

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NU “ZAPORIZHZHIA POLYTECHNIC”

METHODICAL INSTRUCTIONS

**for laboratory works in Theoretical Electrical Engineering
for the students of specialty 141 "Electricity, electrical engineering and
electromechanics" for full-time and part-time forms of education
Part 1**

2025

Methodical instruction for laboratory works in Theoretical Fundamentals of Electrical Engineering for the students of specialty 141 "Electricity, electrical engineering and electromechanics" for full-time and part-time forms of education Part 1 //Authors: Kozlov V.V., Nabokova O.V. - Zaporizhzhia: NU "ZAPORIZHZHIA POLYTECHNIC", 2025. - 46 p.

Authors: V.V. Kozlov, a docent.
O.V. Nabokova, a docent.

Responsible for issue: O.V. Nabokova, a docent.

Затверджено на засіданні
кафедри ЕАПУ
Протокол №7
від "6" лютого 2025 р.

Затверджено на засіданні науково-
методичної комісії
Електротехнічного факультету
Протокол №11
від "26" червня 2025 р.

THE CONTENT

INTRODUCTION	4
THE GENERAL INSTRUCTIONS	4
Laboratory work №1 THE RESEARCH OF THE WORK OF AN ELECTRIC ENERGY SOURCE IN DIFFERENT CONDITIONS	5
Laboratory work №2 THE RESEARCH OF THE RAMIFIED ELECTRICAL CIRCUIT WITH SEVERAL VOLTAGE SOURCES	14
Laboratory work №3 THE RESEARCH OF THE ACTIVE LINEAR TWO - POLE UNIT	21
Laboratory work №4 THE FEATURES OF THE WORK OF SINUSOIDAL ELECTRICAL CIRCUITS	26
Laboratory work №5 THE RESEARCH OF A SERIES RLC SINUSOIDAL CURRENT ELECTRICAL CIRCUIT	34
Laboratory work №6 THE RESEARCH OF THE RAMIFIED SINUSOIDAL CURRENT ELECTRICAL CIRCUIT	40
LITERATURE	45
Appendix A The standard of the title - page	46

INTRODUCTION

During the fulfillment of the laboratory works a student must master the bases of practical application of the direct and alternating current, rational assembling, measuring of some electric values, learn how to analyze electrical circuits while changing their parameters.

The accomplishment of the laboratory works helps to fasten and extend the learning of physical laws, understanding the theoretical part of the Electrical Engineering course, get experience in practical work with different electrical circuits.

There are not only short recommendations in these practical instructions but also determined the order of the accomplishment of laboratory works and a design of the report. The necessary theoretical explanations and the formulas for calculations are given here too.

THE GENERAL INSTRUCTIONS

For the successful performance of the laboratory works it is necessary to do the next actions before the beginning of the studies:

- read the description of the next laboratory work, learn theoretical course according to the Summary of Lectures, given methodical instructions and recommended literature, and prepare oral answers to the control questions;

- prepare the form of the report which must contain a title - page (the example is given in Appendix A), the object of the work, schemes and tables from the part "Spade - work". Drawings must be performed with the usage of drawing - set according to the demands of Ukraine State Standard.

While doing a laboratory work it is necessary:

- get teacher's permission for the accomplishment of the work;
- acquaint with the working place, measuring devices, power sources, electrical switchers, and so on;

- make an electrical circuit and ask for the lecturer to check it up. Carry out all necessary measurements and show the results to a lecturer. The laboratory work is considered to be done if the teacher checked the results of the measurements and made a note in the register;

- after finishing the work one must disjoint the electric circuit;
- get up the work and pass it to the lecturer.

Laboratory work №1

THE RESEARCH OF THE WORK OF AN ELECTRIC ENERGY SOURCE IN DIFFERENT CONDITIONS

The object of the work is to acquaint with the main elements of the electrical circuit, experimentally get an external characteristic of the electromotive force (EMF) source, learn to analyze the work of the energy source with the help of the external characteristic, and study the energy relations in the direct current circuit under different rates.

1.1 Short theoretical information

1.1.1 An idea of the substitution scheme of an electric device

Electric circuit consists of active and passive elements which are connected with wires. These elements are differed from one another in the appointment, form, size and other signs. With an electrical point of view they have the characteristics which are described with the limited quantities of parameters.

For the calculations electric circuits are imagined in the form of equivalent electrical scheme of replacement.

Every real element or a device in these schemes is imagined with one or several ideal elements or mathematical models. Each ideal element replaces some physical effect or a property of a real device.

There are only three elements in the schemes of replacement of direct current circuits:

- an ideal source of electromotive force (EMF) (fig.1.1, a) represents the ability of a real object to create the potential difference across its outer terminals and support a current in a closed electrical circuit with the help of the forces of non-electrical character. The voltage across the terminals of the ideal source does not depend on the strength of a flowing current, and corresponds to the EMF of this source. EMF E is measured in volts (V);

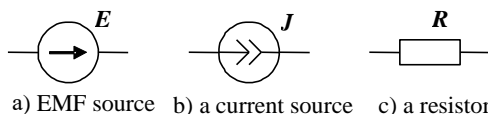


Figure 1.1 – Ideal elements of the schemes of replacement

- an ideal current source J (fig.1.1, b) represents the ability of a real object to create the potential difference across its outer terminals and support a current in a closed electrical circuit with the help of the forces of non-electrical character. The current through an ideal current source does not depend on the voltage across the terminals, and corresponds to the current strength of this source. A current J is measured in amperes (A);

- an ideal resistive element R (fig.1.1, c) represents the ability of a real object to change an electrical energy into other kinds of energy finally, for example, - into the heat. The resistance R is measured in Ohm (Ω).

1.1.2 The substitution schemes of the real energy sources

For the real sources of direct current (d.c.) electrical energy it is necessary to take into account two processes:

- the ability to create the difference of potentials across input terminals and provoke a current in the closed electrical circuit;
- internal heat efficiency when a current flows through a source.

That is why there are two ideal elements of a real energy source in the schemes of substitution.

There are two substitution schemes of a real energy source:

- a series connection of the ideal voltage source and a resistance (fig.1.2,a);
- a parallel connection of the ideal voltage source and a resistance (fig.1.2,b). A resistive element is called an internal resistance.

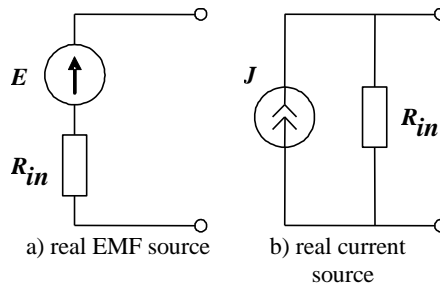


Figure1.2 – The substitution schemes of a real energy sources

There is a following equation for parameters of the substitution scheme

$$E = JR_{in}. \quad (1.1)$$

1.1.3 An external characteristic of an energy source

An external characteristic of an energy source is a dependence of a voltage drop (on the external terms) on a current flowing through a source. The external characteristic is a volt-ampere characteristic (VAC) of a source. An energy source with a rectilinear VAC is linear (fig.1.3).

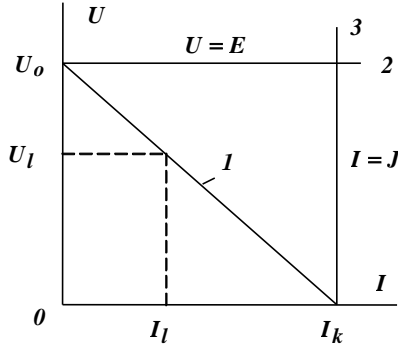


Figure 1.3 - The external characteristics of energy sources

VAC of the real source is a sloping straight line passing through two extreme points: when $I = 0$ we have an open circuit voltage (a voltage of a idling voltage) U_0 ; when $U = 0$ we have a short circuit current I_k (a straight line 1 in fig. 1.3). Its equation is

$$U = U_0 - IR_{in}, \quad (1.2)$$

where $R_{in} = \frac{U_0}{I_k}$.

On this basis one can compose an electrical substitution scheme with a series connection of an ideal source and an internal resistance according to the second Kirchoff's Law (fig. 1.4a). Such a scheme may be described by an equation

$$U = E - IR_{in}. \quad (1.3)$$

To turn to the substitution scheme with a parallel connection of an ideal source and an internal resistance (fig. 1.4b) we rewrite equation (1.2) in the form

$$I = I_k - \frac{U}{R_{in}} = I_k - UG_{in}, \quad (1.4)$$

where $G_{in} = \frac{I_k}{U_0}$ - an internal electrical conductance of a source, Ω^{-1} .

The condition of the substitution scheme can be described by an equation

$$I = J - \frac{U}{R_{in}} = J - UG_{in}. \quad (1.5)$$

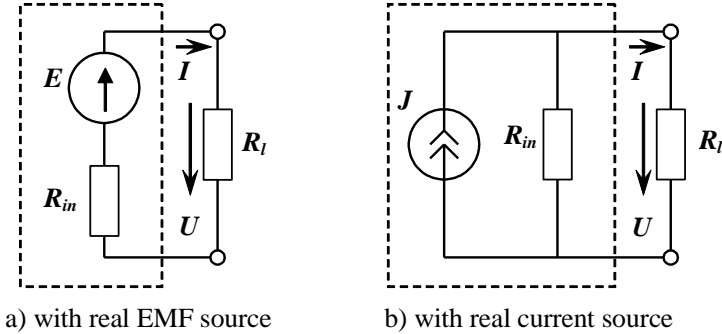


Figure 1.4 – The substitution schemes of energy source and a consumer

The VAC of the ideal source EMF is a horizontal straight line $U = E$ (a straight line 2 in fig. 1.3), and the VAC of the ideal current source is a vertical straight line $I = J$ (a straight line 3 in fig. 1.3). The internal resistance of the ideal source EMF is equal zero $R_{in} = 0$, the internal resistance of the ideal current source is equal infinity $R_{in} = \infty$.

