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Department of  
Electrical Engineering

## **ELECTRICAL ENGINEERING**

Methodological guidelines and assignments for performing laboratory works  
for students of the 5B074600 – Space technique and technologies and  
5B071600 – Instrumentation specialties

Almaty 2019

AUTHORS: Y. H. Zuslina, A. S. Baimaganov, S. J. Kreslina. Electrical engineering. Methodological guidelines and assignments for performing laboratory works for students of the 5B074600 – Space technique and technologies and 5B071600 – Instrumentation specialties – Almaty: AUES, 2019. – 74 p.

Methodological guidelines and assignments for performing laboratory works contains 14 laboratory works in the following sections: DC electrical circuits, single-phase sinusoidal current circuits, resonance of currents and resonance of voltages in electrical circuits, three-phase electrical circuits, transients in electrical circuits, transformers, DC and three-phase alternating current electrical machineries.

Each laboratory work contains the following sections: the purpose of the work, preparation for the laboratory work, the assignment to perform the work, methodological guidelines for carrying out experiments and analyzing the results obtained, as well as conclusions on the work done.

Methodological guidelines and assignments for performing laboratory works correspond to the work programs for the EE 2206 – Electrical engineering compulsory basic discipline for students of the 5B074600 – Space equipment and technology specialty and for the Ele 2203 – Electrical engineering compulsory basic discipline for students of the 5B071600 – Instrumentation specialty.

41 Illustration, 47 tables, 10 items of references.

Reviewer: B. I. Tuzelbayev, Ph.D.

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## Introduction

Methodological guidelines and assignments for performing laboratory works are part of a set of methodological literature on the Electrical Engineering discipline for the 5B074600 – Space technique and technologies and 5B071600 – Instrumentation specialties.

To improve the quality of training, the formation of creative thinking and engineering skills of students, laboratory works are of great importance. Laboratory assignments are a set of experimental and calculated works on the study of linear electric DC circuits, single-phase sinusoidal current, three-phase electrical circuits, transients in linear electrical circuits, transformers, DC and three-phase alternating current electrical machineries. All laboratory works are performed by the frontal method after the material of this topic has been presented in the lecture.

The practical implementation of the laboratory classes at the Electrical Engineering Department provides by the universal educational and research laboratory workbenches (UILS) and special laboratory workbenches on the Electrical Engineering discipline.

The workbench of the UILS is a table on which the panel is fixed, consisting of the shells of the active and passive units assembled into circuits on the dial field. The workbench consists of composing elements and connecting wires with plugs.

The power sources are represented by the case of active units containing DC power supplies, an AC power supply, and a three-phase power supply. The case of passive units contains a unit of variable resistance (VRU), a unit of variable inductance (VIU), a unit of variable capacitance (VCU).

DC power supplies contain:

- adjustable DC voltage source with output voltage from 0 to 20 V;
- not adjustable DC voltage source with an output voltage of about 20 V;
- electronic switch that is used to study transients.

Both voltage sources are equipped with a short circuit and overload protection circuit. The limit of the maximum tripping current is  $I_{tr} = 1.4$  A.

AC power supply is a single-phase AC voltage source with an adjustable frequency of sinusoidal, rectangular and triangular shape. The circuit is equipped with electronic protection against short circuits and overloads. The limit of the tripping current is  $I_{tr} = 1$  A.

Three-phase power supply is a source of three-phase voltage of industrial frequency 50 Hz. All phases are electrically independent on each other. The circuit is equipped with electronic protection against short circuits and overloads. The limit of the tripping current is  $I_{tr} = 1$  A.

Unit of variable resistance (VRU) consists of three not adjustable resistors  $R_1$ ,  $R_2$ ,  $R_3$  and three adjustable resistors  $R_4$ . Adjustable resistance  $R_4$  carried out in steps using the appropriate switches.

Unit of variable inductance (VIU) consists of three unregulated inductors  $L_1$ ,  $L_2$ ,  $L_3$  and three adjustable inductors  $L_4$ . Regulation of inductance is carried out in steps using appropriate switches.

Unit of variable capacitance (VCU) consists of three unregulated capacitors  $C_1$ ,  $C_2$ ,  $C_3$  and three adjustable capacitors  $C_4$ . Capacitance adjustment is carried out in steps using the appropriate switches.

On the front panels of the units are located the alarm bodies (indicators, lamps), controls (knobs of switches, toggle switches, buttons) and measuring instruments.

Panel for electrical circuits assembly is a panel with 67 pairs of definitely connected sockets, designed to connect and install circuit's elements made in the form of transparent plastic boxes, at the end of which there is a plug, and inside the elements of electrical circuits are soldered.

To activate the active unit, set the POWER toggle switch to the ON position, the POWER indicator will light up.

The measuring devices mounted on the front panel of the DC and AC power supplies are designed to control the magnitude of the current and voltage of the adjustable voltage sources. Regulation materializes by a potentiometer.

The frequency of the AC power supply is regulated by a switch stepwise through 1 kHz and by a potentiometer smoothly. When the Frequency smoothly potentiometer is in the extreme right position, the frequency of the output voltage corresponds to the value indicated on the step switch with an accuracy of  $\pm 2\%$ .

The voltage at the output of each phase ThVB can be adjusted stepwise using switches from 1 to 9 V and from 0 to 30 V.

If a short circuit or overload occurs (in the case when the circuit is assembled incorrectly), the electronic protection is activated in the units, and the Protection indicators light up. After eliminating the causes of a short circuit or correcting an error in the dialed circuit, it is necessary, by pressing the Protection button, to return the unit circuit to its working position, and the indicator goes out.

