due to the technological needs of the process of transmitting electricity over networks and instrumental accounting of its receipt and supply. The sum of these components is well described by the term technological losses. The fourth component -commercial losses is the influence of the "human factor" and includes all its manifestations: deliberate theft of electricity by some subscribers by changing meter readings, non-payment or incomplete payment of meter readings, etc. technical losses of electricity, namely losses in cable elements, will be considered in the work.

1.7 The urgency of the problem of determining the components of losses.

It is well known that the problem of electricity losses during its transmission is one of the most acute problems in the electric power industry of Ukraine. Every year, actual losses in the networks reach 20% of the flow of electricity into distribution networks, and power supply companies make a lot of efforts to reduce unnecessary (excess) losses. In international practice, it is generally accepted that if the losses in the main and distribution networks in the amount exceed 8-9% of the flow of electricity into the network, then such transmission and distribution of electricity is considered unprofitable. One of the main reasons for high electricity losses is the low efficiency of measures to reduce them. Usually, energy losses are reduced by increasing the cross-section of wires and reducing the current in them (increasing the voltage with the help of transformers). But this approach requires constant modernization of existing networks, which in conditions of limiting the capacity of power lines is unprofitable and can be implemented in a small amount. Undesirable shortcomings can be avoided by laying more advanced modern cables, which, due to successful design solutions, provide a lower level of energy loss.

Classical methods for calculating energy losses in distribution networks do not take into account design features (type of insulation, protection from environmental influences) and methods of location of cores when laying cable. They take into account only the basic parameters [10]:core material, network voltage, line length, consumer power. On the other hand, analytical dependencies for determining losses in individual cable elements, depending on the location of the laying of cores, are known. Therefore, based on the results of such calculations, using knowledge of the processes that occur in the cable during the transmission of electricity, we can conclude which type of cable provides less energy loss and how it should be located. Establishing and assessing the degree of influence of these factors allows us to identify the causes of irrational energy use [21] and suggest ways to improve the energy efficiency of the system as a whole.

Conclusions to the section.

The section analyzes and classifies cable lines. The design of cables their characteristics and markings is considered. Shown. that currently the most promising are cables made of cross-linked polyethylene. They have good mechanical properties in a wide temperature range, resistance to acids, alkalis, moisture and has high electrical insulation characteristics. The main methods of grounding cable lines and sources of energy losses in cables are considered

2 CALCULATION AND RESEARCH SECTION

2.1 Formulation of a mathematical problem for calculating the load capacity of cable lines

Currently, power cables with insulation made of cross-linked polyethylene for medium voltage (6-35 kV) and high voltage (up to 110 kV -500 kV) are increasingly used in the power systems of large cities, in transport (metro), energy-intensive industrial enterprises and energy facilities, where high reliability of power supply is required, including at power plants to connect electrical equipment, power output from power units to switchgears or transition points [11-13].

An important role in achieving reliable and stable functioning of electrical cables is given to improving the methods of their laying, ensuring optimal operating modes taking into account environmental conditions, including the establishment of an acceptable electrical load on the cables by current, which is determined by the permissible temperature of the conductive cores. The permissible heating temperature of the cores depends on the type of cables, the rated voltage, the method and scheme of laying the cables in the line. To determine the maximum permissible load current of cable lines, along with their electromagnetic calculation, an important role is played by the specified heat calculation.

In this section, in order to determine the ability to load cable lines with insulation from cross-linked polyethylene, a mathematical model of related electromagnetic and thermal processes is described and implemented, taking into account the grounding scheme of cable screens and for various methods of laying lines - underground cable lines and lines laid in overhead structures (tunnels, channels).

In [14], the need to take into account the grounding circuits of the screens in the cable calculations is justified, since this affects the amount of current in the screens in normal and emergency modes, electrical losses in the screens (and hence the thermal mode of the cables and their throughput) and the basic electrical parameters of the cables (active and inductive resistances). The method of connecting screens (one-way, two-way grounding or with transposition) is carried out in article [15] by jointly solving the equations of the magnetic field and the connected electrical circuit.

The mathematical model presented in this section was first described in [16], where a numerical technique developed on its basis was used to calculate an underground double-chain cable line with the location of cables in a triangle. Further, for the horizontal arrangement of cables in underground lines, the associated electromagnetic and thermal problems are solved. The solution is carried out sequentially: first, the electromagnetic problem is solved in a flat formulation, then a stationary thermal problem - in order to take into account possible heterogeneous conditions for laying the line on the highway. The structure of multiphysical task and functional connections between individual tasks in the calculation of electrical thermal processes in an underground cable line are shown in Fig. 2.1.

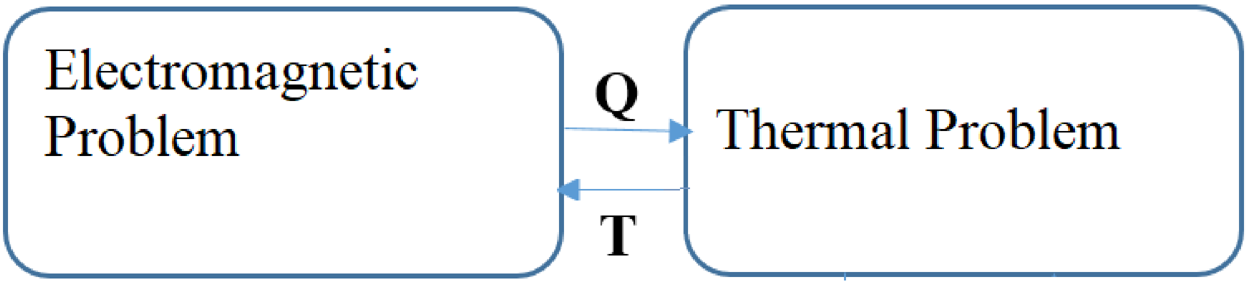


Figure .2.1 – The structure of the multiphysical problem and the relationship between tasks in calculating the load capacity of cable lines

Computer calculations were carried out using the finite element method in the Comsol Multiphysics software package [18].

2.2 Mathematical model of electromagnetic processes

Electromagnetic processes in a stationary mode occurring in a heterogeneous region are modeled. The area includes a cable line. Which consists of three single-phase cables with insulation made of cross-linked polyethylene. The structural elements of the cables in the line taken into account in the calculation are aluminum conductive cores, each of which is surrounded by an insulating layer of cross-linked polyethylene, then a screen made of copper wires and on top of the entire hermetic outer polyethylene sheath.

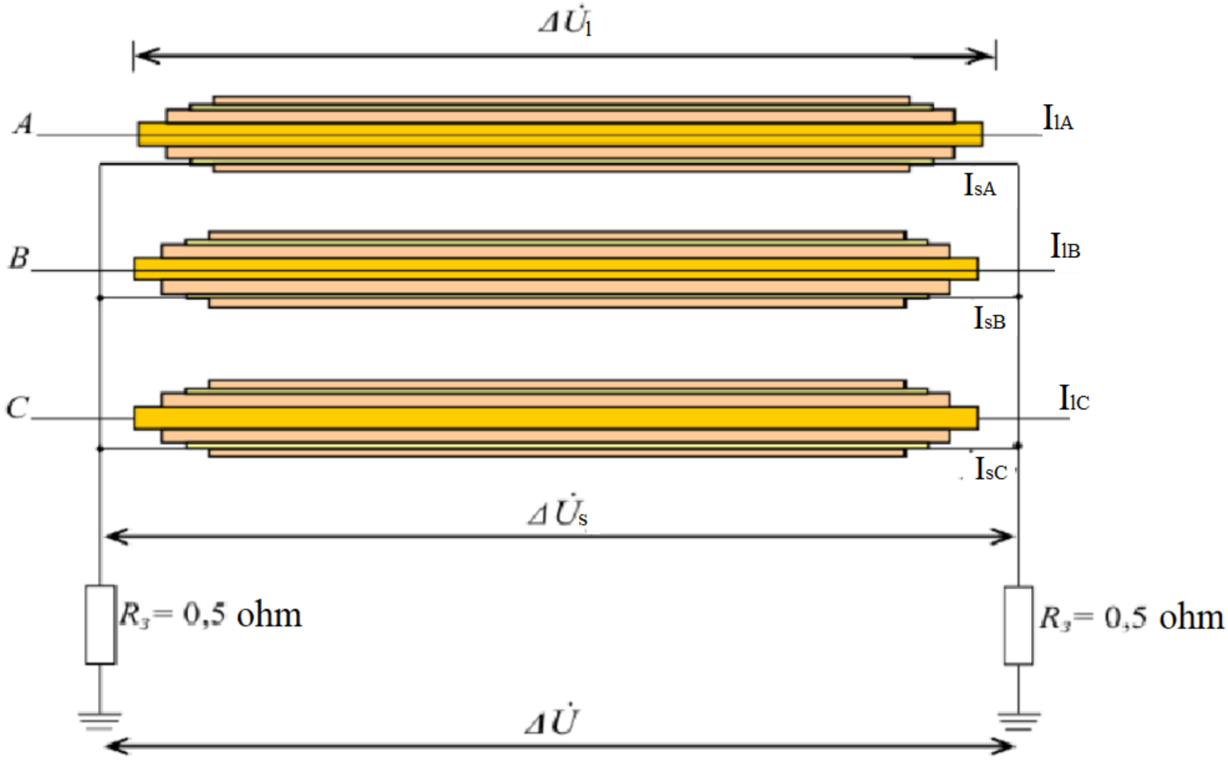


Figure 2.2 – Grounding scheme of cable line screens

Modeling and calculation of the electromagnetic field are carried out on the following assumptions:

- the studied cable lines are rather long and horizontally laid parallel to the surface of the earth at a certain depth;

- cable screens are grounded at the ends of construction sites, as shown in Fig.2.2.

The electromagnetic problem is solved in a two-dimensional formulation, in the cross section of the cable line, in the Cartesian coordinate system relative to the complex vector magnetic potential , characterized by a single z-component .
$\dot{\mathbf{A}} = (0, 0, \dot{A}_z)$ $\dot{A}_z = (x, y)$

Sources of alternating magnetic field in the areas under consideration are three-phase currents flowing in the conductors and cable screens. The problem is solved in the assumption that a three-phase voltage drop system is given per unit core length, and then as a result of this task, currents in the conductors and in the screens are determined, as well as the voltage drop on the screens.

The distribution of the vector potential is determined by the following system of equations:

$$j\omega\sigma\dot{\mathbf{A}} + \nabla \times (\mu_0^{-1}\nabla \times \dot{\mathbf{A}}) = \sigma\Delta\dot{U}_i; \tag{2.1}$$

$$\int_{\sum_i S_i} \dot{J}_z dS = \int_{\sum_i S_i} (-j\omega\sigma\dot{A}_z + \sigma\Delta\dot{U}_i)dS = 0; \tag{2.2}$$

$$\Delta\dot{U}_e = \Delta\dot{U} - 2R_з(I_{eA} + I_{eB} + I_{eC}). \tag{2.3}$$

where, – electrical conductivity and relative value of the magnetic permeability of the medium; σ μ_0

ω – cyclic frequency of current change;

$\dot{J}_z$ – current density;

dS – cross-sectional area of the -th conductive medium within the calculated area (among such environments are considered veins, cable screens and earth); i

$\Delta\dot{U}_i$ – voltage drop in the conductive medium in the area of unit length;

$R_з$ – resistance of the earth;

I_{eA}, , – currents in the phase screens of cables A, B, C, respectively; I_{eB} I_{eC}

$\Delta\dot{U}_i = \Delta\dot{U}_{ж}$ – in the area of veins (considered a known value);

$\Delta\dot{U}_i = \Delta\dot{U}_e$ – in the area of the screen;

$\Delta\dot{U}_i = \Delta\dot{U}$ – in the area of the soil.