1.1.4 The main calculation equations in a non-ramified contour of direct current

The main calculation equations in a source - consumer system for a non-ramified contour (fig.1.4a):

- the current (according to Ohm's Law) for series connection of circuit elements (an internal resistance R_{in} and a load resistance R_l)

$$I = \frac{E}{R_{in} + R_l}; \quad (1.6)$$

- the voltage through input terms of a source and through a load by the second Kirchhoff's Law

$$U = E - R_{in}I = R_lI; \quad (1.7)$$

- a voltage drop in the source

$$\Delta U = R_{in}I ; \quad (1.8)$$

- the power of a source characterizing a velocity of conversion of non-electrical energy into electrical one

$$P_s = EI = \frac{E^2}{R_{in} + R_l} ; \quad (1.9)$$

- the power being given up to a load characterizes a velocity of conversion of electrical energy into other kinds of energy (mechanical, light, heat energy, etc.)

$$P_l = UI = R_l I^2 = \frac{R_l E^2}{(R_{in} + R_l)^2} ; \quad (1.10)$$

- power losses in a source being spent for its heating

$$\Delta P = P_s - P_l = R_{in} I^2 ; \quad (1.11)$$

- an efficiency (a coefficient of useful action) of a source

$$\eta = \frac{P_l}{P_s} = \frac{R_l}{R_{in} + R_l} . \quad (1.12)$$

1.1.5 The working rates of an energy source

When we have a variable load one can appraise the work of the source (fig.1.4a) with the help of its characteristics. Such characteristics are got by changing a load resistance value $0 \leq R_l < \infty$. It is accepted to take a current as a argument and consider characteristics $U(I)$, $P_l(I)$, $P_s(I)$, $\eta(I)$.

Any electrical circuit depending on a load resistance may be in different rates. The main ones are: an idling rate, a short circuit rate, a nominal rate and the rate of coordinated load.

We have an **idling (open circuit) rate** when the load is out ($R_l = \infty$). There is no a current $I = 0$ here. The voltage across the terminals of an energy source is equal to $U = U_o = E$ (an idling voltage). One can measure EMF of the source in this rate. $P_l = 0$, $P_s = 0$, $\eta \rightarrow 1$.

We have an **short circuit** rate when the load resistance is zero ($R_l = 0$). A circuit current will be maximum $I = I_k = E/R_{in}$ (a short circuit current). The voltage on the terms of the energy source $U = 0$. The energy of the source transforms into heat $P_s = R_{in}I_k^2 = E^2/R_{in}$. There may be the overheating and the damage of the source. There is $P_l = 0$, $\eta = 0$ in this rate.

The rate of **concerted load** is the conditions when we can get a maximum power P_s from the source.

The condition of **the coordinated rate** is $R_l = R_{in}$. For this rate $I = 0.5I_k$, $U = 0.5E$, $P_s = E^2/2R_{in}$, $P_l = E^2/4R_{in}$, $\eta = 0.5$.

A **nominal condition** is the rate of the most effective work when there are values of current and voltage determined by a designer. By the nominal current, voltage and power economical production and consumption of the electric power is provided, and the service term designated by a plant-maker is guaranteed. The point of the nominal rate has no a fixed position and depends on the requirements showed to a source. If we need a high efficiency the point of the nominal rate is located closer to the point of the idling rate. If it's necessary to transmit a maximum power from a source to a load, the nominal rate coincides with the rate of concerted load. If we need limit values of the current, the point of the nominal rate is near the point of a short circuit.

The characteristics of electric power source are represented in fig.1.5.

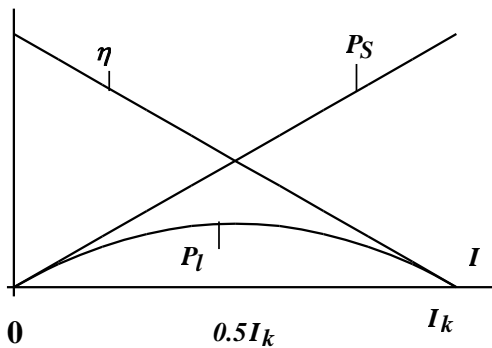


Figure 1.5 - The characteristics of electric power source

1.2 The order of the working out of the spade-work

1.2.1 One must study theoretical material and prepare oral answers to control questions.

1.2.2 Prepare the form of the report which must consist of the purpose of work, a scheme of an electrical circuit (fig. 1.6), and table 1.1. An example of a title page is given in appendix A.

1.3 The description of laboratory plant

To carry out the laboratory work we use:

- a direct current (d.c.) source $E1$ which is switched on with a tumbler S ;

- the variable resistor $R8$ and the invariable resistor $R6$;

- a voltmeter of magneto-electrical system $V1$;

- a milliamperemeter of magneto-electrical system $A1$.

1.4 The order of carrying out of the work

1.4.1 The experiment of an idling rate

Conditionally we consider the internal resistance of the source of source of electro motive force (EMF) is equal to the resistance of resistor $R6$. One should make an electrical circuit (see fig. 1.6a).

Attention! One can turn on the stand only after the teacher check up the scheme and find it to be correct.

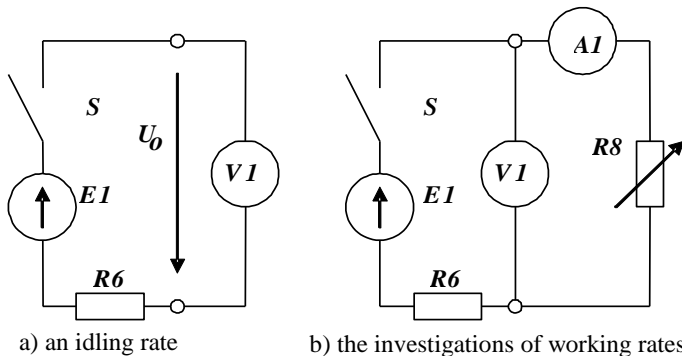


Figure 1.6 - The schemes of electrical circuits

Switch on a tumbler S of the source of constant EMF E_1 and measure an open circuit voltage U_o . The results one must enter in the table 1.1. Turn out tumbler S .

Table 1.1 - Experimental results

Rates		An idling rate	Working rates				A short circuit rate
Measured	№ of a test	1	2	3	4	5	6
	U , V						
	I , mA						
Calculated	P_s , Wt						
	P_l , Wt						
	η , relative units						

1.4.2 An external characteristic of the EMF source and a short circuit experiment

Compose the corresponding electric circuit (see fig. 1.66). Place a handhold of the resistor R_8 in the extreme left-hand position. After a teacher check up a scheme one can turn on the tumbler S .

Turn round the handhold of the resistor R_8 to change its resistance and carry out 3 or 4 experiments. Then turn round the handhold of the resistor R_8 in the extreme right-hand position (a short circuit test). Each time measured currents and voltages are placed into table 1.1.

Turn off the tumbler S . The measured results must be shown to a teacher. Then the scheme may be stripped.

1.5 The processing of measured results and design of the report

1.5.1 By the results of idling and short circuit experiments one must calculate an internal resistance of the source (1.2).

1.5.2 Construct the diagrams of external characteristics for a real and an ideal EMF source.

1.5.3 Write down an external characteristic of the real EMF source.

1.5.4 Calculate the power of the source, the capacity of the consumer and the efficiency according to measured values. The results of calculations are brought in table 1.1.

1.5.5 Calculate a load resistance and a current for coordinated rate.

1.5.6 Construct the graphs of dependences $P_S(I)$, $P_l(I)$, $\eta(I)$ in one scale.

1.5.7 Make conclusions on the work.

1.6 Control questions

1.6.1 Give the determination of parameters R and E .

1.6.2 Give the determination of an electrical circuit.

1.6.3 What elements are called ideal?

1.6.4 What is the scheme of replacement?

1.6.5 Draw equivalent scheme of replacement for a current and a voltage source.

1.6.6 Explain how the law of energy conservation is carried out in direct current electrical circuit.

1.6.7 How calculate the power of the source and the consumer?

1.6.8 Give the characteristic of rates of electro-motive force source.

1.6.9 Prove that the power of the consumer is maximum at a coordinated rate.

1.6.10 Give the definition of the external characteristic of the electric energy source.

1.6.11 Write down the equation of the external characteristic for EMF source.

1.6.12 Give a brief description of all four operation modes of electrical circuit.

Laboratory work №2

THE RESEARCH OF THE RAMIFIED ELECTRICAL CIRCUIT WITH SEVERAL VOLTAGE SOURCES

The purpose of operation is to study the application of Kirchhoff's Laws to the checkout of observed data, acquire a procedure of the analysis of a condition of the electric circuit with the help of a potential diagram.