A universal digital power meter is used to measure current, voltage, frequency, active power, power factor in sinusoidal current circuits. The connection scheme of the power meter is shown in figures 4.1, 4.2, 4.3 and 5.1, 5.2, 5.3: L IN and N IN terminals are connected to the power supply; L OUT and N OUT – to the load. The device is turned on by pressing the Power button.

The display shows the measurement results. On the left is the power measurement reading window, next to which are the indicators of units of measurement (mW, W or kW). The bottom right window shows the results of current measurements, next to which the unit indicators (mA or A). At the top right-hand, there is a window for displaying the measurement results in one of three quantities: voltage (V or kV); frequency (Hz) or power factor (PF – Power factor). To choose the measured value on the control panel, press the corresponding buttons: V, Hz or PF.

Annotation:

1) In normal operation of the instrument, the RUN indicator flashes, otherwise it is constantly lit or not lit.

2) In normal operation of the device, the conversion factor for the voltage transformer and current transformer should be equal to 1. If the re-count factor is

different from 1, then the RATIO indicator is lit (in this case, it is necessary to contact the teacher so that he sets the conversion factor to 1).

Methodological guidelines and assignments for performing of laboratory works correspond to the work programs for the ET 2206 – Electrical engineering compulsory basic discipline for students of the 5B074600 – Space equipment and technology specialty and for the Ele 2203 – Electrical engineering compulsory basic discipline for students of the 5B071600 – Instrumentation specialty.

## 1 Laboratory work №1. Research unbranched linear DC electric circuit

*Purpose* is to obtain the skills of experimental study of DC electric circuits using Ohm's law.

### 1.1 Preparation for the work

Revise a Linear DC electric circuits section of an Electrical engineering textbook.

Answer the questions and do the following:

- 1) Write down Ohm's law for the circuit in figure 1.1.
- 2) How does determine an EMF of the voltage source experimentally?
- 3) How do the resistance and conductivity of resistors on the values of voltage and current determine?
- 4) Write the formulas for determining the potentials of the selected points of the circuit in figure 1.1, taking the potential of one of the points to be zero, according to the specified variant (table 1.1).
- 5) How does a potential diagram for the scheme in figure 1.1, taking the potential of one of the points to be zero, according to a given variant is drawn (table 1.1)?
- 6) Draw a circuit of an electrical circuit (figure 1.1), table 1.2 and table 1.3.

### 1.2 Assignment to perform the laboratory work

1.2.1 Assemble the electrical circuit (figure 1.1), install the EMF  $E_1$ ,  $E_2$  according to a given variant (table 1.1).

Table 1.1

Variant №	1	2	3	4	5	6
$E_1$ , V	20	8	20	10	5	20
$E_2$ , V	10	20	5	20	20	8
Potential that is zero	$\varphi_1$	$\varphi_2$	$\varphi_8$	$\varphi_4$	$\varphi_5$	$\varphi_6$

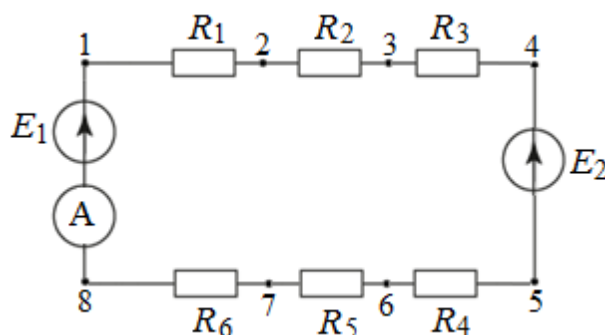


Figure 1.1 – Unbranched DC circuit

1.2.2 Measure the current, EMF of sources  $E_1$  and  $E_2$  and the voltage across the resistors. The results write down in table 1.2.

1.2.3 Measure the potentials of all points of an electrical circuit with respect to one whose potential is assumed to be zero, according to a given variant (table 1.1). The results write down in table 1.3.

Table 1.2

$I =$ ; $E_1 =$ ; $E_2 =$ .						
Resistor	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$	$R_6$
Voltage, V						
Resistance, $\Omega$						
Conductivity, S						

Table 1.3

Potentials	$\varphi_1$	$\varphi_2$	$\varphi_3$	$\varphi_4$	$\varphi_5$	$\varphi_6$	$\varphi_7$	$\varphi_8$
Theoretical calculation								
Experiment								

### 1.3 Processing experimental results

1.3.1 For the circuit (figure 1.1), from the results of the experiments, calculate the resistance and conductivity values of the resistors.

1.3.2 For the circuit (figure 1.1), from the experimentally found resistance values and EMF, calculate the current according to Ohm's law and compare with the measured current.

1.3.3 For the circuit (figure 1.1), from the experimentally found resistance values, the EMF and current calculated in 1.3.2, to determine the potentials of all points of the circuit, taking the potential of an arbitrary point to be zero (according to a given variant). The values of the potentials should be written down to the table in the Theoretical calculation line.

1.3.4 For the circuit (figure 1.1), draw potential diagrams from the calculated and experimental data and determine the current in the circuit from the experimental diagram.