The system of equations (2.1) - (2.3) contains three equations and three unknown quantities and is the basis of the mathematical model of the problem in a closed form. As boundary conditions at the outer boundaries of the calculated region, the condition of magnetic insulation is set: $\dot{A}_z, \Delta\dot{U}_e, \Delta\dot{U}\ \dot{A}_z = 0$

2.3 Mathematical model of thermal processes in underground cable lines

The electromagnetic field of cable lines is determined in accordance with the model described in subsection 2.2. Next, we develop a model for calculating the thermal field of cable lines.

It is believed that the soil around the underground cables is homogeneous and has the same properties in depth; Note that in general, the properties of the Earth undergo changes as a result of the functioning of cable lines, as well as under the influence of meteorological factors due to subsidence, moisture or drying.

The thermal problem for underground cable lines is formed in three-dimensional formulation, taking into account the heterogeneous soil on the laying route relative to the temperature T = *T (x, y, z).*

The distribution of a stationary temperature field is described by the differential equation of thermal conductivity

$$-\nabla \cdot (\lambda \nabla T) = Q, \tag{2.4}$$

where *λ (x, y, z)* is the thermal conductivity of the corresponding material in the homogeneous medium under consideration;

Q - the specific power of thermal sources, which include joule heat generated in the conductors of the cable cores,

$-|J_{ж}|^2 / \sigma_{ж}$, and - the loss of electric current flowing in the copper screen of each cable. In the above formulas: , - respectively, the current density value in the conductors and the induced current in the cable screens; $-|J_e|^2 / \sigma_e\ J_{ж}\ J_e$

$\sigma_{ж}$, - the electrical conductivity of the core and the screen. σ_{e}

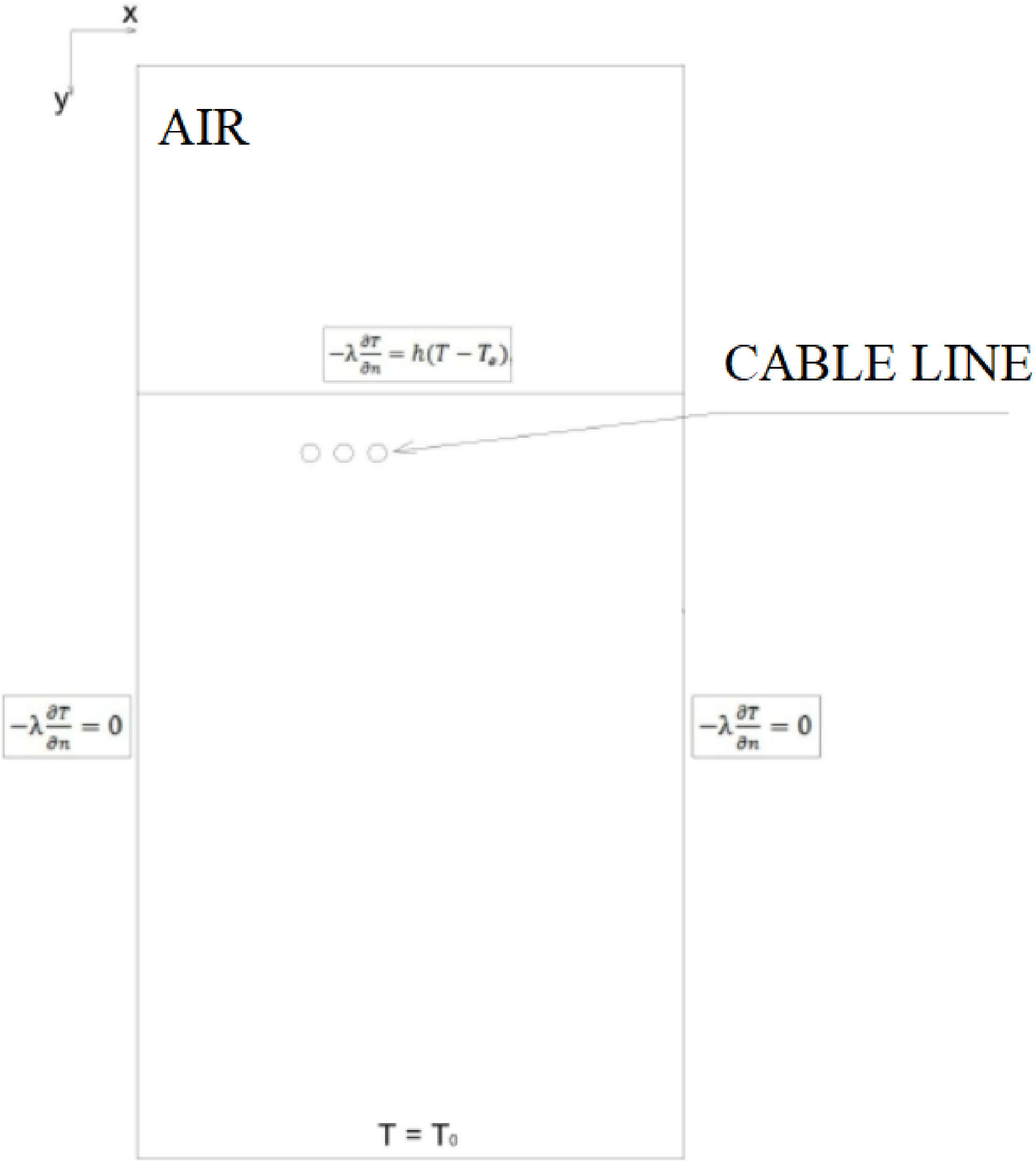


Figure 2.3 Model geometry

Equation (2.4) is complemented by boundary conditions

$T = T_0$ On the borders

$-\lambda \partial T / \partial n = k(T - T_{пов})$ On the border

2.4 Finite element method

One of the possible methods of computer modeling is the finite element method (ITU). The method of finite elements has gained universal recognition as a very effective method for solving a wide variety of problems of mathematical physics and technology. The high popularity of this method is explained by the simplicity of its physical interpretation, as well as the clarity and clarity of the numerical algorithm, which greatly facilitates the programming of complex problems of mathematical physics. At its core, this method is variational. Its emergence and development is associated with the classical works of B. G. Galorkin, I. G. Bubnov and V. Ritz.

The finite element method is based on a local approximation of the solution by polynomial functions. The original region is divided into subregions of the standard form, which in the two-dimensional case are triangles or quadrilaterals (Fig.2.1).

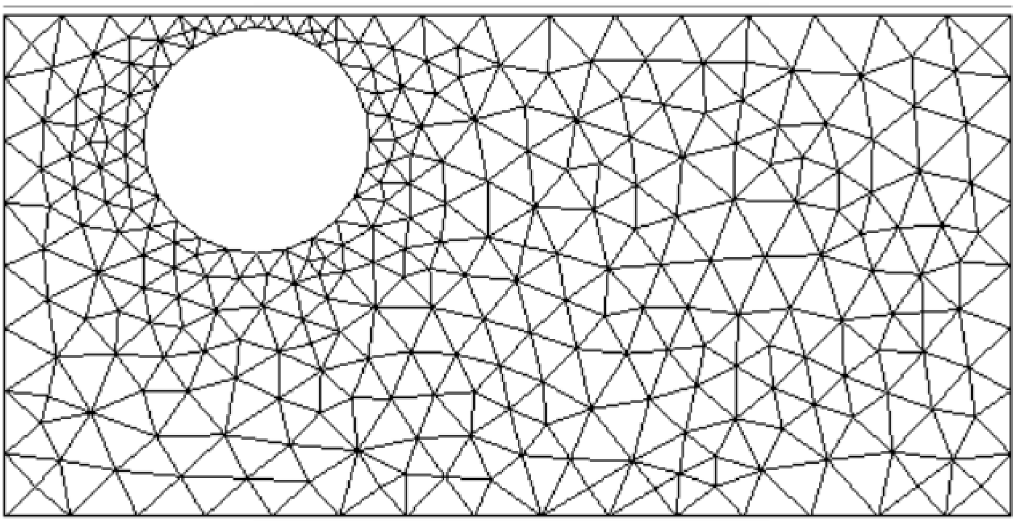


Figure. 2.4 – The idea of the method of finite elements: the division of the studied area into triangles or elements of another shape

By making the subdomain small enough or choosing a sufficiently high degree of polynomials with which the solution is approximated, it is possible to ensure that the approximating function accurately conveys the local behavior of the solution. This method can be used for areas of arbitrary shape and boundary conditions of a general type, and irregular partitioning of the region is possible. Thus, no restrictions are imposed on the location of the elements when dividing the region, which allows the use of the finite element method for a wide range of regions without using a global fixed coordinate system.

The method is widely used to solve problems of mechanics of deforming solids, heat transfer, hydrodynamics, electromagnetic fields and others. The emergence of the method of finite elements is associated with the solution of space research problems in the 1950s (the idea of ITU was developed by Soviet scientists back in 1936, but due to the underdevelopment of computing technology, the method was not developed). This method arose from structural mechanics and the theory of elasticity, and only then its mathematical justification was obtained. ITU received a significant impetus in its development in 1963 after it was proved that it can be considered as one of the variants of the Rayleigh-Ritz method common in construction mechanics, which, by minimizing potential energy, reduces the problem to a system of linear equilibrium equations. After a connection was established with the ITU minimization procedure, it began to be applied to the problems described by the Laplace or Poisson equation. The scope of IECs expanded significantly when it was established (in 1968) that equations defining elements in problems can be easily obtained using variants of the weighted non-binding method, such as the Galorkin method or the least squares method. This played an important role in the theoretical justification of the ITU, as it allowed it to be used in solving many types of differential equations. Thus, the method of finite elements turned into a general method of numerical solution of differential equations or systems of differential equations.

With the development of computational tools, the capabilities of the method are constantly expanding, and the class of tasks to be solved is also expanding. Almost all modern strength calculations are carried out using the finite element method.

The most important advantages of the finite element method,thanks to which it is widely used, are the following:

- the properties of materials of adjacent elements do not have to be the same, which allows you to apply the method to objects composed of several materials;

- the curvilinear region can be approximated using rectilinear elements or accurately described using curvilinear elements, therefore, ITU can be used for areas with any form of border;

- the dimensions of the elements can be variable, which allows to enlarge or grind the network of partitioning the area into elements and set the variable density of the placement of network elements;

- ITU allows us to consider boundary conditions with a ruptured surface load, as well as mixed boundary conditions.

The listed advantages of the finite element method are used in the preparation of programs for solving a fairly wide class of problems.

The disadvantages of the finite element method include: artificial limitation of the calculation area, sampling of the surrounding space, performing a new discretization when changing the position of the elements. Although the resources for improving ITU are almost exhausted, nevertheless, numerical methods are being developed, as well as their implementing software systems, allowing more economical use of computing resources and guaranteeing the effective solution of multivariate problems of analysis and design. For example, a combined method of finite and boundary elements (CMSiGE) has been created, which realizes the advantages of ITU and does not have its disadvantages.