2.1 Short theoretical data

2.1.1 The basic definitions

The electrical branch is a part of an electric circuit along which a current at any moment has the same value. The branch can contain one or several elements. The electrical unit is a point where branches are joined. The point where three or more branches are connected is called a junction. The mesh (a contour) is a closed path along the electric circuit on which any element is not iterated.

The positive direction of a current is the direction of the moving of positive charges. At the beginning of calculation one must set any positive directions of current (or voltage) at will. The real directions of currents is defined with signs got in the result of calculations. When a current is negative it means that its real direction will be opposite to earlier given.

The positive direction of EMF source is taken from a terminal "-" up to a terminal "+" (i.e. coincides with the direction of action of forces of not electrical origin). The arrow of EMF specifies a terminal with a more potential. The positive current direction in a source of the electric power coincides with the direction of EMF. The positive voltage direction on EMF source is opposite to the direction of EMF, and the positive directions of a current and a voltage coincide on resistors.

2.1.2 Kirchhoff's Laws for direct current circuits

The first Kirchhoff's Law: the algebraic sum of branch currents in a node of the electric circuit is equal to zero.

$$\sum_{j=1}^n I_j = 0, \quad (2.1)$$

where I_j is the current of branch "j".

The currents guided to a junction are taken positive, and currents guided from a junction are taken negative.

So, for unit in fig. 2.1a we have $I_1 - I_2 + I_3 - I_4 = 0$

The second Kirchoff's Law: the algebraic sum of EMFs in any closed mesh is equal to the algebraic sum of voltage drops round the mesh:

$$\sum_{j=1}^n E_j = \sum_{j=1}^n R_j I_j, \quad (2.2)$$

where E_j , R_j are correspondently EMF and a resistance of branch "j."

Drawing up the equations by the second Kirchoff's law the direction of summation round the mesh is taken at will. EMF and voltage drops are accepted positive if directions of currents and EMFs coincide with the direction of summation. Otherwise they are accepted negative. For example, for the mesh in fig. 2.1b (the direction of summation is clockwise) we have $E_1 - E_3 = R_1 I_1 - R_2 I_2 - R_3 I_3 + R_4 I_4$.

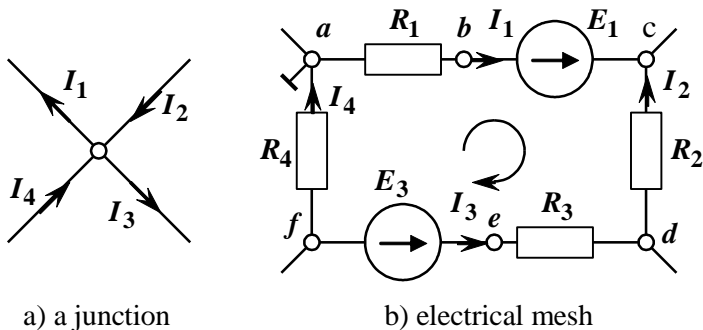


Figure 2.1- The parts of electrical circuits for Kirchoff's laws record

The solution of simultaneous equations by Kirchoff's laws is the universal method for evaluation of currents in branches of a ramified electrical circuit with several energy sources. The total quantity of equations corresponds to the amount of unknowns currents, i.e. to the quantities of branches to which current sources do not enter. By the first law the quantity of independent equations on a unity less than the quantity of junctions in the circuit. The rest of equations are made by the second Kirchoff's law for contours using all the branches of the circuit without current sources.

2.1.3 Potential diagram

The potential of one arbitrary point of an electrical circuit it is possible to attach to any meaning except zero. In Electrical Engineering the earth potential is accepted for a zero potential. Therefore representation to some point of a zero potential is equivalent to its grounding (unification with the Earth). The potential diagram is constructed in a rectangular coordinate system. For a direct current circuit meanings of resistances are disposed on an abscissa axis of sections (each following from the end of a previous one), and potentials of points are placed on an axis of ordinate in an arbitrary scale. The initial point accepted for a zero potential is placed in origin of coordinates. The points which answer potentials are connected with a broken line. The potential diagram built for any closed circuit is a pictorial illustration of the second Kirchhoff's Law.

We shall build, for example, a potential diagram for the mesh which is represented in figure 2.1b. We accept that potential of a point "a" is equal to zero. Building it we consider that elected directions of currents coincide with the real. The potentials of points one can calculate according to the following formulas:

$$\begin{aligned}
 \varphi_a &= 0 ; \\
 \varphi_b &= \varphi_a - R_1 I_1 ; \\
 \varphi_c &= \varphi_b + E_1 ; \\
 \varphi_d &= \varphi_c + R_2 I_2 ; \\
 \varphi_e &= \varphi_d + R_3 I_3 ; \\
 \varphi_f &= \varphi_e - E_3 ; \\
 \varphi_a &= \varphi_f - R_4 I_4 = 0 .
 \end{aligned}
 \tag{2.3}$$

The calculation of the last potential is verifying.

The potential diagram for this case is given in fig. 2.2.

In potential diagram it is possible to determine a voltage between any two points as a projection between these points on an axis of ordinate. The tangent to a slope angle of a piece of a broken line which corresponds to a section with resistance, is proportional to a current through this section. It is

easy to prove if to consider, for example, a right-angled triangle with sides R_1 and U_{ab}

$$\operatorname{tg}\alpha = \frac{m_U U_{cd}}{m_R R_2} = I_2 \frac{m_U}{m_R}, \quad (2.4)$$

where m_U , m_R - are the scales for a voltage and a current.

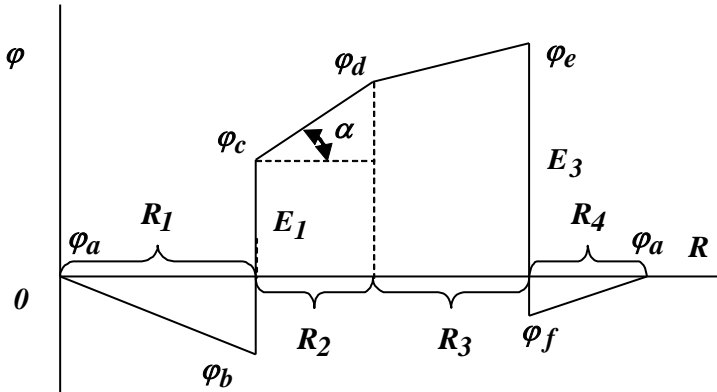


Figure 2.2 – The potential diagram

2.1.4 An energy balance

The heat is given in active resistances when currents flow through them. On the basis of conservation energy law the quantity of such heat should be equal to the energy given by an energy sources to a circuit. If the actual direction of a current which flows through EMF source coincides with the direction of a source the last gives energy equaled to EI to the circuit for a unit of time. If the actual direction of a current is opposite to direction of EMF the source consumes energy from the circuit (for example, when the accumulator is charged).

When there are current sources in a circuit drawing up of an energy balance it is necessary to take into account the energy which is given into a circuit by current sources. Let a current source is

directed from unit b to unit a . Then in a unit of time the current source gives into a circuit the energy which is equal to $JU_{ab} = JU_J$.

The general view of the energy balance equation

$$\sum_{k=1}^n I_k^2 R_k = \sum_{k=1}^n E_k I_k + \sum_{k=1}^n J_k U_{J_k}, \quad (2.5)$$

2.2 The order of carrying out of a spadework

2.2.1 Study a theoretical material and prepare oral answers to control questions.

2.2.2 Prepare a blank form of a report which must contain the purpose of the work, the electric circuit (fig.2.4) and tables 2.1 both 2.3 and the calculation by item 2.2.3.

2.2.3 Make calculation for the circuit (fig.2.3) with the help of Kirchhoff's laws if the next data are given:

$$E_1 = 20 + 5 \cdot b \text{ V},$$

$$E_2 = 5 + 10 \cdot b \text{ V},$$

$$R_1 = 350 + 10n \text{ } \Omega,$$

$$R_2 = 1500 + 100n \text{ } \Omega,$$

$$R_3 = 1500 + 200n \text{ } \Omega,$$

$$R_4 = 50 + 5n \text{ } \Omega,$$

where n is a number of a team which is set by a lecturer, a , b , c are the 1st, 2nd and 3rd digits of the group number, respectively.

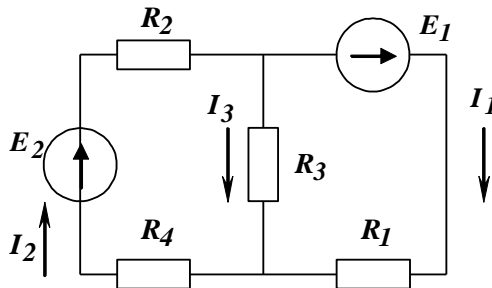


Figure 2.3 The circuit for calculation

2.3 The description of the laboratory plant

We use here the following settings:

- two direct current voltage sources E_1 and E_2 ;
- active resistors R_1 , R_2 , R_5 , R_9 ;
- a voltmeter of magneto-electrical system V_1 ;
- milliamperimeters of magneto-electrical system A_1 , A_2 .

2.4 The order of conducting of a spadework

2.4.1 Make electrical circuit (fig. 2.4). Invite a lecturer to check up it.

2.4.2 Switch on tumblers of EMF sources E_1 and E_2 .

Measure branch currents I_1 , I_2 , voltage drops across resistors U_1 , U_4 , U_5 , U_9 , EMFs of voltage sources E_1 , E_2 (we consider EMF sources are ideal). The results of measurements must be brought into table 2.1.