1.3.5 Compare the results of experiments and theoretical calculations.

### 1.4 Methodological guidelines

The potential diagram is a graph of the potential change along the loop, starting from one point, the potential of which is taken as zero. The resistance of the circuit sections is placed along the abscissa axis, and the ordinate axis - the potentials of the corresponding points. The current on the potential diagram for the unbranched circuit is determined by the formula:

$$I = \frac{m_u}{m_R} \operatorname{tg} \alpha ,$$

where  $m_u, m_R$  are the scales of potentials and resistances, respectively;  
 $\operatorname{tg} \alpha$  – is the tangent of the inclination angle to the abscissa axis of the straight section of the potential diagram.

## 2 Laboratory work №2. Research of the branched linear electrical DC circuit

*Purpose* is to obtain the skills of experimental study of complex branched DC circuits using the Kirchhoff's laws, mesh current analysis and nodal analysis.

### 2.1 Preparation for work

Revise the following topics in the Linear DC electric circuits section: Kirchhoff's laws, mesh current and nodal analysis of an Electrical engineering textbook.

Answer the questions and do the following:

1) For the circuit of the electric circuit, according to a given variant (figures 2.1 - 2.6), write the equations according to the Kirchhoff's laws.

2) For the electrical circuit (figures 2.1 – 2.6), using the resistance values  $R_1 \div R_6$  from laboratory work №1 (table 1.2) and the EMF values, according to a given variant (table 2.1), calculate all currents using the mesh current analysis (MCA). The results of the calculations write in table 2.2 in the Theoretical calculation line.

3) For the electrical circuit (figures 2.1 – 2.6), using the resistance values  $R_1 \dots R_6$  from laboratory work №1 (table 1.2) and the EMF values, according to a given variant (table 2.1), calculate the potentials of the circuit nodes and the currents in the branches using the node analysis (NA), the potential of one of the nodes of the circuit is zero according to a given variant (table 2.1). The results of the calculations write in table 2.2 in the Theoretical calculation line.

4) Draw a circuit of the electric circuit according to a given variant (figures 2.1 – 2.6) and table 2.2.

Table 2.1

Variant №	1	2	3	4	5	6
Scheme №	2.1	2.2	2.3	2.4	2.5	2.6
$E_1, \text{V}$	20	10	20	15	8	20
$E_2, \text{V}$	10	20	15	20	18	12
Potential which is zero	$\varphi_1$	$\varphi_2$	$\varphi_3$	$\varphi_4$	$\varphi_2$	$\varphi_3$

### 2.2 Assignment to perform the laboratory work

2.2.1 Assemble the electrical circuit according to the scheme (figures 2.1 – 2.6) according to a given variant.

2.2.2 Measure and write down in table 2.2 in the Experiment line the indications of ammeters (values of currents in all branches  $I_1 - I_6$ ).



2.2.3 Measure the values of the potentials of the nodes and write down the indications of voltmeters in table 2.2 in the Experiment line. The potential of one of the nodes, according to a given variant, is taken equal to zero.