2.5 Calculation of cable parameters

The values of the cable parameters are made to calculate the currents and voltages in the cable line. We introduce the basic designations of the design of the cable and cable lines. Consider a single-core cable (Fig. 2.5).

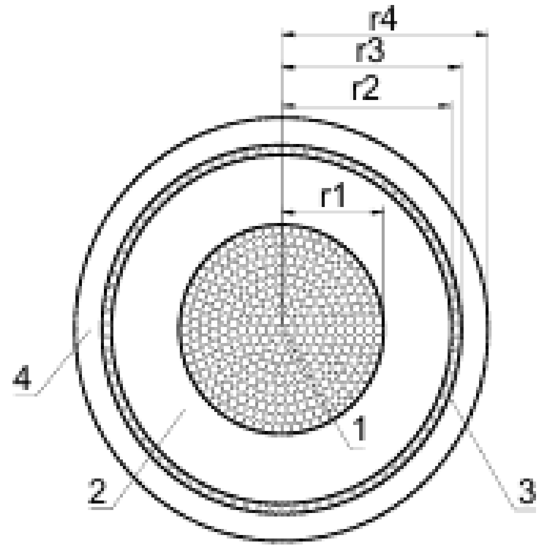


Figure 2.5 – Sketch of cable cross-section with insulation made of cross-linked polyethylene:
1 - current conductive core, 2 - insulation, 3 - cable screen, 4 - sheath

For further calculation, we use the following designations of the radius of the core - , diameter - . For the screen in the inner radius, denote , the outer - , r_1 and the diameter of the screen - . the outer radius of the cable is $d_{жс}$ r_2 , the outer diameter r_3 of the d_e cable is r_4 .D

Consider the location of the three-phase group of single-core cables (Figure 2. 6) when laying cable lines.

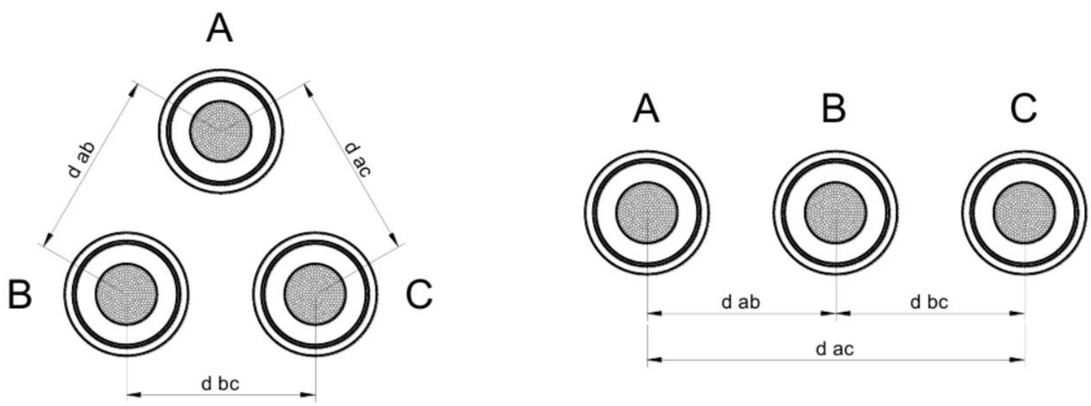


Figure 2.6 – Methods of laying the cable: triangle – left,
in the plane - on the right

To indicate the average geometric distance between the phases, we introduce the parameter s.

When laying with a triangle, the distance between each pair of phases is equal to a and is equal to the outer diameter of the cable:

$$s = d_{ab} = d_{bc} = d_{ac} = D \quad (2.5)$$

where is the distance between the d_{ij} axes of the i and *j* phase cables, D is the outer diameter *of the* cable.

When laying in a plane, the distance between the extreme cables is twice as large as between the extreme and central, so the average distance you are listed as:

$$s = \sqrt[3]{d_{ab} \cdot d_{bc} \cdot d_{ac}} = \sqrt[3]{2d^3_{ab}} = 1.26 d_{ab} \quad (2.6)$$

Consider the current flow scheme along cable lines. In networks for a voltage of 6-500 kV, circuits with a deaf-grounded, isolated and resistive-grounded neutral are used, in which the ground plays the role of a neutral wire. The current in the ground is usually taken into account by currents in three fictitious wires, the axes of which are located at a distance D from the axes of the phase conductors. This distance is called the equivalent depth of the reverse current, won and depends on the frequency of alternating current and the specific conductivity of the soil:

$$D_з = 2.24\sqrt{\frac{\rho_з}{\omega\mu_0}} \quad (2.7)$$

where $\rho_з$ is the specific conductivity of the soil.

This concept is taken from the theory of overhead lines, used mainly outside the built-up areas. Along the entire length of the overhead line route, there are practically no natural groundings, so the equivalent depth of the reverse current is determined only by the properties of the soil.

Cable lines are laid in cities in a built-up area with a large number of natural groundings. In the territories of power grid objects, artificial grounding circuits are arranged, therefore, the equivalent depth of the reverse current flow is assumed to be equal to the depth of the grounding circuit. In addition, the lengths of overhead lines are much superior to cable ones, and it is not entirely correct to neglect the final effects when calculating Dз.

To solve a system of equations (3.3) it is necessary to determine the running parameters of the cables. If we assume that the parameters do not depend on the frequency and mutually influence each other, and the distances inside the cable with respect to the inter-cable ones when considering their location in a three-phase system can be neglected, then the mathematical model for calculating resistances will look like.

The resistance of the core consists of active core resistance , the inductive resistance, veins, active resistance of the earth.

$$\dot{Z}_{ж} = R_{з} + R_{ж} + j\omega L_{ж} \tag{2.8}$$

where is the active resistance of $R_{з}$ the earth, - the $R_{ж}$ active resistance of the vein $L_{ж}$, - the inductance of the vein.

$$R_{з} = (\pi / 4)\mu_0 f, \tag{2.9}$$

$$R_{ж} = \rho_{ж} / F_{ж}. \tag{2.10}$$

The inductance of the core is determined by the po formula

$$L_{ж} = \frac{\mu_0}{2\pi} \ln\left(\frac{D_з}{r_1}\right) \quad (2.11)$$

where the nearside of the contour is the surface of the core, which is at a distance of r $_1$, and the far side of the fictitious conductor at a distance of Dz.

The screen resistance consists of active screen, an inductive resistance, screen, active resistance of the earth.

$$\dot{Z}_e = R_з + R_e + j\omega L_e \quad (2.12)$$

where is the R_e active resistance of the screen, is the L_e inductance of the screen.

$$R_e = \rho_e / F_e \quad (2.13)$$

The inductiveness of the screen is determined from

$$L_e = \frac{\mu_0}{2\pi} \ln\left(\frac{D_з}{r_2}\right) \quad (2.14)$$

where the near side of the contour is the surface of the screeny, which is at a distance of r_2, and the far side of the fictitious conductor at a distance Dз:

The mutual resistance between the residential and the cable screen is explained by the effect of current leakage in the adjacent cable circuit: for the core in the screen, and for the screen - in the conductor. It consists of active ground resistance and mutual inductive resistance between the living and the screen in the cable.

$$\dot{Z}_{же} = R_з + j\omega M_{же} \quad (2.15)$$

Where, M is the mutual inductance of the core and the screen of the cable.

The mutual inductance of the same cables is determined with

$$M_k = \frac{\mu_0}{2\pi} \ln\left(\frac{D_з}{s}\right) \qquad (2.16)$$

where the near side of the circuit is the surface of the core (screen) of the adjacent cable, located at a distance s, and the far side of the fictitious conductor at a distance of $D_з$:

2.6 Double-sided grounding of screens

According to the requirements [22], the metal sheaths of the cables must be grounded on both sides (Fig.2.7) of the cable line.

In the design of cables with insulation from cross-linked polyethylene, a metal screen is a grounding circuit for diverting short-circuit currents from a conductive core into grounding devices, which is easier to connect to at the ends of the line.

Performing double-sided grounding does not require much labor, installation consists only in the output cable screen in front of the end coupling and connecting it to the existing grounding circuit.

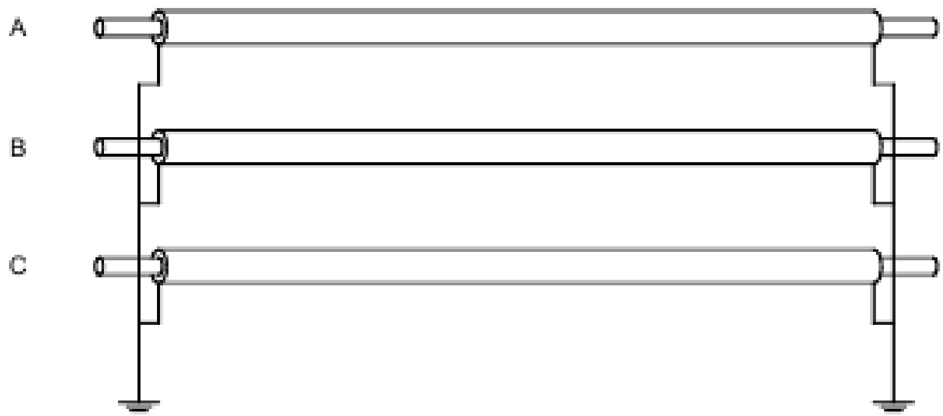


Figure 2.7 - Scheme of double-sided grounding of screens

With this connection scheme, the screens of all cables have the potential of the earth, but currents begin to flow in their closed circuits, causing additional power losses and worsening the temperature regime of the cable, which negatively affects its throughput and service life.

When grounding cable screens on both sides, the condition of the connection scheme:

$$\Delta\dot{U}_{eA} = \Delta\dot{U}_{eB} = \Delta\dot{U}_{eC} = 0 \tag{2.17}$$

Resistance of direct sequence of three-phase group of single-phase cables:

$$\dot{Z}_1 = (\dot{Z}_{ж} - \dot{Z}_{к}) - \frac{(\dot{Z}_{же} - \dot{Z}_{к})^2}{\dot{Z}_{е} - \dot{Z}_{к}} \tag{2.18}$$

Resistance of the zero sequence of a three-phase group of single-phase cables:

$$\dot{Z}_0 = (\dot{Z}_{ж} + 2\dot{Z}_{к}) - \frac{(\dot{Z}_{же} + 2\dot{Z}_{к})^2}{\dot{Z}_{е} + 2\dot{Z}_{к}} \tag{2.19}$$

Taking into account (2.15) when solving a system of equations (2.16), we obtain currents in the cable screens in normal mode:

$$\dot{I}_{eA} = -\frac{\dot{Z}_{же} - \dot{Z}_{к}}{\dot{Z}_{е} - \dot{Z}_{к}}\dot{I}_{жA} \tag{2.20}$$

$$\dot{I}_{eB} = -\frac{\dot{Z}_{же} - \dot{Z}_{к}}{\dot{Z}_{е} - \dot{Z}_{к}}\dot{I}_{жB} \tag{2.21}$$

$$\dot{I}_{eC} = -\frac{\dot{Z}_{жe} - \dot{Z}_{к}}{\dot{Z}_{e} - \dot{Z}_{к}} \dot{I}_{жC} \tag{2.22}$$

Thus, considering (2.20), (2.21) and (2.22) we get:

$$I_e = -\frac{I_{ж}}{\sqrt{1+\left(\frac{R_e}{X}\right)^2}} \quad \text{where} \quad X = \omega \frac{\mu_0}{2\pi} \ln\left(\frac{2s}{d_e}\right) \tag{2.23}$$

The expression (3.19) determines the amount of current in the system screen with two sideways grounding of screens, which depends on:

- current in the core of the same,
- the active resistance of the screen *Re* (that is, from the material and cross-section of the screen F_e),
- the diameter of the cable on the screen d_e,
- distances between phase cables

The share of current in the screen from the current in the core is:

$$\frac{I_e}{I_{ж}} = \frac{1}{\sqrt{1+\left(\frac{R_e}{X}\right)^2}} \tag{2.24}$$

The advantages of double-sided grounding of screens are the absence of voltage on the screen, ease of installation, low cost of execution. The disadvantages of the system include the flow of currents in the screens, which is an additional source of heat dissipation, additional power losses, and a reduction in the service life of cables.