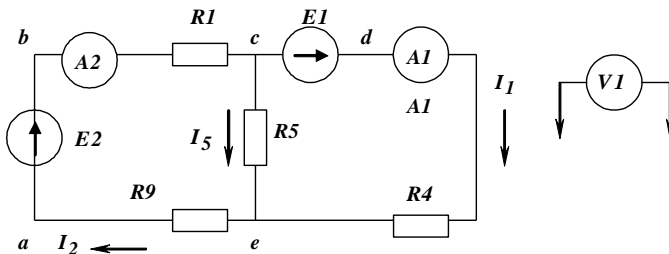


Figure 2.4 The scheme of the electrical circuit

Table2.1 - Experimental results

E_1, V	E_2, V	I_1, mA	I_2, mA	I_5, mA	U_1, V	U_4, V	U_5, V	U_9, V

2.4.2 Measure potentials round the circuit, (fig. 2.4). Each team must choose a conditionally grounded node according to table 2.2.

Table 2.2 - The nodes to be grounded conditionally

№ of a team	1	2	3	4	5	6
Marked nodes	a	b	c	d	e	a

To measure potentials round the circuit, one must connect a negative terminal of a voltmeter V_1 to a grounded junction, and a positive terminal must be joined to others junction in turn. If a voltmeter needle swung to the left it is necessary to change its polarity. A potential value is negative in this case. The results are taken into a table 2.3.

Turn off voltage sources. The measured results must be shown to a lecturer. The electrical circuit is disconnected.

Table 2.3 - Nodal potentials of the circuit

Nodes	a	b	c	d	e
Nodal potentials, V					

2.5 The processing measurement results and reporting

2.5.1 Calculate current I_5 by KCL

$$I_5 = I_1 - I_2 .$$

2.5.2 Make up an equation by KVL for an external contour of the circuit (fig. 2.4) and check up the results of experiments.

2.5.3 Calculate active resistances R_1 , R_4 , R_5 , R_9 by Ohm's Law

$$R_k = \frac{U_k}{I_k}$$

2.5.4 construct a potential diagram for an external mesh.

2.5.5 Check up the results of experiments by making up the balance of powers. Make the conclusion to the work done.

2.6 Control questions

2.6.1 Give the determination of a junction, a branch, a contour.

2.6.2 Give the determination of Kirchhoff's current and voltage laws.

2.6.3 Write down equations by KCL and KVL for any circuit.

2.6.4 What is a potential diagram?

2.6.5 How can we determine the voltage between two nodes with the help of potential diagram?

2.6.6 How can one make a scheme of a circuit by a potential diagram?

2.6.7 How can we determine a current flowing through a part of the circuit by a potential diagram?

2.6.8 What is the difference between the measurements of a potential and a voltage?

2.6.9 What is called a potential and a voltage?

2.6.10 Formulate the principle of the balance of powers. How can one use it for checking up of calculation?

Laboratory work №3

THE RESEARCH OF THE ACTIVE LINEAR TWO-POLE UNIT

The purpose of operation is to acquaint with parameters and characteristics of a two-pole unit, and learn to get them with the help of experiments.

3.1 Short theoretical data

In any scheme of an electrical circuit always it is possible to allocate mentally one branch, and the rest part of a circuit, irrespective of its complexity, may be conventionally represented in the form of some rectangle. Concerning the allocated branch all other part of the circuit represents a two-pole unit.

Two-pole unit is the name of any part of an electrical circuit which has two terminals. Two-pole unit is depicted as a rectangle in the figure.

If two-pole unit contains energy sources which do not compensate each other such a two-pole unit is called active and a rectangle is marked with letter *A* (fig. 3.1, a). The active two-pole unit is characterized by three interdependent parameters: an idling voltage U_o (or a voltage of open circuit rate), a short-circuit current I_k and an input resistance R_{in} .

$$U_o = I_k R_{in}. \quad (3.1)$$

The active two-pole unit can be exchanged either with the equivalent EMF source, the electromotive force of which is equal to an idling voltage on the terminals of a two-pole unit, and the internal resistance is equal to the input resistance of a two-pole unit, or with the current source whose current is equal to a short-circuit current of a two-pole unit, and the internal resistance is equal to an input resistance of it.

Input resistance of a two-pole unit concerning terminals is found by eliminating all energy sources from the calculated circuit (branches with ideal current sources are torn, and ideal EMF sources in branches are isolated). A short-circuit current and an idling voltage are defined by any calculated method. The parameters of a two-pole unit can be determined with the help of two experiments: an open circuit rate (a voltmeter is connected to the terminals of a two-pole unit) and a short circuit rate (the

ammeter is connected to the same terminals). The input resistance in this case is defined from the equation (3.1).

If there are no energy sources in a two-pole unit or they compensate each other such a two-pole unit is called passive, and we put letter **P** in a rectangle (fig. 3.1, b). A passive two-pole unit is characterized only by one parameter. It is an internal resistance R_{in} . An idling voltage U_0 and a short-circuit current I_k of such a two-pole unit are equal to zero.

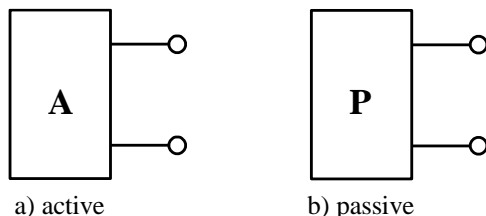


Figure 3.1 - Electrical schemes of active and passive two-pole units

3.2 The order of the working out of the spadework

3.2.1 One must study theoretical material and prepare oral answers to control questions.

3.2.2 Prepare the form of the report which must consist of the purpose of work, a scheme of an electrical circuit (fig. 3.3), and table 3.1 and the calculation according p.3.2.3.

3.2.3 Calculate the idling voltage U_0 , the short circuit current I_k and input resistance R_{in} of the two-pole unit which one can see in fig.3.2, when the following data are given:

$$\begin{aligned}
 E &= 10 \text{ V}, \\
 R_1 &= 10 + n \ \Omega, \\
 R_2 &= 25 + 2n \ \Omega, \\
 R_3 &= 20 - 2n \ \Omega, \\
 R_4 &= 20 + 4n \ \Omega, \\
 R_5 &= 20 - 3n \ \Omega,
 \end{aligned}$$

where n is a number of a team which is set by a lecturer.

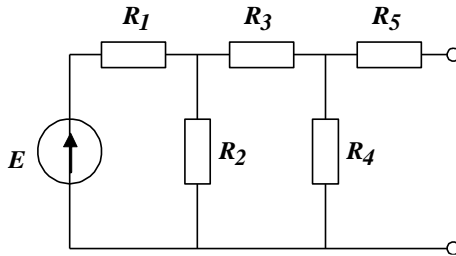


Figure 3.2 - The electric circuit for calculations

This preparatory work consists of three separate calculations.

1. For the circuit shown in Fig. 3.2 one should calculate the idling voltage U_o between open right terminals using mesh-current method for two loops or the method of circuit convolution (method of equivalent transformations) in order to simplify the circuit.

2. For the same circuit determine the input resistance R_{in} of this two-pole unit relatively of open terminals.

3. Connect two open terminals and you will make short circuit between them. Then short circuit current I_k is equal to the current flowing through resistance R_5 . This current is easier calculated by the mesh-current method for a circuit with three loops.

Check up the calculation by substituting three found values into equation (3.1).

3.3 The description of laboratory installation

For fulfilment of laboratory work on the stand we use: a direct current EMF source $E1$; active resistors $R1$, $R2$, $R3$, $R4$, $R5$, $R9$; the variable resistor $R8$; the voltmeter of magneto-electrical system $V1$; milliammeters of magneto-electrical system $A1$, $A2$.

3.4 The order of carrying out of the work

3.4.1 Make up an electric circuit (fig. 3.3). Invite a lecturer for checking up of the electric circuit.

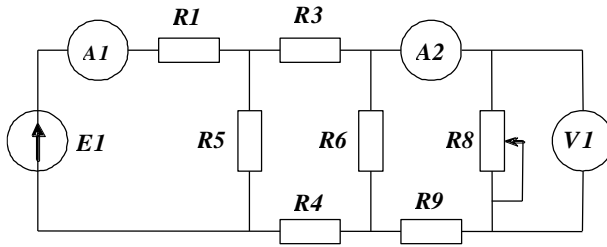


Figure 3.3 - The electric circuit for investigation

3.4.2 An open circuit experiment. Disconnect the load resistor $R8$. Turn on a switch of EMF source $E1$. Measure branch currents I_1 , I_2 , an idling voltage of a two-pole unit. The results of measurements are brought in table 3.1. Switch off the switch of EMF source $E1$.

Table 3.1 - Experimental results

Parameter	An open circuit experiment	1	2	3	4	A short circuit experiment
Voltage, V						
Current I_1 , mA						
Current I_2 , mA						
The load resistance, Ω						
The power of a source, Wt						
The power of a load, Wt						
Efficiency, relative units						

3.4.3. Connect the load resistor. Turn on a switch of EMF source. Changing the load resistance by rotating a handle of the variable resistor $R8$, measure branch currents I_1 , I_2 , voltage drops on the load resistor. The results of measurements are brought in table 3.1. Switch off the switch of EMF source. Experimental results must be shown to a lecturer. The electric circuit should be disassembled.