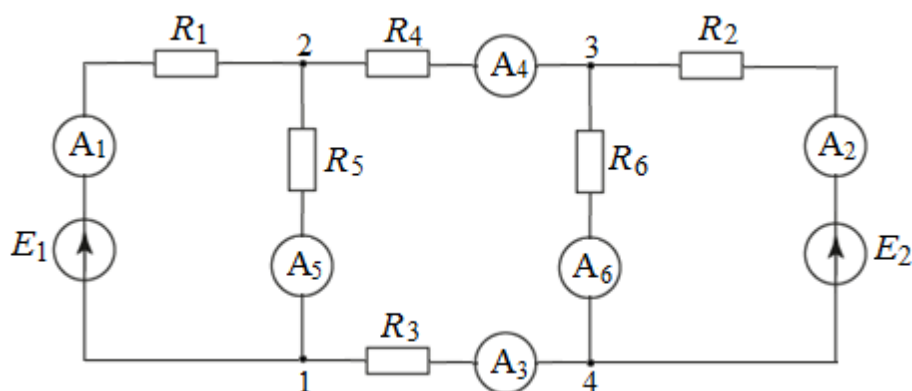


Figure 2.1

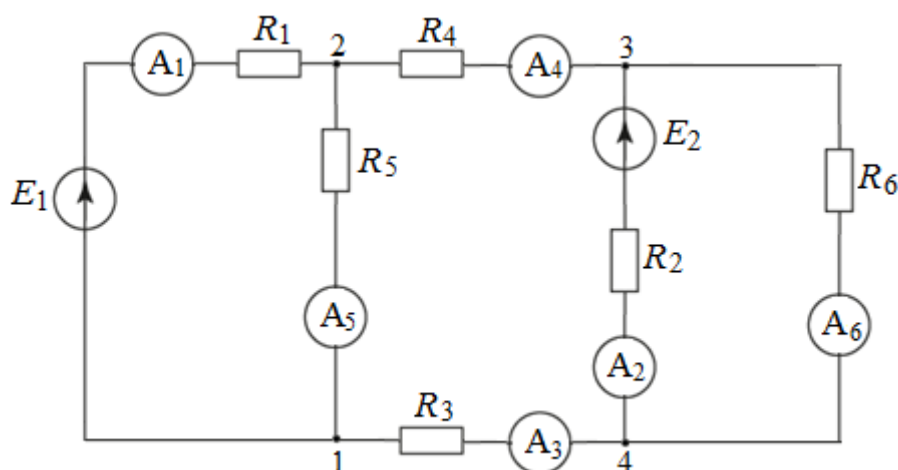


Figure 2.2

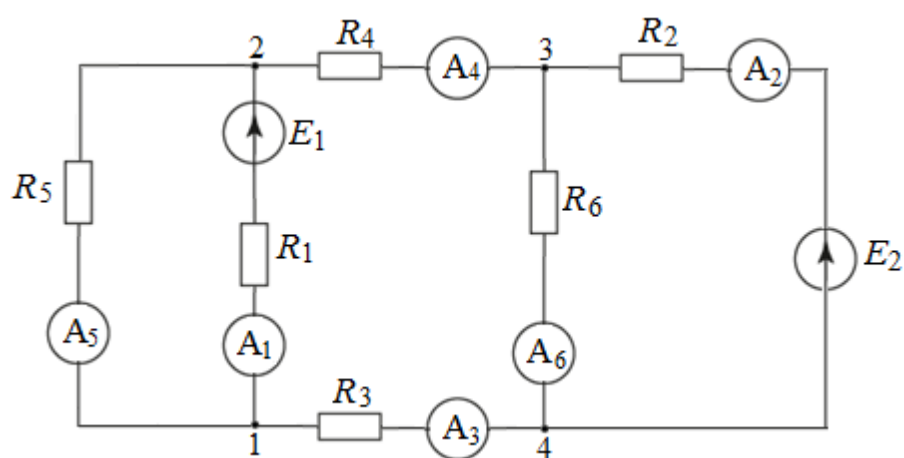


Figure 2.3

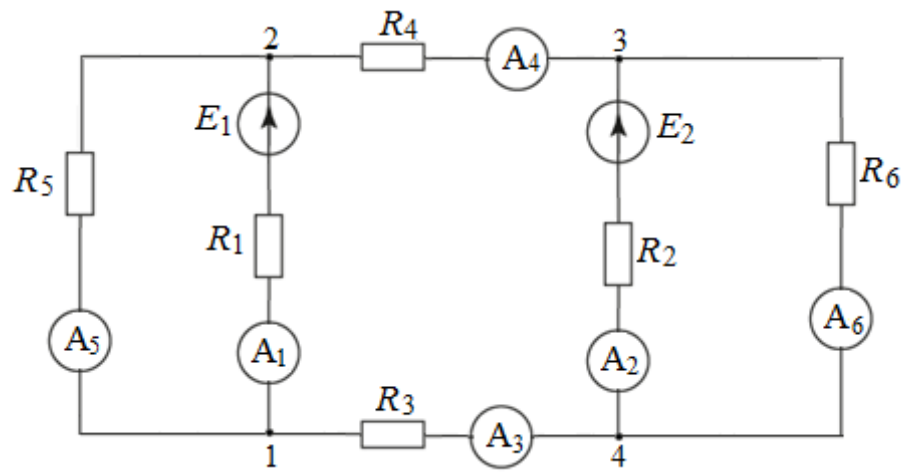


Figure 2.4

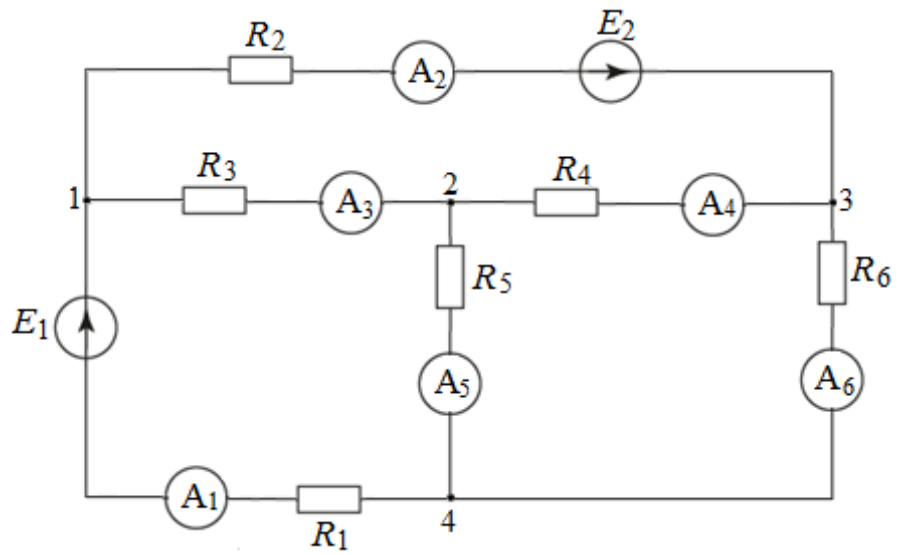


Figure 2.5

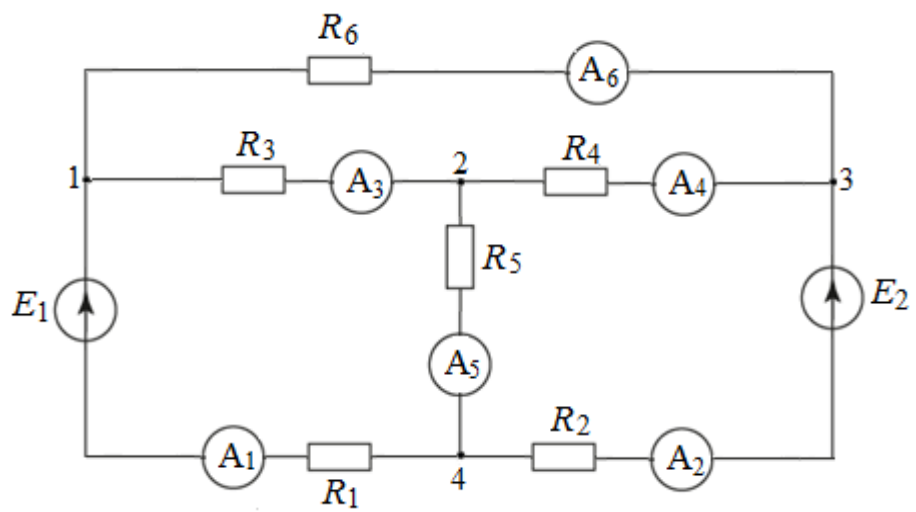


Figure 2.6

Table 2.2

Type of re-search	Calculation method	$\varphi_1$	$\varphi_2$	$\varphi_3$	$\varphi_4$	$I_1$	$I_2$	$I_3$	$I_4$	$I_5$	$I_6$
Theoretical calculation	MCA										
	NA										
Experiment											