2.7 One-way grounding of screens

When grounding the screens at one end of the cable line, the metal screens of the three phases are interconnected and grounded on a common device with normalized resistance. With a single-page grounding of the screen , the path for the flow of longitudinal currents in it is broken. Relatively small losses in the screen are due only to eddy currents that do not determine the thermal mode of operation of the cable.

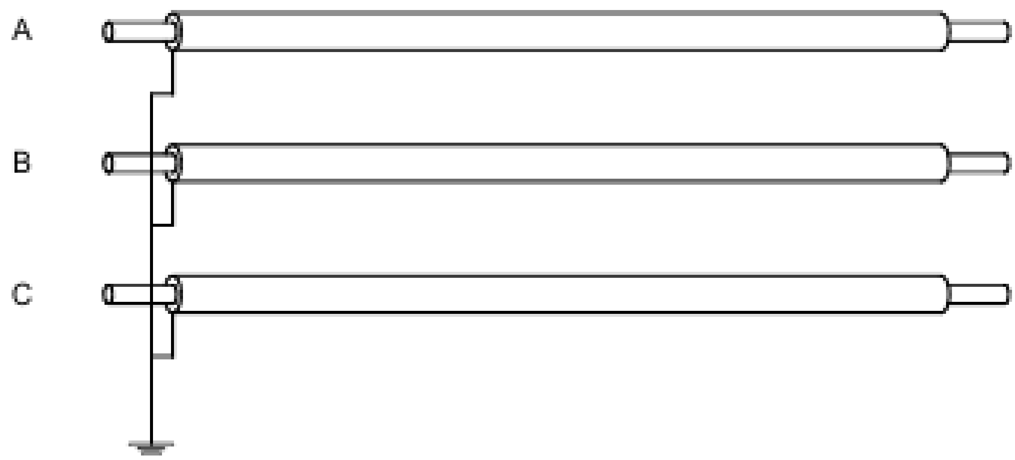


Figure 2/8 - Scheme of one-sided grounding of screens

However, in this mode of operation of the screens, it is necessary to take into account the following factors:

1. The appearance of impulse surges dangerous for the protective sheath, the value of which may exceed the electrical strength of the insulating sheath, which can lead to penetration of moisture into the insulating structure of the cable (during underground laying and use of cable without sealing).

2. Installation of additional equipment: end couplings with insulated screens, protective devices on unearthed ends of the screen. Requires certain additional costs during the construction of the screen grounding system.

3. The induced potential at the unearthed ends of the screen, the value of which is proportional to the operating current in the core and the length of the cable, can be

dangerous for maintenance personnel, and can also cause corrosive damage in case of violation of the integrity of the cable sheath.

The above potential arises both in the normal operation of the cable and in the emergency mode during a short circuit in the network. In this case, the short-circuit current passes completely through the core without going into the screen, although the insulation breakdown does not occur.

If a short circuit occurs directly in the cable during insulation breakdown, then the potential is not given, but the short-circuit current flows into the grounding devices along the circuit "core - place of short circuit - screen - grounding".

If the contact between a person and the screen is excluded when servicing the cable line, then the given potential should not exceed the voltage value that determines the strength of the screen insulation, that is, the cable sheath. In case of mechanical damage to the cable sheath, the potential of the screen should not create a dangerous step voltage or touch voltage for people and animals.

When implementing one-way grounding, it is recommended to take the permissible value of the voltage shown on the screen no more than 100 V in normal mode. With a short circuit, the maximum value of the induced voltage on the screen ne should exceed 5 kV , which can lead to a violation of the electrical strength of the insulating shell and the penetration of moisture into the cable structure.

With decent electrical safety requirements, the voltage at the open end of the screen relative to the ground in all modes should not exceed 25 V [23]. Otherwise, special end boxes must be installed that restrict access to the cable screen, and all work related to touching the cable sheaths should be performed only when the cable is disconnected. End boxes are both single-phase and three-phase. Installed at the open end of the screen.

The choice of protective characteristics of the OPN must be chosen on the basis of the maximum possible impulse and voltage of the gi, which is applied to the OPN, and the maximum duration of the short circuit on the ground in the scheme of application of the LC.

To protect the shell from impulse over voltages, it is necessary to install an OPN with the highest operating voltage of 6 kV and a specific absorption energy of 2-3 kJ/kV. The specific value of the highest operating voltage of the OPN is defined as the voltage at the place of its installation during an external short circuit of the cable divided by 1.25.

When the current flow circuit is broken in the screens with this connection scheme :

$$\dot{I}_{eA} = \dot{I}_{eB} = \dot{I}_{eC} = 0 \quad (2.25)$$

Resistance of direct sequence of three-phase group of single-phase cables:

$$\dot{Z}_0 = \dot{Z}_{ж} + 2\dot{Z}_{к} \quad (2.26)$$

Taking into account (2.26) when solving a system of equations (2.18), we obtain the voltage on the screens of different phases:

$$\Delta\dot{U}_{eA} = Z_{жe}\dot{I}_{жA} + Z_{к}\dot{I}_{жB} + Z_{к}\dot{I}_{жC} \quad (2.27)$$

$$\Delta\dot{U}_{eB} = Z_{жe}\dot{I}_{жB} + Z_{к}\dot{I}_{жA} + Z_{к}\dot{I}_{жC} \quad (2.28)$$

$$\Delta\dot{U}_{eC} = Z_{жe}\dot{I}_{жC} + Z_{к}\dot{I}_{жA} + Z_{к}\dot{I}_{жB} \quad (2.29)$$

Consider cases for different modes of operation of the cable and determine the voltages on the screen relative to the ground in normal operation and with various symmetrical and asymmetric short circuits in the network.

In normal operation and with a three-phase short circuit, the sum of the currents of the three phases is zero:

$$\dot{I}_{жсA} = \dot{I}_{жсB} = \dot{I}_{жсC} = 0 \tag{2.30}$$

Then the voltage on the screen according to (2.30):

$$\Delta\dot{U}_{eA} = (\dot{Z}_{жсе} - \dot{Z}_{к})\dot{I}_{жсA} \tag{2.31}$$

$$\Delta\dot{U}_{eB} = (\dot{Z}_{жсе} - \dot{Z}_{к})\dot{I}_{жсB} \tag{2.32}$$

$$\Delta\dot{U}_{eC} = (\dot{Z}_{жсе} - \dot{Z}_{к})\dot{I}_{жсC} \tag{2.33}$$

To reduce the voltage on the cable screen, one-way grounding on the cable line can be performed several times. To do this, the line is divided into segments of equal length (section), in each of which the fault is grounded only once.

Then the formula for calculating the voltage on the cable screen for one-way grounding and screens in symmetrical mode using linear parameters is:

$$\Delta\dot{U}_{e} = \frac{1}{K}(\dot{Z}_{жсе} - \dot{Z}_{k})\dot{I}_{жс}L_{k} \tag{2.34}$$

where K is the number of sections of one-way grounding of screens

Taking into account (2.31) and (3.34) we finally get:

$$\Delta U_{e} = \frac{1}{K} jI_{жс}L_{жс} \quad \text{where } X = \omega\frac{\mu_0}{2\pi}\ln\left(\frac{2s}{d_e}\right) \tag{2.35}$$

The expression (2.35) is the voltage value that is given on the screen of the system with one-way grounding of the screens which depend on:

current in the core $I_{жс}$,

cable line lengths $L_{жс}$,

the diameter of the cable on the screen d_e,

distances between the facables s,

depth of flow of reverse current in the ground Dз.

In general, the graph the dependence of the voltage on the screen, wound on the length of the cable (Fig. 2.9) has a linear characteristic, so the maximum potential will be given at the open end of the screen.

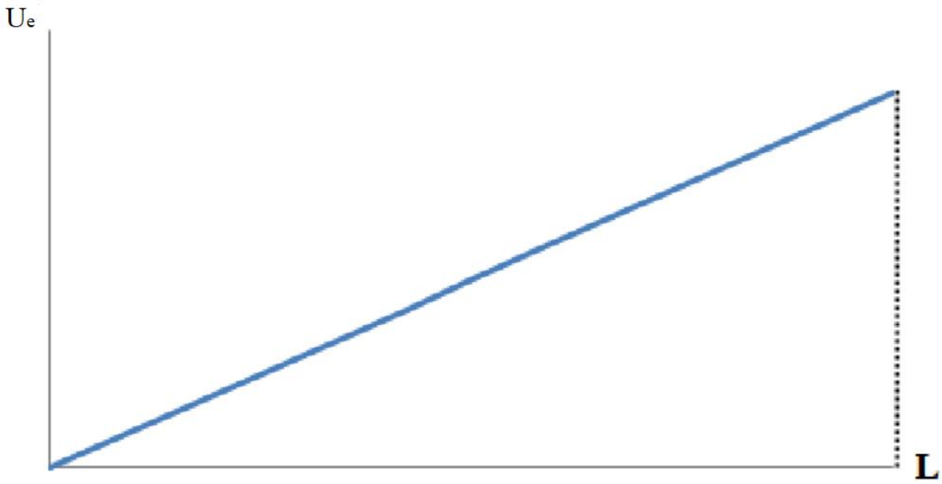


Figure 2.9 - Graph of the dependence of $U_e(L)$ with one-sided grounding and screens

The advantages of one-way grounding of screens are the absence of currents and additional power losses in the screen and additional heating of the cable. The disadvantages of the system include the presence of the above potential on the screen, the need to install surge protectors, additional costs during construction.

2.8 Transposition of screens

The transposition of the screen (Fig. 2.10) is performed in such a way that the screen passes through three sections along each of the phases that make up the full transposition cycle.

Since at different sections of the same length the EMF on the screen is induced from different phases, the total emf of the circuit is zero. As a result, longitudinal currents are absent, and only vortex currents are induced, as in the case of one-way grounding.