3.5 The processing measurement results and reporting

3.5.1 Define the input resistance of the two-pole unit

$$R_{in} = \frac{U_o}{I_k} \cdot 10^{-3}, \Omega.$$

3.5.2 Calculate a load resistance by Ohm's law for each rate

$$R_l = \frac{U_8}{I_2} \cdot 10^{-3}, \Omega$$

3.5.3 Define powers of equivalent EMF source and a load, and the efficiency of the equivalent source

$$P_s = U_o I_2 \cdot 10^3, \text{ Wt};$$

$$P_l = U_8 I_2 \cdot 10^3, \text{ Wt};$$

$$\eta = \frac{P_l}{P_s}$$

Record the results into tab. 3.1.

3.5.4 Construct the schedule of dependence $I_2 = f(I_1)$, make conclusions about linearity of the two-pole unit.

3.5.5 Construct schedules of dependences $P_s = f(R_l)$, $P_l = f(R_l)$, $\eta = f(R_l)$.

3.6 Control questions

3.6.1 Give the definition of a linear two-pole unit.

3.6.2 How can we define the input resistance of a two-pole unit experimentally?

3.6.3 At what load resistance is the maximal power allocated?

3.6.4 Explain the difference between active and passive two-pole units.

3.6.5 How can we define the parameters of the two-pole unit?

3.6.7. How can we get open circuit rate in the circuit?

3.6.8. How can we get short circuit rate in the circuit?

Laboratory work №4

THE FEATURES OF THE WORK OF SINUSOIDAL ELECTRICAL CIRCUITS

The purpose of the work is to acquaint with the features of the work of sinusoidal current (s.c.) electrical circuits and get practical skills in analysis of such circuits with the help of vector diagrams, and learn some ways for the definition of an angle of phase shift.

4.1 Short theoretical data

4.1.1 The features of electromagnetic processes in sinusoidal current electric circuits

In electric circuits of sinusoidal current electrical values of EMF, a voltage and a current are sinusoidal functions of time

$$\begin{aligned} e &= E_m \sin(\omega t + \psi_e); \\ u &= U_m \sin(\omega t + \psi_u); \\ i &= I_m \sin(\omega t + \psi_i). \end{aligned} \quad (4.1)$$

where E_m , U_m , I_m - peak values;

ψ_e , ψ_m , ψ_i - initial phases;

ω - an angular (circular) frequency.

The basic displays of electromagnetic field in receivers of electric energy are:

- electric current heats up a conductor;
- alternating magnetic circuit rouses a self-induction EMF;
- alternating magnetic field inducts an electric current of displacement in a dielectric.

These physical phenomena in the circuits of displacement are displayed by ideal passive elements such as a resistor, an inductor and a capacitor. Ohm's law establishes dependence of a voltage on a current for each of these elements accordingly

$$\begin{aligned} u_R &= Ri = RI_m \sin(\omega t + \psi_i); \\ u_L &= L \frac{di}{dt} = L\omega I_m \sin(\omega t + \psi_i + \frac{\pi}{2}); \\ u_C &= \frac{1}{C} \int idt = \frac{1}{C\omega} I_m \sin(\omega t + \psi_i - \frac{\pi}{2}). \end{aligned} \quad (4.2)$$

where L is an inductance, H;

C is a capacitance, F.

Thus inductive voltage leads a current on a phase by a quarter of a period, and capacitor voltage lags behind a current by a quarter of a period. In resistive element a current and a voltage coincide on a phase. By analogy to active resistance R the values are called reactive resistances or reactances

$$\begin{aligned} X_L &= \omega L; \\ X_C &= \frac{1}{\omega C}. \end{aligned} \quad (4.3)$$

Making calculations we use effective values of sinusoidal quantities

$$E = \frac{E_m}{\sqrt{2}}; U = \frac{U_m}{\sqrt{2}}; I = \frac{I_m}{\sqrt{2}} \quad (4.4)$$

It is also necessary to take into account initial phases of effective values. It is convenient to do with the help of so-called complexes of amplitudes (of effective values)

$$\begin{aligned} \underline{E}_m &= E_m e^{j\psi_e}; \underline{U}_m = U_m e^{j\psi_u}; \underline{I}_m = I_m e^{j\psi_i}; \\ \text{или } \underline{E} &= E e^{j\psi_e}; \underline{U} = U e^{j\psi_u}; \underline{I} = I e^{j\psi_i}. \end{aligned} \quad (4.5)$$

The concept of complex resistance (impedance) follows from here

$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{U}{I} e^{j(\psi_u - \psi_i)} = Z e^{j\varphi} = R + j(X_L - X_C), \quad (4.6)$$

where φ is a phase shift between a voltage and a current on a section where we define impedance Z .

4.1.2 Vector diagrams

EMF, a voltage and a current are scalar sizes, but for their presentation and convenience it is possible to represent them as radiuses - vectors. The length of such a vector is equal to the amplitude value, and an angle concerning a horizontal axis equals to an initial phase. Positive angles are placed counter-clockwise. The set of vectors which represent currents and voltages of some electric circuit name is called a vector diagram.

Phase shift between a current and a voltage on a circuit section is set from a current vector to a voltage vector on a diagram.

Vector diagrams for separate elements of sinusoidal current electric circuits are represented in fig. 4.1.

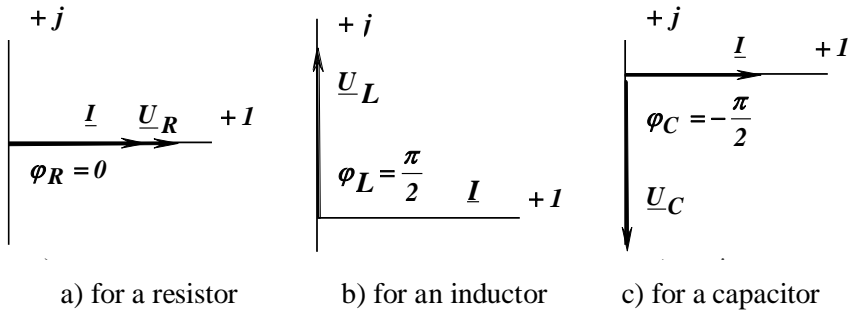


Figure 4.1 - Vector diagrams for separate elements

4.1.3 The series connection of two ideal elements

According to Ohm's law a complex current for the series connection of two ideal active elements

$$\underline{I} = \frac{\underline{U}}{\underline{R}_1 + \underline{R}_2}. \quad (4.7)$$

According to the second Kirchhoff's law

$$\underline{U} = \underline{U}_{R1} + \underline{U}_{R2} = \underline{I}R_1 + \underline{I}R_2. \quad (4.8)$$

The vector diagram for a case of two resistors connected in series is resulted in fig. 4.2a.

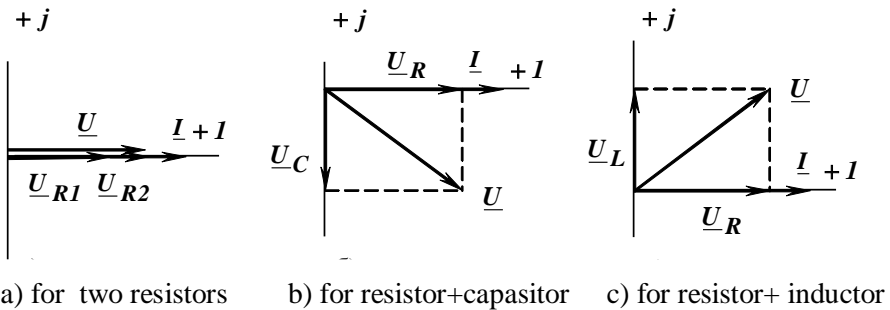


Figure 4.2 - Vector diagrams for two series elements

By Ohm's law a complex current for the series connection of an active and a capacitor elements

$$\underline{I} = \frac{\underline{U}}{\underline{R} - j\underline{X}_C}. \quad (4.9)$$

According to the second Kirchhoff's law

$$\underline{U} = \underline{U}_R + \underline{U}_C = \underline{I}\underline{R} - j\underline{I}\underline{X}_C. \quad (4.10)$$

The vector diagram for a case of a series connection of an active and a capacitor elements is resulted in fig. 4.2b.

According to Ohm's law a complex current for the series connection of active and inductive elements

$$\underline{I} = \frac{\underline{U}}{\underline{R} + j\underline{X}_L}. \quad (4.11)$$

By the second Kirchhoff's law

$$\underline{U} = \underline{U}_R + \underline{U}_L = \underline{I}\underline{R} + j\underline{I}\underline{X}_L. \quad (4.12)$$

The vector diagram for a case of a series connection of an active and an inductive elements is resulted in fig. 4.2c.

One can see rectangular triangles (voltage triangles) on vector diagrams. We can define an effective value of a total voltage for series active and reactive elements from these triangles. So, for the load in fig. 4.2b

$$U = \sqrt{U_R^2 + U_C^2}. \quad (4.13)$$

And for the load in fig. 4.2c

$$U = \sqrt{U_R^2 + U_L^2}. \quad (4.14)$$

4.1.4 Power ratios in a sinusoidal current circuit

In direct current electrical circuits an electrical energy in consumers irrevocably turns to other kinds of energy. The speed of these transformations is characterized by active power (capacity) P .