## 2.3 Processing experimental results

2.3.1 Check Kirchhoff's laws.

2.3.2 Compare the currents and potentials of the nodes, obtained experimentally with the calculated values (table 2.2).

2.3.3 An error of the calculation is determined by the formulas:

$$\delta_I = \frac{I_{theor} - I_{exp}}{I_{theor}} \cdot 100\% ; \quad \delta_\varphi = \frac{\varphi_{theor} - \varphi_{exp}}{\varphi_{theor}} \cdot 100\% .$$

## 2.4 Methodological guidelines

*Kirchhoff's current Law:*

$$\sum_{k=1}^n I_k = 0 .$$

Currents directed to the node are written with a "+" sign, currents directed from the node are written with a "-" sign (or vice versa).

*Kirchhoff's voltage law:*

$$\sum_{k=1}^n R_k I_k = \sum_{k=1}^n E_k .$$

The voltages  $R_k \cdot I_k$  are written with a "+" sign if the positive direction of the current  $I_k$  coincides with the direction of the circuit bypass, with the sign "-" if the direction of the current  $I_k$  is opposite to the direction of the circuit bypass. EMF  $E_K$ , the directions of which coincide with the direction of the circuit bypass, are written with a "+" sign, and EMF  $E_K$ , directed against the circuit bypass, with a "-" sign.

The procedure of equation formations according to Kirchhoff's laws:

- choose arbitrarily positive directions of the circuit branch's currents and write equations for the nodes of the circuit according to the Kirchhoff's current law;
- choose independent loops (loops are independent if each subsequent loop has at least one new branch), arbitrarily choose directions of traversal of these loops, then write equations for these loops according to the Kirchhoff's voltage law.

*Mesh current analysis (MCA).* Mesh current analysis is based on the fact that a loop current is introduced in each independent loop of an electrical circuit. At least one loop current must flow through any branch of an electrical circuit. To determine the loop currents are formed by the equation of the Kirchhoff's voltage law.

The current in any branch can be represented as an algebraic sum of the loop currents flowing through this branch. Loop current equations are written as (for three independent loops):

$$\left. \begin{aligned} R_{11}I_{11} + R_{12}I_{22} + R_{13}I_{33} &= E_{11} \\ R_{21}I_{11} + R_{22}I_{22} + R_{23}I_{33} &= E_{22} \\ R_{31}I_{11} + R_{32}I_{22} + R_{33}I_{33} &= E_{33} \end{aligned} \right\},$$

where  $R_{pp}$  is the own resistance of the loop  $p$  ( $p = 1, 2, 3$ ), equal to the sum of the resistances included in the loop  $p$ ;

$R_{pm} = R_{mp}$  is the common resistance of the adjacent branches of the loops  $p$  and  $m$ , equal to the sum of the resistances of the adjacent branches of the loops  $p$  and  $m$  (1<sup>st</sup> and 2<sup>nd</sup>, 1<sup>st</sup> and 3<sup>rd</sup> or 2<sup>nd</sup> and 3<sup>rd</sup>). The common resistance is written with a “+” sign, if the loop currents flowing along the adjacent branch are directed in the same way, otherwise the resistance is written with a “-” sign

$E_{pp}$  is the loop’s EMF that is equal to the algebraic sum of the EMFs included in the loop  $p$ . The EMF is written with the plus sign, the directions of which coincide with the direction of the loop current, otherwise the EMF is written with the negative sign.

*Nodal analysis.* The essence of the nodal analysis is to determine the potentials of the nodes of the electrical circuit, the currents are calculated according to Ohm’s law. When making up the equations of nodal potentials, the potential one of the nodes is assumed to be zero, and equations are made up to determine the potentials of the remaining nodes. Let’s make the equation for the scheme with four nodes. For example, we take the potential of the fourth node to be zero:  $\varphi_4 = 0$ . For the remaining three potentials, we write the equations:

$$\left. \begin{aligned} g_{11}\varphi_1 - g_{12}\varphi_2 - g_{13}\varphi_3 &= \sum_1 E g \\ -g_{21}\varphi_1 + g_{22}\varphi_2 - g_{23}\varphi_3 &= \sum_2 E g \\ -g_{31}\varphi_1 - g_{32}\varphi_2 + g_{33}\varphi_3 &= \sum_3 E g \end{aligned} \right\},$$

where  $g_{pp}$  is the own nodal conductivity of the node  $p$  ( $p = 1, 2, 3$ ), equal to the sum of the conductivities of the branches attached to the node  $p$ ;

$g_{pm} = g_{mp}$  is the common nodal conductivity of nodes  $p$  and  $m$ , equal to the sum of the conductances of the branches connecting the nodes  $p$  and  $m$  ( $g_{12} = g_{21}$ ,  $g_{13} = g_{31}$ ,  $g_{23} = g_{32}$ );

$\sum E g$  is the algebraic sum of the EMF products of the branches attached to the corresponding node on the conductance of these branches, and the summands  $E g$  are written with a “+” sign, if the corresponding EMF  $E$  is directed to the node being considered and the summands  $E g$  are written with a “-” sign, EMF  $E$  is directed from the node.