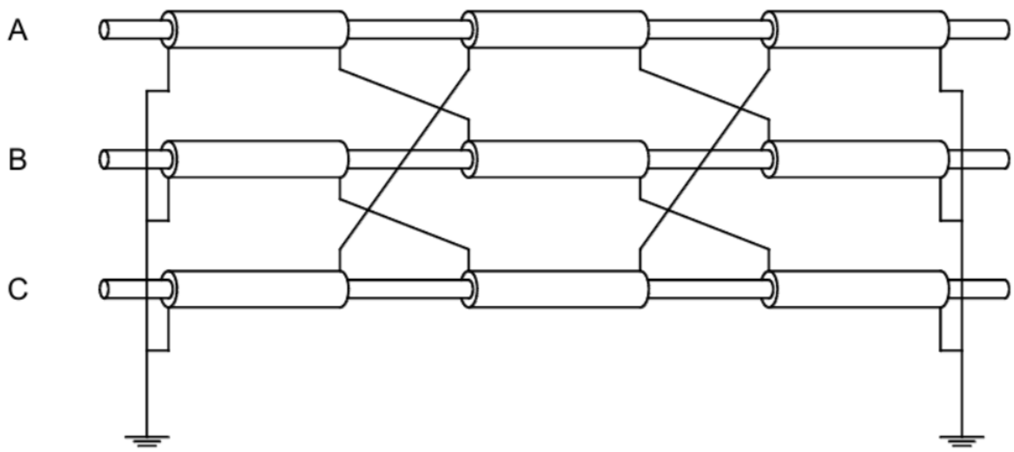


Figure 2.10 - Scheme of transposition of screens

When transposing screens, you must consider:

1. The appearance of impulse overvoltages dangerous for the protective shell in the transposition nodes;

2. Installation of additional equipment: screen-separating couplings, transposition boxes with protective devices in the transposition nodes of screens.

In the case of laying the cable in the ground, it is necessary to provide for the construction of special transpassembly chambers with a grounding device for installing screen transposition boxes. This increases the cost of the grounding system of the screens. In the ultrals of the transposition, you can equip the installation of couplings in the cameras, if they are located in the right places along the cable line. In this case, the additional costs will be only the difference in cost couplings and remuneration of installers for the installation of the transposition device.

With a full transposition cycle, the screen becomes common to all three phases. In the first and third sections, the voltage of the screen relative to the ground is equal to the corresponding intensity of the potential with a linear dependence on the length. For the middle section, the given potential determines both the EMF of the first section and the EMF of the third section, for which currents of different cores are significant. Ne-great potential is given and in transposition nodes (Figure 2.11).

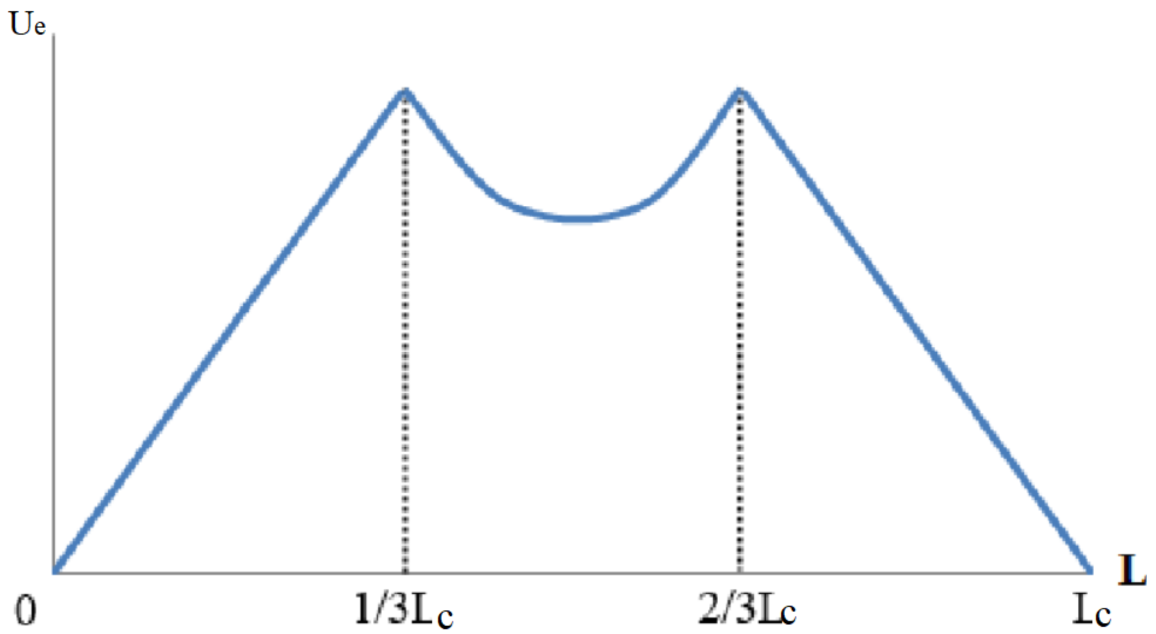


Figure 2.11 - Graph of the dependence of Ue (L) during the transposition of screens

Permissible voltages on the screen, the choice of characteristics of surge protectors coincide with the solutions for one-way grounding of screens.

The grounding system with transposition of screens is the most expensive in terms of construction, as it requires two couplings, possibly cable wells with a grounding device for installing boxes with protective devices.

Having carried out similar reasoning and for previous cases, the value of the given voltage U_e in the case of applying the transposition of the screens will be determined from the expression

$$\Delta U_e = \frac{1}{3N} jXI_{жс}L_{жс} \quad \text{where} \quad X = \omega \frac{\mu_0}{2\pi} \ln\left(\frac{2s}{d_e}\right) \tag{2.36}$$

The advantages of a system with transposition of screens are the absence of currents and additional power losses in the screen, the absence of an additional source of cable heating, grounding of screens at both ends of the cable line.

The disadvantages include the need to install surge protectors, the possible additional construction of cameras for the installation of equipment in transposition nodes (at least at two points), the highest cost of building a grounding scheme.

Conclusions to the section

1. A multiphysical problem for calculating electromagnetic and thermal processes in cable lines has been developed, which takes into account:
   - geometric arrangement of cables;
   - heat exchange with the environment, the temperature of the medium is set;
   - the effect of the induced currents when laying the cable;
   - connection of the working current in the line with heat generation due to all electromagnetic and thermal effects;
2. The algorithm for constructing a mathematical model of a cable line in the Comsol Multiphysics environment is proposed, and the principle of implementing the finite element method for this software package is considered.
3. A mathematical model has been chosen that allows you to calculate the electrical parameters of grounding systems.
4. For double-sided grounding of screens, it is necessary to calculate the currents and power losses in the screens, which depend on the amount of current in the core, the cross section of the screen, the diameter of the cable and the distance between the cables.
5. For one-way grounding of screens, it is necessary to calculate the given potential at the open end of the screen, which depends on the current in the core, the length of the cable line, the diameter of the cable, the distance between the cables and the depth of the reverse current in the ground.

6. For the transposition of screens, it is necessary to calculate the given potential in the transposition nodes, which depends on the current in the conductor, the length of the cable line, the diameter of the cable, the distance between the cables.

3 PROJECT DESIGNING SECTION

3.1 Choosing a cable to build a model

One of the most important tasks in the design of cable lines is to increase the reliability of high-voltage cable lines when laying in the ground and efficient transmission of electricity. This is possible only when taking into account all the factors affecting the operation of the cable line, the correct choice of brand and geometric parameters of the cable, the method of laying the line and grounding the screens.

To calculate the current loads, an APEV-10 1x50 cable was chosen. The cable design is shown in Fig.3.1.

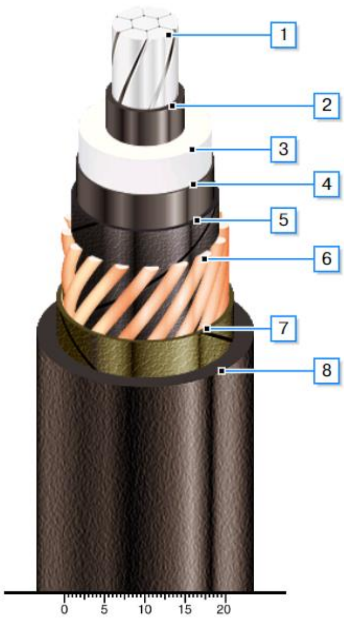


Figure 3.1 – The design of the cable brand APVEV-10 1x50: 1-luminium conductive core 2- the interior extruded and semiconducting layer. 3- insulation from cross-linked polyethylene. 4- external extruded semiconducting layer. 5- layer windings of semiconducting water-swelling tape: 6 - screen. 7- layer with a ribbon of non-woven tape winding. 8-outer shell made of PVC compound.

This cable is used for laying: in rooms, tunnels, channels, mines, dry soil and in the open air under a canopy.

Cable specifications are summarized in tables 3.1

Table 3.1 Technical characteristics of cable APEV-10 1x500

Rated voltage	10 kV
Maximum voltage	12 kV
Number and nominal cross-section of conductive cores	1×500 mm^2
The thickness of the insulation	3,4 mm
Minimum screen cross section	35 mm^2
Permissible short-circuit current on the minimum cross-section screen	7,1 kA
The maximum allowable short-circuit current of the conductive core	47 kA
Long-term permissible current loads when laying a triangle in the air when laid in a plane in the air when laying a triangle in the ground when laid in a plane in the soil	 786 A 881 A 526 A 522 A
Maximum permissible temperature lived trippling time in emergency mode with a short circuit	 +90 °C +130 °C +250 °C
Operating temperature range	-50...+50 °C
Outer diameter of the cable	46 mm

Long-term permissible current loads are calculated for the following conditions: core temperature 90 ° C, air temperature 30 ° C, soil temperature 20 ° C, ground specific thermal resistance 1.5 ° K • m / W, laying depth in the ground 0.8 m, when laying in a plane, the distance between the cables in the lumen is equal to the diameter of the cable, when laying in a triangle, the cables are laid closely, the screens are grounded at both ends of the line

Based on the above technical characteristics, the calculation of the required geometric dimensions of the cable for building the geometry of the model was carried out.

To simplify the geometry of the model in the cable design, we will take into account only the conductive core, insulation, screen and shell, Figure 3.2.

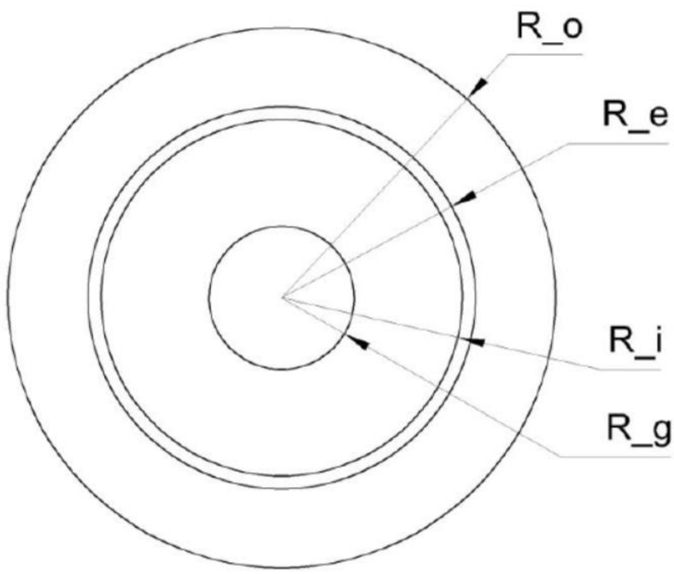


Figure 3.2 – Geometric parameters of the cable

Radius of conductive core:

$$R_{\_g} = \sqrt{\frac{S_{ж}}{\pi}} = \sqrt{\frac{500}{3,14}} = 12,6 \text{ mm.}$$

Isolation radius

$$R_{\_i} = R_{\_g} + 3.4мм = 16 \text{ mm}$$

Screen radius;

$$R_{\_e} = \sqrt{\frac{S_e + \pi(R_{жс} + 3.4)^2}{\pi}} = 16,4 \text{ mm.}$$

The radius of the cable sheath is

$$R_{\_o} = 23 \text{ mm.}$$

3.2 Calculation of electromagnetic characteristics

For this calculation, the model developed in section 2 was used. It was believed that the cable is in the mass of the earth at a depth $H = 0.7$ of m.