Such transformations also take place in circuits of sinusoidal current. In the circuits of sinusoidal current there is energy exchange between an electromagnetic field of a source and consumers, and also between magnetic and electric fields of consumers. The speed of these transformations is characterized by reactive capacity Q .

There is also a concept of full capacity S . This capacity will be used for estimation of common opportunities of an electrical circuit. Nominal parameters of devices on alternating current are usually set by full capacity.

$$P = \sum_{k=1}^n P_k = \sum_{k=1}^n I_k^2 R_k$$

$$Q = Q_L - Q_C = \sum_{k=1}^n Q_{Lk} - \sum_{k=1}^n Q_{Ck} = \sum_{k=1}^n I_k^2 (X_{Lk} - X_{Ck}) \quad (4.15)$$

$$S = \sqrt{P^2 + Q^2}$$

4.1.5 An equivalent scheme of inductive coil

An inductive coil in electric circuits is used for creation of an electric field (fig. 4.3). Flowing current heats it. So, its equivalent scheme consists of two elements - resistive and inductive. Therefore to measure a voltage either on inductive or resistive element is impossible. If we connect the voltmeter to terminals of the inductive coil it will show the value of a full voltage on it.

$$U_k = \sqrt{U_{R_k}^2 + U_L^2} \quad (4.16)$$

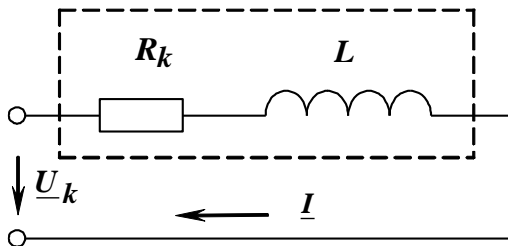


Figure 4.3 - An equivalent scheme of inductive coil

4.2 The order of carrying out of a spadework

4.2.1 One must study theoretical material and prepare oral answers to control questions.

4.2.2 Prepare the form of the report which must consist of the purpose of work, a scheme of an electrical circuit (fig. 4.5, 4.6), and table 4.1, 4.2 and the calculation according p.4.2.3

4.2.3 Calculate full impedance Z_k , active resistance R_k , inductive reactance of the coil X_L ; a phase angle of shift φ ; active, reactive and apparent capacities of an electric circuit (see fig. 4.4) if it is given:

$$U = 100 \text{ V}, U_R = U_k = 50 + 10n \text{ V}, I = 0.1n \text{ A},$$

Where n - number of a team, set by the teacher.

4.3 The description of laboratory installation

For fulfilment of the laboratory work on the stand we use:

- a sinusoidal current EMF source (terminals **A** and **B**);
- the active resistor **R14**;
- the inductive coil **LI**;
- the block of capacitors **C3-C7**;
- the voltmeters of electromagnetic system **V3**, **V4**;
- the ammeter of electromagnetic system **A5**;
- the wattmeter of electromagnetic system **W1**.

4.4 The order of carrying out of the work

4.4.1 Make an electric circuit (fig. 4.5). A capacitor is chosen by teacher's indication. Invite the teacher for checking up of the electric circuit.

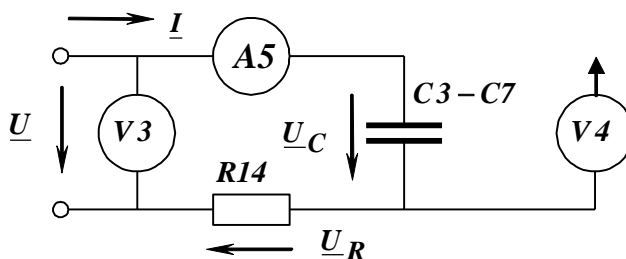


Figure 4.5 - A series connection of the resistor and the capacitor

Turn on a source of sinusoidal current. Measure the voltage of energy source U , voltage drops on the resistor U_R and the capacitor U_C (with the help of the voltmeter **V4**), current I . The results of measurements are brought in table 4.1. Switch off an energy source with the help of the automatic device. Show the results of experiments to the lecturer.

4.5 The processing of experimental results

4.5.1 According the results of the first experiment (item 4.4.1, table 4.1) check up the measurements: $U = \sqrt{U_R^2 + U_C^2}$ and calculate:

- impedance: $Z = U / I$, Ω ;
- active resistance: $R = U_R / I$, Ω ;
- capacitance: $X_C = U_C / I$, Ω ;
- shift phase angle: $\varphi = -\arccos \frac{R}{Z} = -\arctg \frac{X_C}{R}$, deg;
- apparent capacity: $S = UI$, VA
- active capacity: $P = S \cos \varphi$, Wt;
- reactive capacitor capacity: $Q = S \sin \varphi$, VAR.

The results of calculations are brought into table 4.1. Construct a vector diagram for this case.

4.5.2 By the results of the second experiment (item 4.4.2, table 4.2) calculate:

- Impedance: $Z = U / I$, Ω ;
- Shift phase angle: $\varphi = \arccos \frac{P}{UI}$, deg;
- Active resistance: $R_{14} = U_R / I$, Ω ;
- A total inductive impedance: $Z_k = U_k / I$, Ω ;
- Reactive inductance: $X_L = Z \sin \varphi$, Ω
- Active resistance of inductive coil: $R_k = \sqrt{Z_k^2 - X_L^2}$, Ω
- Shift phase angle in inductive coil: $\varphi_k = \arccos \frac{R_k}{Z_k}$, deg.

The results of calculations are brought into table 4.2. Construct a vector diagram for this case.

4.6 Control questions

4.6.1 What can you say about the behavior of active resistance, a capacitive reactance and an inductive reactance in direct current and sinusoidal current circuits?

4.6.2 What is a shift phase angle? What does it depend on?

4.6.3 What do you know about these angles of shift for an active resistance, a capacitive reactance and an inductive reactance in sinusoidal current circuits?

4.6.3 What is called a vector diagram, for which purposes is it drawn?

4.6.4 What is the triangle of voltages and in which case is it rectangular in?

4.6.5 How can we define a voltage drop on any section of the circuit with the help of a vector diagram?

4.5.6 How can we check up the rightness of measurements? What calculations are made? What Law must we use in this checking?

Laboratory work №5

THE RESEARCH OF A SERIES RLC SINUSOIDAL CURRENT ELECTRICAL CIRCUIT

The purpose of work: to study a technique of application of Kirchoff's voltage law to the analysis of non-ramified electrical circuit of sinusoidal current; to get habits of such circuits analysis with the help of vector diagrams; to familiarize with the working features of a series electrical circuit.

5.1 Short theoretical data

5.1.1 Series connection of elements in an electrical circuit

When resistive, inductive and capacitive elements are connected in series (fig. 5.1), a current is the same through all elements, and the geometrical sum of effective voltage values across separate elements is equal to the effective value of input voltage.

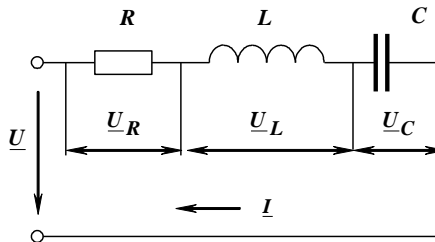


Figure 5.1 - The series connection of resistive, inductive and capacitive elements

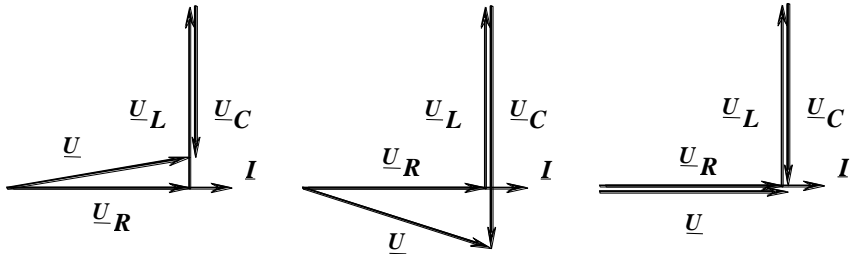
Ohm's law for effective values of voltage and a current looks like

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{\underline{U}}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} = \frac{\underline{U}}{\sqrt{R^2 + (X_L - X_C)^2}} \quad (5.1)$$

Kirchoff's voltage law in a complex form

$$\underline{U} = \underline{U}_R + \underline{U}_L + \underline{U}_C = (R + jX_L - jX_C)\underline{I} = \underline{Z}\underline{I} \quad (5.2)$$

Let's construct vector diagrams for different operating modes of an electrical circuit (fig. 5.2).



a) active-inductive rate b) active-capacitive rate c) a voltage resonance

Figure 5.2 - Vector diagrams for different operating modes of an electrical circuit

When $X_L > X_C$, a current lags behind a common voltage ($\varphi > 0$), and a character of a loading is active - inductive (fig. 5.2, a) When $X_L < X_C$, a current leads a common voltage ($\varphi < 0$), and a character of a loading is active - capacity (fig. 5.2, b).

5.1.2 The mode of voltage resonance

In a case when $X_L = X_C$, the resonance of voltages takes place in a circuit. A common impedance will be equal to an active one despite of presence of inductive and capacitive elements, and a circuit current reaches a maximum value and coincides with the common voltage in a phase (fig. 5.2, c).