### 3 Laboratory work №3. The principle of superposition

*Purpose* is to obtain the skills of experimental study the principle of superposition in a linear electric DC circuit.

#### 3.1 Preparation for work

Revise the superposition theorem topic in the Linear DC electric circuits section of an Electrical engineering textbook.

Answer the questions and do the following:

1) What is the principle of superposition? For any electrical circuits is carried out the principle of superposition, is it true or false?

2) For an electrical circuit (figure 3.1), draw schemes for determining the partial currents (figures 3.2, 3.3) and write down the equations for calculating the currents using the principle of superposition.

3) For an electric circuit (figure 3.1), calculate the currents by the principle of superposition according to a given variant (table 3.1). The results of the calculation write in table 3.2 in the Theoretical calculation line.

4) Draw schemes (figures 3.1, 3.2, 3.3) and table 3.2 for an experimental research the principle of superposition. In the schemes, the positive directions of the currents are the same as in the theoretical calculations.

Table 3.1

Variant №	1	2	3	4	5	6
$E_1, \text{V}$	20	10	20	12	20	8
$E_2, \text{V}$	10	20	8	20	10	20
$R_1, \Omega$	100	150	200	150	150	75
$R_2, \Omega$	150	200	150	100	200	100
$R_3, \Omega$	50	100	100	75	50	50

Table 3.2

Type of research	$EMF$	$I_1$	$I_2$	$I_3$
Theoretical calculation	$E_1 \neq 0; E_2 = 0$ scheme 3.2			
	$E_1 = 0; E_2 \neq 0$ scheme 3.3			
	$E_1 \neq 0; E_2 \neq 0$ scheme 3.1			
Experiment	$E_1 \neq 0; E_2 = 0$ scheme 3.2			
	$E_1 = 0; E_2 \neq 0$ scheme 3.3			
	$E_1 \neq 0; E_2 \neq 0$ scheme 3.1			
Calculation by experimental data				

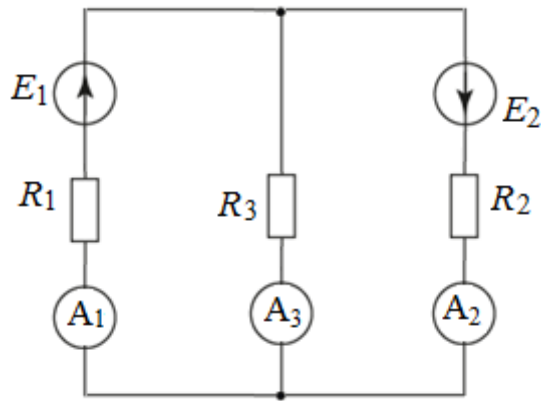


Figure 3.1

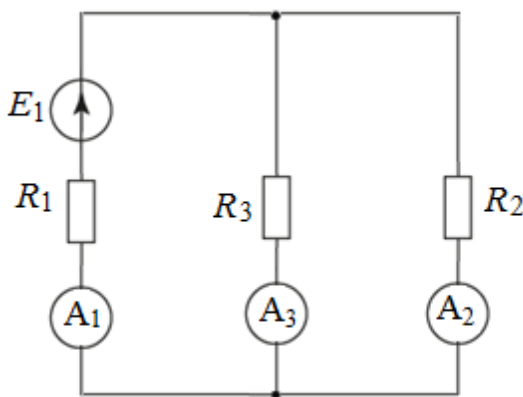


Figure 3.2

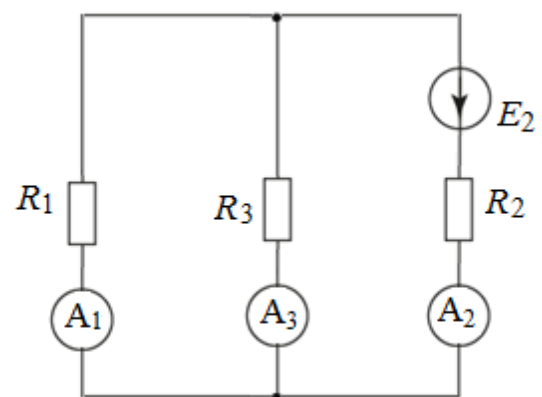


Figure 3.3

### 3.2 Assignment to perform the laboratory work

3.2.1 Assemble the electrical circuit according to the scheme in figure 3.2.

3.2.2 Measure and write in table 3.2 in the Experiment line the indications of ammeters (values of currents  $I_1$ ,  $I_2$ ,  $I_3$  in all branches of the circuit).

3.2.3 Assemble the electrical circuit according to the scheme in figure 3.3.

3.2.4 Measure and write in table 3.2 in the Experiment line the indications of ammeters (values of currents  $I_1$ ,  $I_2$ ,  $I_3$  in all branches of the circuit).

3.2.5 Assemble the electrical circuit according to the scheme in figure 3.1.

3.2.6 Measure and write down in table 3.2 in the Experiment line the ammeter readings (values of currents  $I_1$ ,  $I_2$ ,  $I_3$  in all branches of the circuit).