Electrical properties of the structural elements of the power cable and the model as a whole

Table 3.2 Electrical properties of the structural elements of the power cable

Element	Material	Relative magnetic permeability μ_0	Relative dielectric constant ε_0	Electric itoma σ Conductivity (cm/m)
Vein	Aluminium	1,000021	1	$38 \cdot 10^6$
Insulation	Cross-linked polyethylene	1	2,3	0
Screen	copper	0,99999	1	$58 \cdot 10^6$
Shell	PVC	1	3,1	0
Massif of land	Ground	1	5,7	10^{-5}

Consider a three-phase cable line assembled from three single-phase cables with a voltage of 10 kV with different methods of combining single-phase cables into a three-phase group;

1. triangle

2. Parallel

In this section, the underground arrangement of cables with falling asleep with ambient soil is analyzed, however, the technique is also suitable for other laying conditions, including falling asleep with special soil, in cable trays, in the air, etc.

We set the length of the cable line to 1 km. The task is to calculate the induced currents in the screens, as well as the losses from them. Let us accept as an assumption the symmetrical nature of the load and the imetricity of the system of currents of cores with an operating current value of one phase of 520 A. The assumption of the symmetry of the core currents is a simplifying assumption , since due to the peculiarities of the cable location, the magnetic conditions for the interaction of different phases are slightly different. However, this assumption is common for the practice of calculations. It is important to note that no assumptions about the symmetry of currents are made regarding the screens.

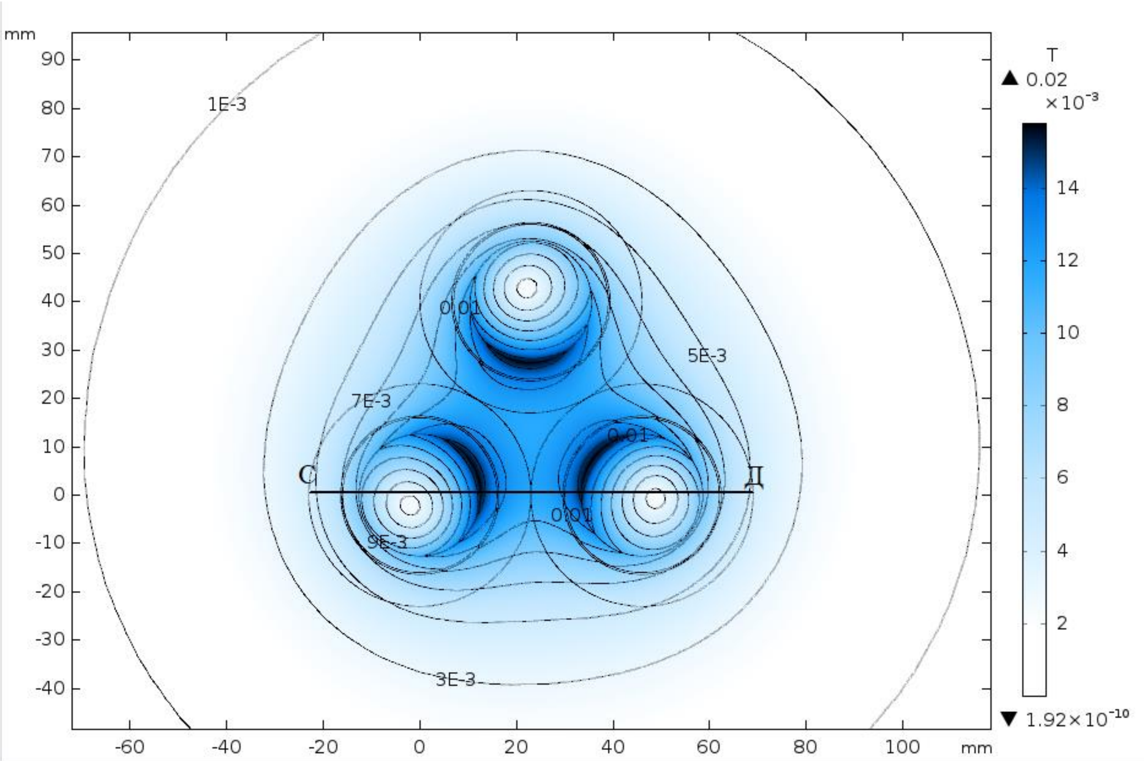


Figure 3.3 – Distribution of the magnetic field of the cable network when combined into a triangle

In fig. Fig. 3.3, and Fig. 3.4 shows the distribution of the magnetic field of the cable network when laying in a triangle and in parallel.

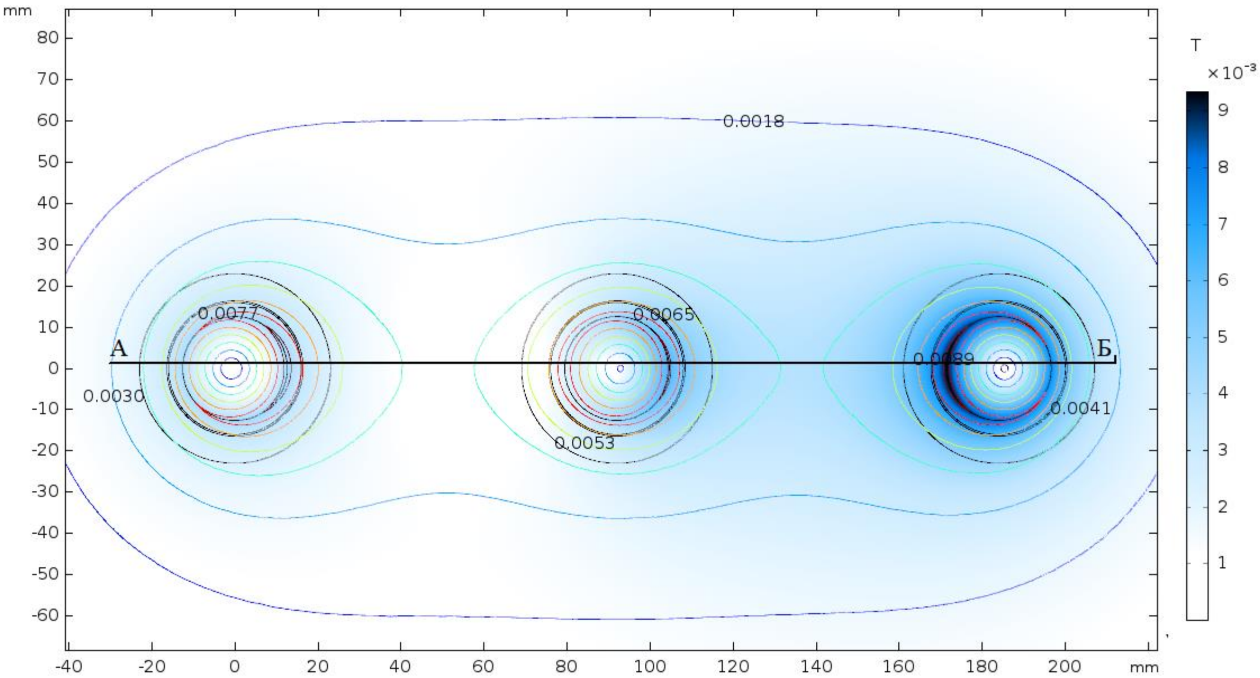
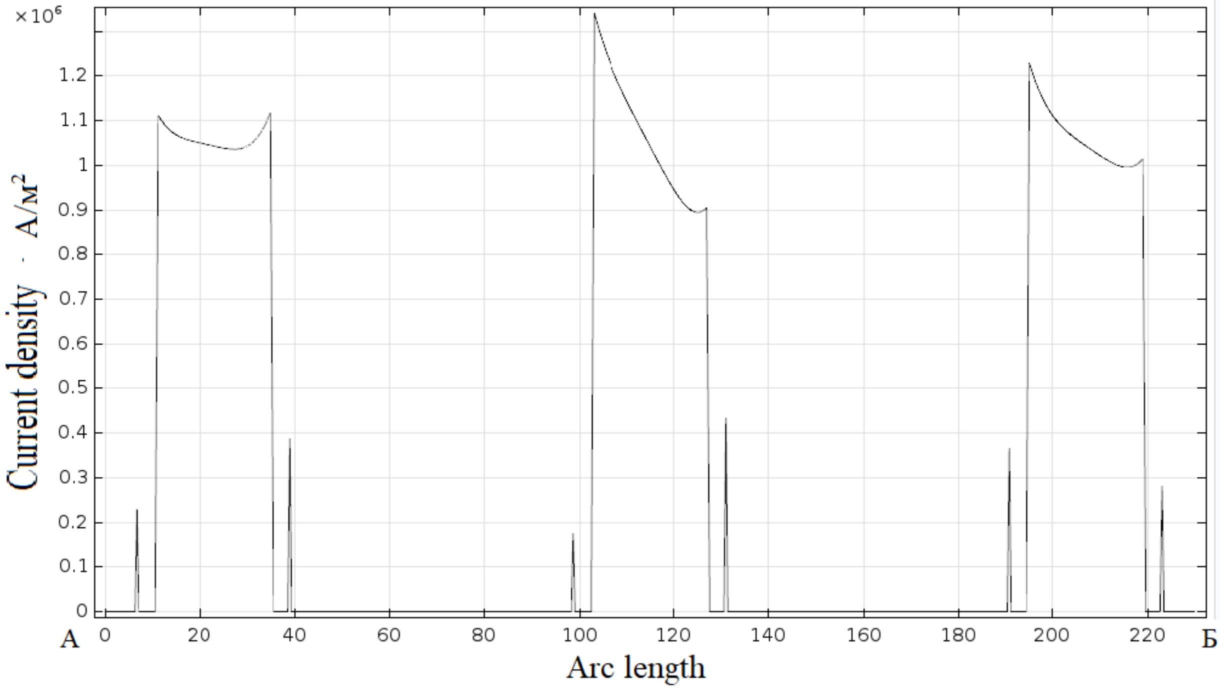


Figure 3.4– Distribution of the magnetic field of the cable network when laying in parallel