A resonance frequency

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad (5.3)$$

A voltage across inductive and capacitive elements can considerably surpass the common voltage in this mode. The ratio of the capacitive (or inductive) voltage to the common voltage is called a resonance factor or a quality factor

$$D = \frac{U_C}{U} = \frac{U_L}{U} = \frac{X_C I}{R I} = \frac{X_C}{R} = \frac{\rho}{R} \quad (5.4)$$

where $\rho = \omega_0 L = \frac{1}{\omega_0 C} = \sqrt{\frac{L}{C}}$ is a wave resistance of a circuit.

5.2 The order of carrying out of a spadework

5.2.1 One must study theoretical material and prepare oral answers to control questions.

5.2.2 Prepare the form of the report which must consist of the purpose of work, a scheme of an electrical circuit (fig. 5.3), and table 5.1, and the calculation according p. 5.2.3

5.2.3 Calculate a current and voltage drops for elements of the circuit (fig.5.1) and draw a vector diagram if it is set

$$U = 10 \text{ V},$$

$$R = 10 + n \ \Omega,$$

$$X_L = 40 - n \ \Omega,$$

$$X_C = 20 + n \ \Omega,$$

where n is a number of a team which is set by a lecturer.

5.3 The description of laboratory installation

For fulfilment of the laboratory work on the stand we use:

- a sinusoidal current EMF source (terminals **A** and **B**);
- inductive coils $L1$, $L2$;
- the block of capacitors $C3$ - $C7$;
- the voltmeters of electromagnetic system $V3$, $V4$;
- the ammeter of electromagnetic system $A5$;
- the wattmeter of electromagnetic system $W1$.

5.4 The order of carrying out of the work

5.4.1 Make an electric circuit (fig. 5.3). Invite a lecturer for checking up of the electrical circuit.

5.4.2 Turn on the stand and measure capacity P , voltage drops across two inductive coils U_k and across the capacitor U_C , and the current I connecting capacitors $C4$, $C5$, $C6$, $C7$ in turn. Bring the results of measurements into tab. 5.1. Switch off the stand. Show the results of measurements to a lecturer. An electric circuit is disconnected.

5.4.3 Connect the voltmeter $V3$ to the terminals of a sinusoidal current EMF source. Turn on the stand and measure input voltage across the terminals of EMF source. Switch off the stand. Show the results of measurements to a lecturer. An electric circuit is disconnected.

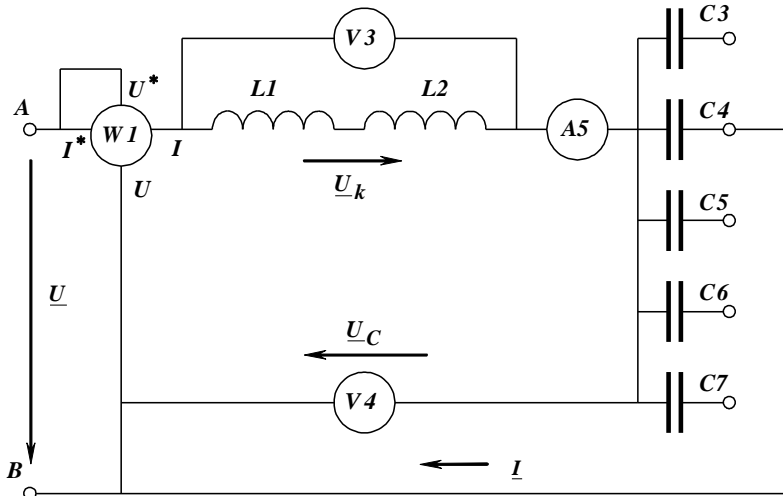


Figure 5.3 - The scheme of the non-ramified electrical circuit

Table 5.1 - The result of the experiment

C_i	Measured				Calculated									
	U_C , V	P , Wt	U_k , V	I , A	Z , Ω	X_C , Ω	Z_k , Ω	R_k , Ω	X_L , Ω	U_R , V	U_L , V	S , VA	Q , VAr	$\cos \varphi$
C4														
C5														
C6														
C7														

5.5 The processing of experimental results

5.5.1 According to the results of each experiment one must calculate:

- an impedance of the circuit - $Z = \frac{U}{I}$;
- an capacity reactance - $X_C = \frac{U_C}{I}$;
- a common inductive impedance - $Z_k = \frac{U_k}{I}$;
- an active resistance of a coil - $R_k = \frac{P}{I^2}$;

- an inductive reactance of a coil - $X_L = \sqrt{Z_k^2 - R_k^2}$;
- an active component of the coil voltage drop - $U_R = R_k I$;
- a reactive component of the coil voltage drop - $U_L = X_L I$;
- a total capacity of the electrical circuit - $S = UI$;
- a reactive capacity of the electrical circuit - $Q = \sqrt{S^2 - P^2}$;
- a capacity factor - $\cos \varphi = \frac{P}{S}$.

Bring up the results into tab. 5.1.

5.5.2 Using calculations construct vector diagrams for each experiment in one scale.

5.5.3 Determine a load character for each experiment.

5.5.4 Define the experiment being the most corresponding to the mode of resonance.

5.5.5 Construct the following schedules of dependences on one field:

$I = f_1(X_C)$, $Z = f_2(X_C)$, $U_L = f_3(X_C)$, $U_C = f_4(X_C)$,
 $\cos \varphi = f_5(X_C)$.

5.6 Control questions

5.6.1 Which shift phase angles corresponds to resistive, inductive and capacitive elements?

5.6.2 What is called a vector diagram of an electric current, and which purpose is it built with?

5.6.3 What is an active capacity, how can one measure and calculate it for a sinusoidal current circuit?

5.6.4 What are reactive and apparent capacities? How are they calculated?

5.6.5 What is a capacity factor?

5.6.6 What do we call the resonance of voltages, in which electric circuit is it possible?

5.6.7 Explain the condition of a resonance of voltages and the properties of this rate.

5.6.8 How can we define the effective value of a sinusoidal current or a voltage?

5.6.9. What will the total current be in the circuit at voltage resonance and why?

5.6.10. In which case can an ideal vector diagram of voltages be obtained?

Laboratory work №6

THE RESEARCH OF THE RAMIFIED SINUSOIDAL CURRENT ELECTRICAL CIRCUIT

The purpose of work: to familiarize with the working features of a parallel connection of inductive coil and a capacitor, to learn a technique of calculations of these circuits, to construct vector diagrams.

6.1 Short theoretical data

6.1.1 The basic equations in an electrical circuit for parallel connection of elements

At parallel connection of elements an instantaneously value of a common current in non-ramified part of an electrical circuit is equal to the algebraic sum of instantaneously values of currents in parallel branches by Kirchhoff's current law (fig. 6.1)

$$i = i_1 + i_2 \quad (6.1)$$

The complex current in a branch with an inductive coil

$$\underline{I}_1 = \frac{\underline{U}}{\underline{Z}_1}, \quad (6.2)$$

where $\underline{Z}_1 = R_k + jX_L$ is the complex impedance of a real inductive coil.

The complex current in a branch with a capacitor

$$\underline{I}_2 = \frac{\underline{U}}{\underline{Z}_2} \quad (6.3)$$

where $\underline{Z}_2 = -jX_C$ is the complex capacitance impedance.

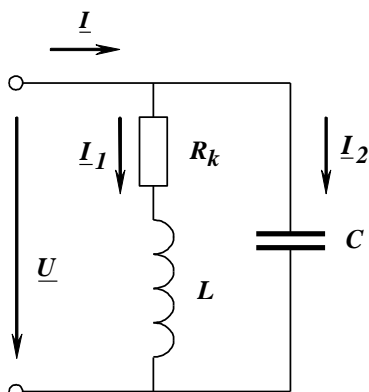


Figure 6.1 - The scheme of ramified electrical circuit

The current in every branch is equal to the algebraic sum of active and reactive current components

$$\underline{I}_1 = \frac{\underline{U}}{R_k + jX_L} \cdot \frac{R_k - jX_L}{R_k - jX_L} = \left(\frac{R_k}{R_k^2 + X_L^2} - j \frac{X_L}{R_k^2 + X_L^2} \right) \underline{U} = (G_1 - jB_L) \underline{U} = \underline{Y}_1 \underline{U} \quad (6.4)$$

$$\underline{I}_2 = \frac{\underline{U}}{-jX_C} \cdot \frac{jX_C}{jX_C} = j \frac{1}{X_C} \underline{U} = jB_C \underline{U} = \underline{Y}_2 \underline{U}$$

where $G_1 = \frac{R_k}{R_k^2 + X_L^2}$ is an active conductivity of the first branch;

$B_L = \frac{X_L}{R_k^2 + X_L^2}$ is a susceptance of the first branch; $B_C = \frac{1}{X_C}$ is a

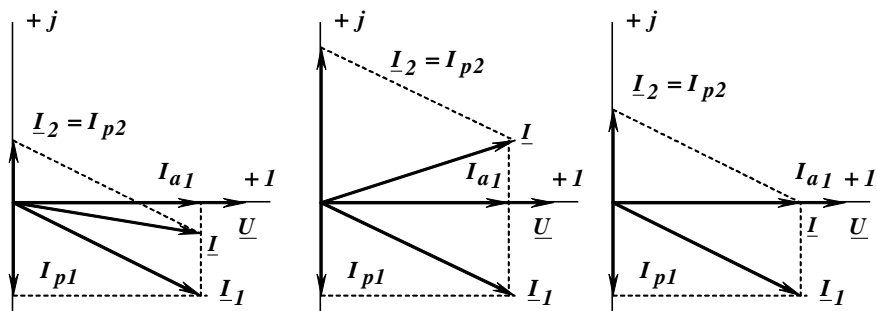
susceptance of the second branch; \underline{Y}_1 , \underline{Y}_2 are complex values of admittances of the first and the second branches.