### 3.3 Processing experimental results

3.3.1 Experimental verification of the superposition theorem: for this purpose calculate the currents in the branches of the electric circuit (figure 3.1) by adding the currents in the corresponding branches obtained experimentally (sections 3.2.2 and 3.2.4). The results should be written down in table 3.2 in the Calculation by experimental data line.

3.3.2 Compare the currents in the branches of the electric circuit in figure 3.1, obtained experimentally, with the calculated values of the currents by the experimental data (table 3.2).

An error of the calculation is determined by the formula:

$$\delta_I = \frac{I_{CALC.} - I_{EXP.}}{I_{CALC.}} \cdot 100\% .$$

3.3.3 Compare the currents in the branches of electrical circuits (figure 3.1, 3.2, 3.3), obtained experimentally, with currents calculated theoretically (table 3.2).

An error of the calculation is determined by the formula:

$$\delta_I = \frac{I_{CALC.} - I_{EXP.}}{I_{CALC.}} \cdot 100\% .$$

### **3.4 Methodological guidelines**

The essence of the principle of superposition is as followed: the current in any branch of the electrical circuit containing several sources of electrical energy is equal to the algebraic sum of the partial currents in the same branch from the action of each source separately.

The procedure for the calculation of currents by the principle of superposition:

- 1) Based on the initial scheme, specific calculation schemes are made, in each of which only one source of EMF. At the same time, the remaining EMF sources are replaced by short-circuited areas.
- 2) Partial currents in specific circuits are calculated by any method.
- 3) The currents in the branches of the initial circuit are determined by algebraic summation of the partial currents of the corresponding branches of the specific calculation schemes.

## **4 Laboratory work №4. Research unbranched electrical circuit single-phase sinusoidal current**

*Purposes* are to perform experimental researches of unbranched AC circuits and to construct phasor diagrams of currents and voltages.

### **4.1 Preparation for work**

Revise topic of the linear electrical circuits of a single-phase sinusoidal current in the Electrical engineering textbook.

Answer the questions and do the following:

- 1) Write down Ohm's law and Kirchhoff's voltage law in a complex form for schemes (figures 4.1 – 4.3).

2) How do complex current and complex voltage to their instantaneous values convert?

3) What is the effective value of sinusoidal electrical quantities (current, voltage, EMF)?

4) For the scheme (figure 4.1), calculate the values of the parameters of your variant (table 4.1):

a) inductive impedance  $X_L$ , impedance  $Z$ , phase angle  $\varphi$  between the voltage at the input of the circuit and the current, the power factor  $\cos\varphi$ ; write the results in table 4.2 in the Theoretical calculation line;

b) complex current values in the circuit and voltages on each element; write the effective values of current and voltage in table 4.2 in the Theoretical calculation line;

c) active, reactive and apparent power; write the results in table 4.2 in the Theoretical calculation line.

5) According to the results of calculations, construct a phasor diagram of current and voltage, triangles of impedance and power.

6) For the scheme (figure 4.2), calculate the values of the parameters of your variant (table 4.1):

a) capacitance impedance  $X_C$ , impedance  $Z$ , phase angle  $\varphi$  between the voltage at the input of the circuit and the current, the power factor  $\cos\varphi$ ; write the results in table 4.3 in the Theoretical calculation line;

b) complex current values in the circuit and voltages on each element; write the current values of current and voltages in table 4.3 in the Theoretical calculation line;

c) active, reactive and apparent power; write the results in table 4.3 in the Theoretical calculation line.

7) According to the results of calculations, construct a phasor diagram of current and voltage, triangles of impedance and power.

8) For the scheme (figure 4.3), calculate the values of the parameters of your variant (table 4.1):

a) impedance  $Z$ , phase angle  $\varphi$  between the voltage at the input of the circuit and the current, the power factor  $\cos\varphi$ ; write the results in table 4.4 in the Theoretical calculation line;

b) active, reactive and apparent power; write the results in table 4.4 in the Theoretical calculation line.

9) 4.1.10 According to the results of calculations, construct a phasor diagram of current and voltage, triangles of impedance and power.

10) 4.1.11 Draw schemes (figures 4.1, 4.2, 4.3) and tables 4.2, 4.3, 4.4.

## **4.2 Assignment to perform the laboratory work**

4.2.1 Assemble the electrical circuit according to the scheme in figure 4.1; set the parameters of the circuit, according to a given variant (table 4.1). Measure cur-



rent, voltages at the input of the circuit and across each element, active power and power factor  $\cos\varphi$ . The results write down in table 4.2 in the Experiment line.

4.2.2 Assemble the electrical circuit according to the scheme in figure 4.2; set the parameters of the circuit, according to a given variant (table 4.1). Measure current, voltages at the input of the circuit and at each element, active power and power factor  $\cos\varphi$ . The results write down in table 4.3 in the Experiment line.

4.2.3 Assemble the electrical circuit according to the scheme in figure 4.3; set the parameters of the circuit, according to a given variant (table 4.1). Measure current, voltages at the input of the circuit and across each element, active power and power factor  $\cos\varphi$ . The results write down in table 4.4 in the Experiment line.