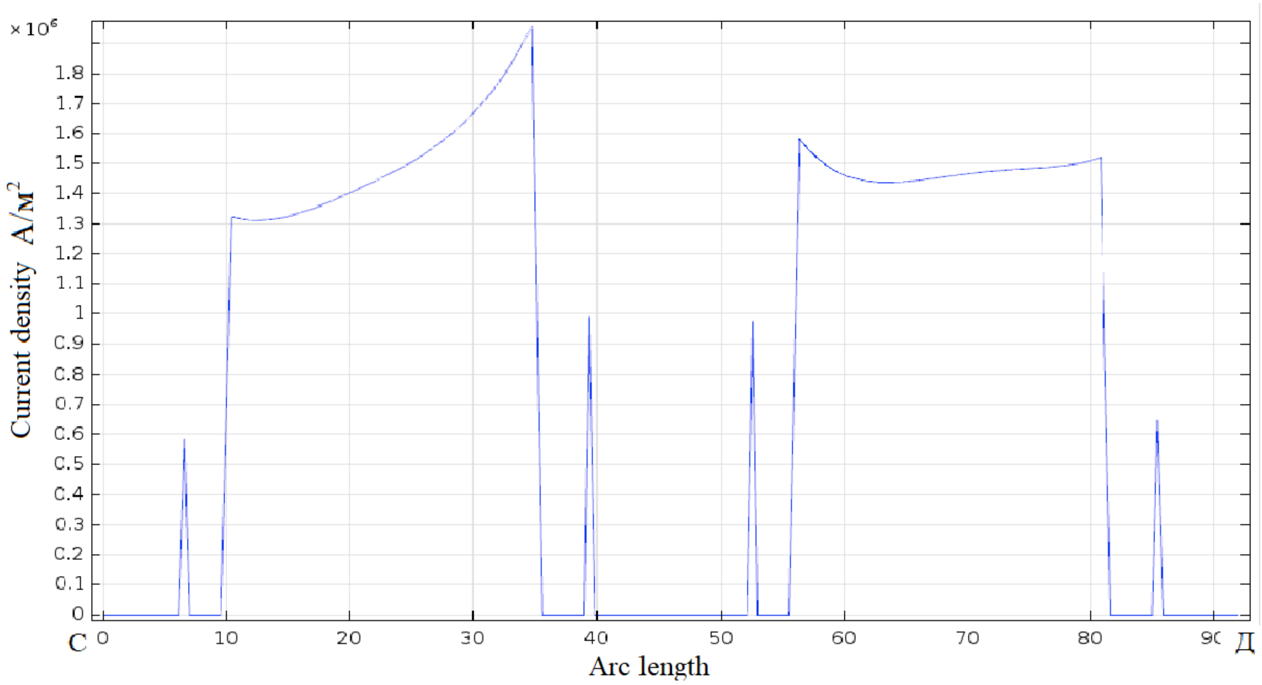
You can see that in the first case, the magnetic field is concentrated in the area of the cable network. Its maximum value is 0.02 ·T. in the case of placing the cable network in the plane, the maximum magnetic field is concentrated near the phase A cable, and its maximum value is

$9 \cdot ^{10\text{-}3}$ T. Characteristic of both cases is the concentration of the field on the surface of the conductive cores.

In fig. 3.5, a and 3.5, b show the current density in the cable network.



(a)



b)

Figure 3.5 Distribution of current density along

In fig. Fig. 3.5 reflects the mutual influence of conductors (cores and screens) of cables, which is manifested in the displacement of current to the surface, also affects the influence of the magnetic field from the side of a symmetrically located cable line. Pictures of the distribution of current density separately in the conductors and cable screens reflect the result of the joint manifestation of the proximity effect and the skin effect. There is an asymmetry of currents in the conductors and screens. This is due to the complex mutual influence of conductors each cable and the impact of cable lines among themselves.

3.3 Temperature calculation

Calculation of the current load of the cable, and the screen allows you to calculate the thermal mode of the cable line. Consider the thermal state of the cable line and under the condition of laying in the ground. The thermal properties of the materials used in the design model are shown in Table 3.3.

Table 3.3 Thermal properties of materials

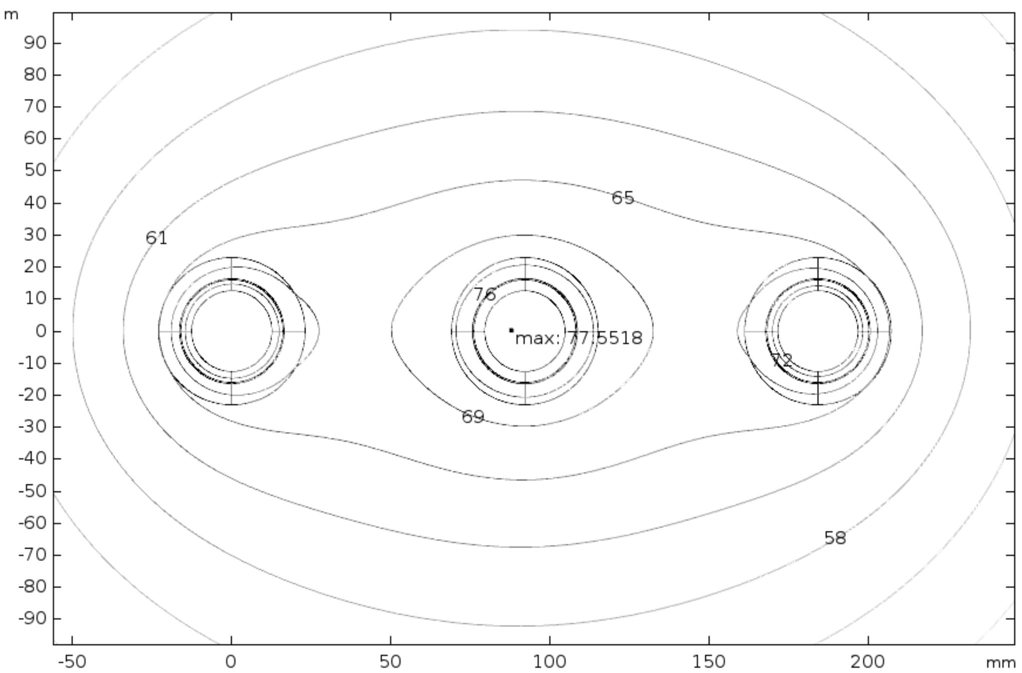
Element	Material	Density ρ (kg/m^3)	Specific heat capacity coefficient C (J/kg·S)	Thermal conductivity coefficient λ (W/m·S)
Vein	Aluminium	2698	930	237
Insulation	Cross-linked polyethylene	942	2300	0,35
Screen	Copper	8920	385	401
Shell	PVC	1620	1000	0,17
Massif of land	Ground	2000	2500	0,4

It is known that the thermal conductivity of cross-linked polyethylene and other materials, generally speaking, depends on temperature. When such a dependence is taken into account, the thermal conductivity equation becomes nonlinear, and the time of its solution increases significantly. Studies showed that when assessing the thermal load of the cable in a stationary nominal mode, accounting for nonlinearity does not lead to a significantly noticeable increase in accuracy. However, it can be significant in solving other problems, for example, in short-term or emergency modes.

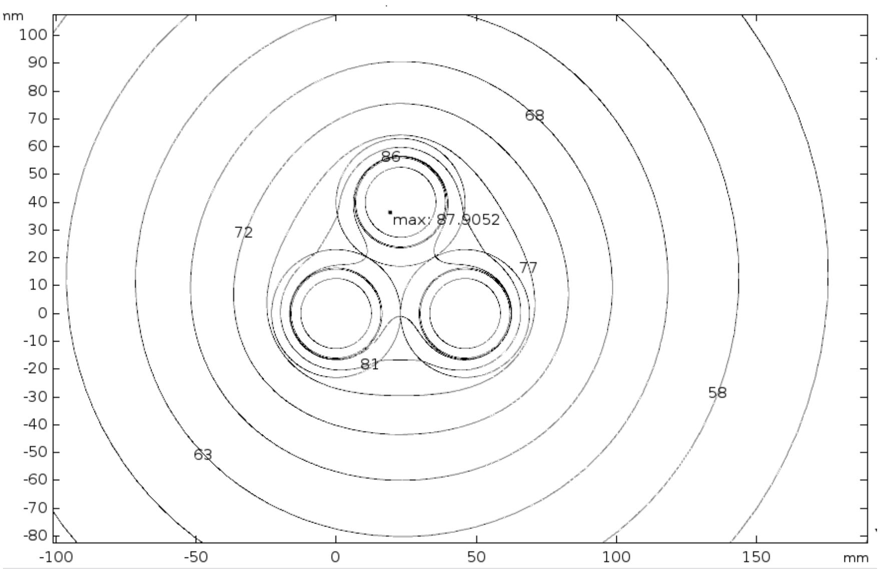
The source of the temperature field for this task is the distribution along the cross section of conductive cores, and screens of the specific density of joules and losses, which is calculated in the previous model. Both problems are solved on the same grid of finite elements. Data transfer from electromagnetic calculation in thermal occurs automatically.

The limiting condition for establishing a stable thermal regime is the condition of convection into the air from the surface of the earth. We take the ambient air temperature is 2 0 ºC, and the convection coefficient α = 1.5 W / K m^2. Other boundaries of the model, assigned to the right and left at a distance of approximately the depth of the cable, are described by the boundary condition of zero normal heat flux. Numerical experiments show that the distance of the conditional lateral boundaries of the calculated region over a greater distance does not affect the final temperature of the cables.

The result of the stationary heat calculationis the picture of the temperature field, shown in Fig. 3.6.



(a)



b)

Figure 3.6 – Picture of the thermal field of the network when laying parallel (a), and triangle (b).

The calculation shows that at ambient temperature T 0 = 2_0 ºC, the maximum core temperature when laying in parallel will be $T_{f=}$77.6 ºC, and when laid with a triangle T_f = 88 ºC. It is worth noting that the maximum allowable temperature of long-term operation of the selected cable is 90 ºC. You can also see that the placement of cables in the same plane shows a lower core temperature compared to the placement of cables in a triangle.

The temperature of the cables significantly depends on the temperature of the groot in which it is located. In turn, it will vary depending on the time of year. Table 4.4 shows the value of soil temperature at a depth of 0.8 m.

Table 3.4 – The value of soil temperature at a depth of 0.8 m

town	Temperature ºC			
	winter	Spring	summer	Autumn
Kiev	1,2	5,2	18,1	11
Odessa	4,4	7,2	16	14,6

Iteratively repeating the electromagnetic and thermal calculations, it is possible to select the current load so that the temperature of the core and the screen comes close to the permissible values for this type of cable. A computational procedure can be constructed by simply enumerating current values in a given temperature range.

When the ambient temperature drops, it becomes possible to load cable lines with current load. Such a need may arise during the emergency mode of operation of neighboring cable lines or during overload mode.

A graph of the dependence of the core temperature on the current for different values of soil temperature is shown in Fig. 3.7.