The current in non-ramified part of a circuit is equal to the algebraic sum of the currents in parallel branches

$$\underline{I} = \underline{I}_1 + \underline{I}_2 = (G_1 - j(B_L - B_C)) \underline{U} = (G - jB) \underline{U} = \underline{Y} \cdot \underline{U} \quad (6.5)$$

where $G = G_1$ is an active conductivity of the circuit; $B = B_L - B_C$ is a susceptance of the circuit; \underline{Y} is the complex value of admittance.

Let's construct vector diagrams for different operating modes of the electrical circuit (fig. 6.2).



a) active-inductive rate b) active-capacitive rate c) a current resonance

Figure 6.2 - The vector diagrams for different operating modes

When $B_L > B_C$, a current lags behind a voltage ($\varphi > 0$), and we have an active-inductive load (fig. 6.2, a). When $B_L < B_C$, a current leads a voltage ($\varphi < 0$), and a load character is active-capacitance (fig. 6.2, b).

6.1.2 The resonance of currents

In the case when $B_L = B_C$, there is a resonance of currents in the circuit. And the admittance is equal to the active conductance

$$Y = \sqrt{G_I^2 + (B_L - B_C)^2} = G_I = G \quad (6.6)$$

A common current will be minimum. It is equal to an active component of the current in the first branch. It coincides with a common voltage in phase (fig. 6.2, c). A resonant frequency of the circuit (fig. 6.1)

$$\omega_0 = \frac{1}{L} \sqrt{\rho^2 - R_k^2} \quad (6.7)$$

where $\rho = \sqrt{\frac{L}{C}}$ is a wave resistance of the circuit.

The resonance of currents is a useful phenomenon as it reduces a current in transmission lines. As a result that leads to reduction of capacity losses and voltage at transportation of the electric power.

6.2 The order of carrying out of a spadework

6.2.1 One must study theoretical material on this theme.

6.2.2 Prepare the form of the report which must consist of the purpose of work, a scheme of a circuit (fig. 6.3), and table 6.1.

6.2.3 Calculate a common current and currents in branches (see fig. 6.1) and construct vector diagrams if it is given

$$U = 10n \text{ V},$$

$$R = 10 + n \ \Omega,$$

$$X_L = 40 - n \ \Omega,$$

$$X_C = 5 + n \ \Omega,$$

where n is a number of a team which is set by a lecturer.

6.3 The description of laboratory installation

For fulfilment of the laboratory work on the stand we use:

a s.c. EMF source (terminals **A** and **B**);

inductive coils $L1$, $L2$;

the block of capacitors $C3$ - $C7$;

the voltmeter of electromagnetic system $V3$;

the ammeters of electromagnetic system $A5$, $A6$, $A7$.

6.4 The order of carrying out of the work

6.4.1 Make an electric circuit (fig. 6.3). Invite a lecturer for checking up of the electrical circuit.

6.4.2 Turn on the circuit and measure a common current I , currents in branches I_1 , I_2 and voltage U поочередно connecting capacitors $C4$, $C5$, $C6$, $C7$ in turn. Switch off the stand. Write down the results of measurements in tab.6.1 and show them to a lecturer. An electric circuit is disconnected.

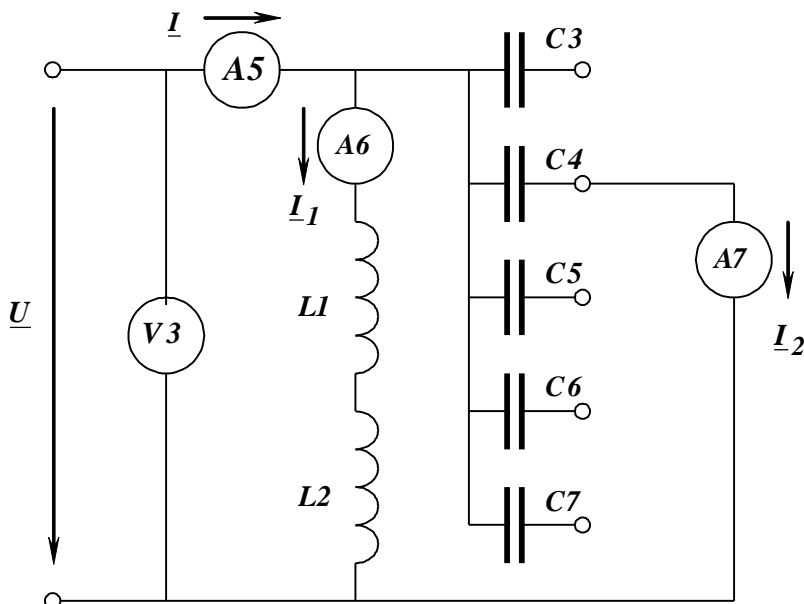


Figure 6.3 - The scheme of the circuit with parallel connection

Table 6.1 - The results of experiments

C_i	Measured				Calculated							
	U , V	I , A	I_1 , A	I_2 , A	Y , Ω^{-1}	Y_1 , Ω^{-1}	Y_2 , Ω^{-1}	I_{a1} , A	I_{p1} , A	$\cos \varphi$ -	$\cos \varphi_k$ -	
$C4$												
$C5$												
$C6$												
$C7$												

6.5 The processing of experimental results

6.5.1 According to the results of each experiment one must calculate:

an admittance of the electrical circuit - $Y = \frac{I}{U}$; an admittance of the first

branch - $Y_1 = \frac{I_1}{U}$; an admittance of the second branch - $Y_2 = B_2 = \frac{I_2}{U}$.

6.5.2 Draw vector diagrams for each experiment in one scale. Define active and reactive current components I_{a1} , I_{r1} .

6.5.3 Calculate capacity factors of inductive coil $\cos \varphi_k = \frac{I_{a1}}{I_1}$ and

all the circuit $\cos \varphi = \frac{I_{a1}}{I}$. Write down the results in tab. 6.1.

6.5.4 Define the experiment being the most corresponding to the mode of a resonance of currents.

6.5.5 Construct the following schedules of dependences on one field:

$$I = f_1(B_2), \cos \varphi = f_2(B_2), Y = f_3(B_2).$$

6.6 Control questions

6.6.1 When and where may the resonance of currents occur? What is a condition of its occurrence?

6.6.2 What can we say about a capacity factor, admittance and resonant current?

6.6.3 How can one define a load character by a vector diagram??

6.6.4 How is a load character determined by a vector diagram?

6.6.5 How the vector diagram for parallel association of consumers by a method of "notches" is under construction?

6.6.6 What can we say about the compensation of the reactive capacity?

6.6.7. In which electrical circuit is current resonance possible?

6.6.8. Name the condition for the occurrence of current resonance in parallel branches.

6.6.9. In what case can an ideal vector diagram of currents be obtained?

6.6.10. What will the total current be in the circuit at current resonance and why?

LITERATURE

1. Atabekov G.I. Linear Network Theory. London, Great Britain: Pergamon Press, 1964. - 635 p.

2. Khilov V.S. Theoretical fundamentals of Electrical Engineering. Dnipro, Ukraine: National Mining University, 2018. – 467 p.

3. Nabokova O.V. Theoretical Electrical Engineering. Zaporizhzhia: ZNTU, 2015. - 477 p.

4 Theoretical fundamentals of Electrical Engineering: part 1 (Electronic resource): tutorial for students in speciality141 “Electric Power Engineering, Electric Engineering and Electromechanics” /Y. Peretyatko, L. Spinul, M. Shcherba; Igor Sikorsky Kyiv Politechnic Institute.- Electronic text data (1 file: 10,2 MB). – Kyiv: Igor Sikorsky Kyiv Politechnic Institute, 2021. – 136 p.

5 ENGLISH-UKRAINIAN DICTIONARY of electrical and technical terminology for the students of specialty 141 "Electricity, electrical engineering and electromechanics"//Authors: Kozlov V.V., Nabokova O.V. - Zaporizhzhia: NU “ZAPORIZHZHIA POLYTECHNIC”, 2024. - 62 p.

6 Міліх В.І. Електротехніка та електромеханіка: Навч. посібник. К.: Каравела, 2003. – 376 с.

7 Козлов В.В., Набокова О.В. Теоретичні основи електротехніки. Усталені режими у лінійних електричних колах. Запоріжжя: ЗНТУ, 2016. – 428 с.

Appendix A
The standard of the title - page

The Ministry of Education and Science of Ukraine
NU "ZAPORIZHZHYA POLYTECHNIC"

EAPU Chair

Laboratory work №1
The research of the work of electrical energy source in different
conditions

Admitted by	Docent Nabokova O.V.
Worked out by	a student of E-411a Golubtsova V.R.
Taken by	Docent Nabokova O.V.

Zaporizhzhia, 2025