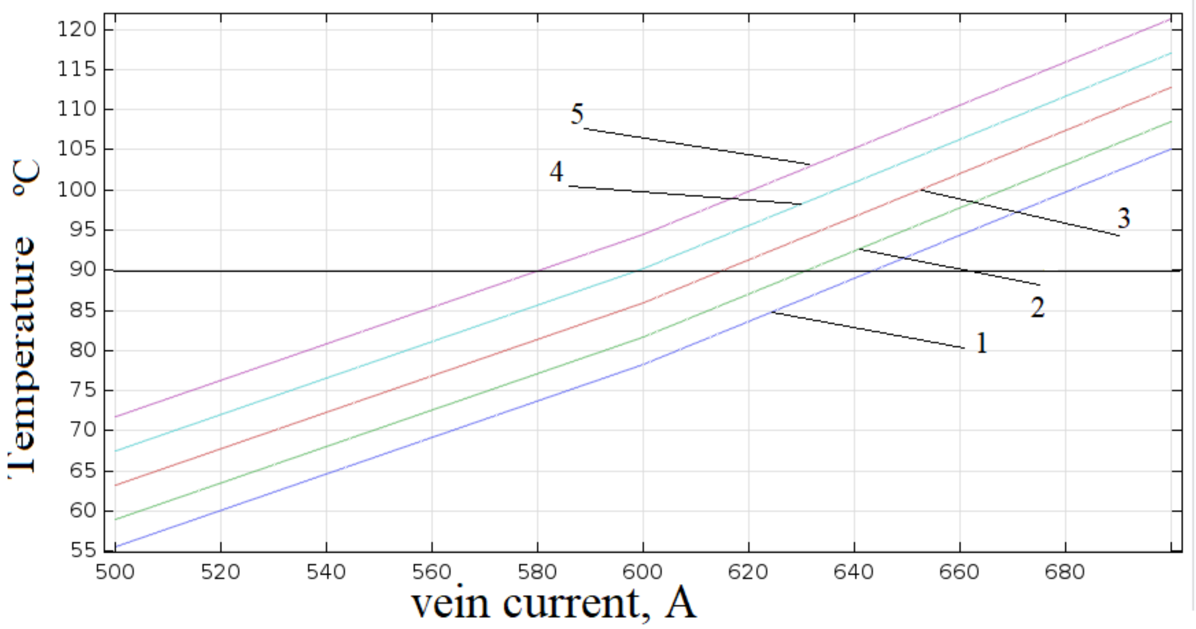


Figure 3.7 – Graph of the dependence of the core temperature on the current for different values of soil temperature: 1 – T g = 1 ° C, 2 – T g = 5 ° C, 3 – T_g= 10 ° C,

4 – T g=15 °C, 5 – T_g=20 °C,

The table shows that in winter the soil temperature for Kiev and Odessa does not exceed 4.5 ºC. This will increase the transmitted network capacity by 20%.

Conclusions to the section

1. A mathematical model is proposed that takes into account thermal and electrodynamic processes occurring in cable lines to determine current loads.
2. Taking into account additional heat dissipations in the metal screens of power cables allows you to calculate the optimal current load of the cable line for the safe operation of the electrical system.
3. Changes in environmental climatic conditions affect the temperature field in the cable line, which, in turn, allows you to increase or decrease the load capacity of power cables.

4 LABOUR OCCUPATIONAL SAFETY AND SECURITY IN EMERGENCY SITUATIONS

4.1 Electrical safety measures when working with electrical equipment

The current-carrying parts of the electrical installation should be inaccessible for accidental direct contact with them, and the exposed parts available for touch and foreign conductive parts should not be under voltage, which poses a danger of electric shock both in the normal mode of operation of the electrical installation and in case of damage to its insulation.

To protect against electric shock by direct touch, the following basic protection measures should be applied, separately or in combination:

– main insulation of current-carrying parts;

– fences and shells;

–Barriers;

– placement out of reach;

– ultra-low (low) voltage. For additional protection against direct touch in electrical installations

voltage up to 1 kV can be used protective displacement.

Direct touch protection is not required if nominal

The voltage does not exceed:

– 25 V AC or 60 V DC when used

BNN systems, as well as ZNNN systems in the case when electrical equipment operated only in dry rooms and is in the coverage area

systems of equalization of potentials, and the probability of human contact with parts that are energized, small;

– 6 V AC or 15 V DC in all other cases.

To protect against electric shock in case of indirect

touch should be applied, individually or in combination, such measures

Protection:

– protective grounding;

– automatic power off;

– equalization of potentials;

– equalization of potentials;

– double or reinforced insulation;

– protective electrical separation of circles;

– insulating (non-conductive) premises, zones, platforms;

– ultra-low (low) voltage.

Indirect touch protection should be performed in all cases if the voltage of the electrical installation exceeds 50 V AC and 120 V DC. In rooms with increased danger, in particularly dangerous and in external installations, protection against indirect touch may be required at lower voltages, for example: 25 V AC and 60 V DC or 12 V AC and 30 V DC in the presence of appropriate requirements for specific electrical installations or electrical receivers.

Protection measures against electric shock should be provided for in the electrical installation or part of it or applied to individual electrical receivers and can be implemented in the manufacture of electrical equipment, or during the installation of an electrical installation or in both cases. The use of two or more protection measures in an electrical installation should not have a mutual impact, which reduces the effectiveness of each of them.

For protective grounding of electrical installations, artificial and natural earthing devices can be used. First of all, you should use natural groundings. If, when using natural groundings, the resistance of grounding devices satisfies the requirements imposed on them, then the execution of artificial grounding devices in electrical installations with a voltage of up to 1 kV is not necessary. The use of natural grounding devices as elements of grounding devices should not lead to their damage when short-circuit currents flow through them or to disruption of the operation of the devices with which they are connected.

For grounding in electrical installations of various purposes and voltages, geographically convergent, it is necessary, as a rule, to use one common grounding device.

The grounding device used to ground electrical installations of the same or different purposes and voltages must meet all the requirements for grounding these electrical installations: protecting people from electric shock in case of damage to the insulation; conditions of network operating modes; protection of electrical equipment from overvoltage; electromagnetic compatibility of computer and microprocessor systems, relay protection systems and automated process control systems, which are used in these electrical installations, etc. - throughout the entire period of operation. First of all, the requirements for protective grounding must be met.

When performing an independent separate grounding device for functional grounding under the conditions of operation of information or other equipment sensitive to interference, special measures should be taken to protect against electric shock, which exclude simultaneous contact with parts that may be under a dangerous potential difference if the insulation is damaged.

To combine the grounding devices of different electrical installations into one common grounding device, natural and artificial grounding conductors can be used with at least two of them.

The required values of the touch voltages and resistances of grounding devices when locking currents to the ground and leakage currents from them should be ensured under the most adverse conditions at any time of the year.

In determining the resistance of grounding devices, artificial and natural grounding devices should be taken into account. In determining the resistivity of the earth for the calculated should take its seasonal value, which corresponds to the most unfavorable conditions. Grounding devices must be mechanically strong and dynamically resistant to ground locking currents and should not be thermally damaged during their leakage. The material and cross-section of the grounding devices must ensure their resistance to corrosion for the entire period of operation.

Electrical installations with a voltage of up to 1 kV of residential, public and industrial buildings, premises for keeping animals and outdoor installations should, as a rule, be powered from a source with a deaf-grounded neutral using the TN grounding system. Requirements for the choice of the TN-C, TN-S, TN-C-S system for specific electrical installations are submitted in the relevant chapters of the PUE.

TN-S grounding system – Zero working and zero protective conductors operate separately throughout the system. TN-C-S grounding system – the functions of the zero working and zero protective conductors are combined in one conductor in part of the network.

TN-C grounding system – the functions of the zero working and zero protective conductors are combined into one conductor throughout the network.

IT-grounding system – the power supply network of the IT system does not have a direct connection of the current-carrying parts with the ground, and the open conductive parts of the electrical installation are grounded.

L – phase conductor.

N – zero working conductor.

PE – zero protective conductor.

PEN – combined zero working and protective conductor.

To protect against electric shock by indirect contact, electrical installations with the TN system must automatically turn off the power in accordance with subsection 1.4. On overhead lines of networks with a TN system, the PEN conductor must be re-grounded in accordance with the requirements of subsection 1.6. It is also recommended to re-ground the PEN (PE) – the conductor at the input into the electrical installations of houses in accordance with subsection 1.6. In the middle of large and multi-storey buildings, a similar function is performed by equalizing the potentials by attaching a zero protective conductor to the main grounding bus. For protective automatic power off in case of indirect touch, it is necessary to use devices for protection against overcurrents or protective devices. RCD devices can be installed in the circles of individual electrical receivers, group circles and at the input to the electrical installation. In electrical installations with the TN-C system, protective disconnect devices should not be used.

In electrical installations with a TN-C-S system, the PE conductor must be connected to the PEN conductor from the power side with respect to the protective disconnect device.

The characteristics of the devices used for protective shutdown and the parameters of protective conductors in electrical installations with a voltage of up to 1 kV must be coordinated to ensure automatic power off within the normalized time sufficient to ensure the electrical safety of a person or animal, when the current-carrying part is closed to an open conductive part or protective conductor.

When applying a protective automatic power off for indirect touch protection, the main potential equalization system must be carried out, and, if necessary, an additional (local) potential equalization system in accordance with subsection 1.4.

4.2 The stability of the work of economic objects and factors affecting sustainability

The efficiency of the state's economy depends on the extent to which individual sectors of the economy are able to work sustainably not only in normal conditions, but also in the conditions of peaceful and wartime emergencies. Significant destruction, fires and losses among the population caused by the consequences of emergencies can cause a sharp reduction in the production of industrial and agricultural products, and therefore a decrease in the economic potential of the state. There is a need to take measures in advance to ensure the stable operation of industrial facilities in case of emergencies.

Knowing the possible emergencies characteristic of some terrain and production allows the differentiated and purposeful development and implementation of measures that can prevent or mitigate accidents, disasters and natural disasters.

The stability of the work of a business object is its ability in conditions of emergency to produce products in the planned volume and a certain nomenclature, and in case of weak and medium destruction or disruption of material supply, resume production on its own in a short time.

The stability of an industrial facility is influenced by the following factors:

– protection of workers and employees from damaging factors in emergencies;

– the ability of the engineering and technical complex of the object (buildings, structures, equipment and utilities and energy networks) to withstand the destructive effects of the damaging factors of accidents, disasters, natural disasters and modern weapons;

– reliability of supply of the facility with electricity, water, fuel, components and raw materials;

– preparedness of the facility for emergency rescue and restoration work;

– efficiency of production management and implementation of central nervous system measures in emergencies.

Increasing the stability of the object is achieved by carrying out a complex of engineering, technical, technological, organizational measures.

Engineering and technical measures include work that ensures the stability of industrial buildings and structures, equipment and utilities and energy systems.

Technological measures provide an increase in the stability of the facility by simplifying the technological process of production of final products and eliminating or limiting the development of accidents.

Organizational measures include the development of effective actions of the management, services and formations of the central nervous system, aimed at protecting production personnel, carrying out rescue and other emergency work and restoring production.

GENERAL CONCLUSIONS

On the basis of the research carried out in this paper, a mathematical model was developed, which makes it possible to calculate the magnetic, electrical and temperature characteristics of power cable lines during their design. The following results were obtained:

1. The main technical and operational features of power cable lines are considered. The physical processes that take place in them and the methods of their modeling are analyzed.
2. It is shown that for two-way grounding of screens, it is necessary to calculate the currents and power losses in the screens, which depend on the amount of current in the conductor, the area of the screen section, the diameter of the cable and the distance between the cables.
3. The calculation of the thermal field of the cable network for laying the cable in a triangle and in the plane was carried out. It is shown that the temperature of the cable conductors, with a constant current strength in the case of laying with a triangle, is higher by 10 ° C.
4. Changes in environmental climatic conditions affect the temperature field in the cable line, which, in turn, allows you to increase or decrease the load capacity of the power cables. Shown. that in the winter season, the transmitted network power can be increased by 20%.

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