Table 4.1

Variant	1	2	3	4	5	6
$R, \Omega$	100	50	80	50	70	100
$C, \mu\text{F}$	3	2	5	7	6	8
$L, \text{mH}$	20	30	25	50	35	40
$f, \text{Hz}$	400	450	350	300	400	450
$U, \text{V}$	3	3	3	3	3	3

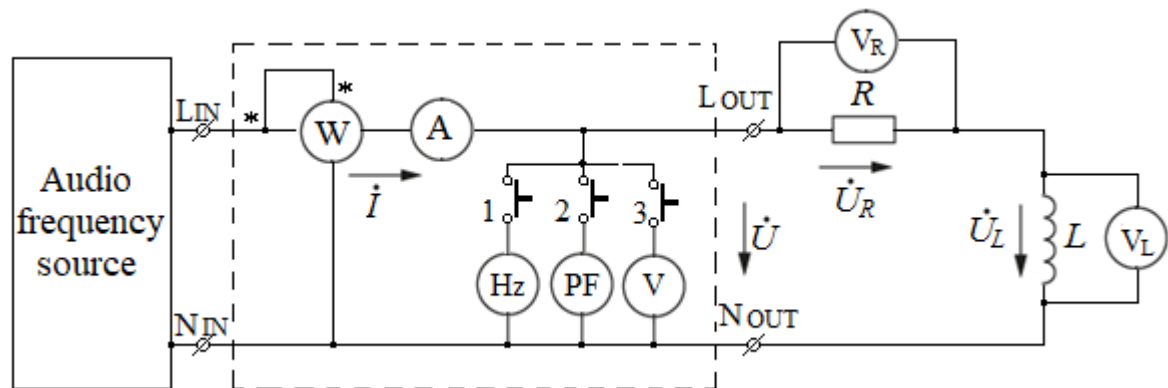


Figure 4.1 – Circuit with a series connection elements  $R, L$

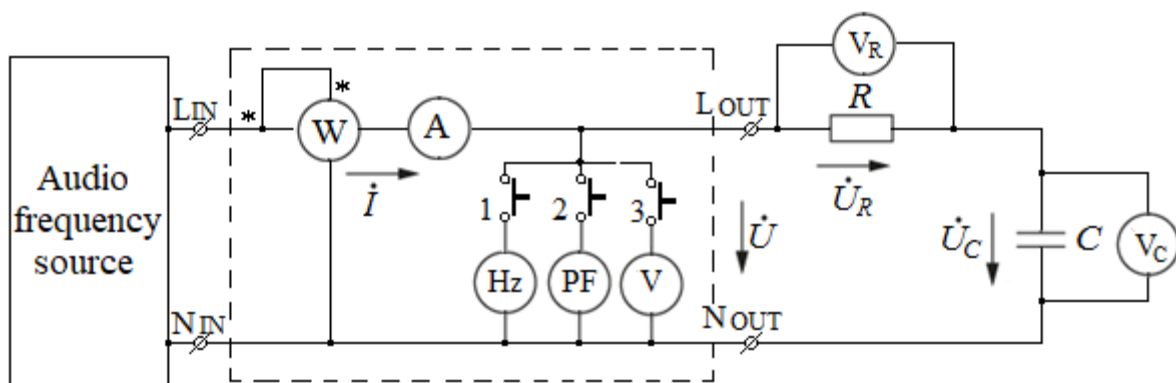


Figure 4.2 – Circuit with a series connection elements  $R, C$

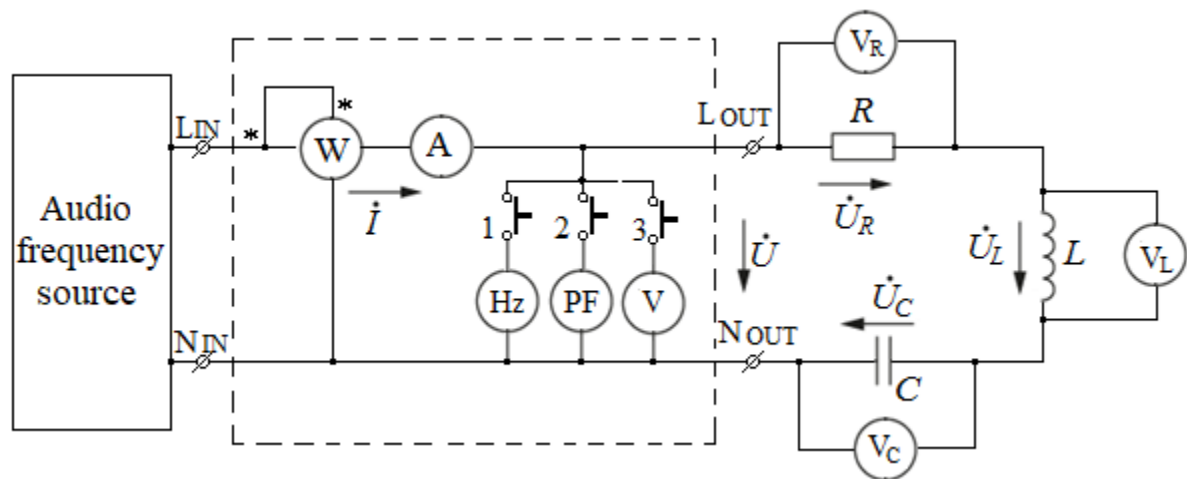


Figure 4.3 – Circuit with a series connection elements  $R, L, C$

Table 4.2

Type of re-search	$U$ , V	$f$ , Hz	$X_L$ , $\Omega$	$Z$ , $\Omega$	$U_R$ , V	$U_L$ , V	$I$ , mA	$\cos\varphi$	$P$ , W	$Q$ , var	$S$ , VA
Theoretical calculation											
Experiment											

Table 4.3

Type of re-search	$U$ , V	$f$ , Hz	$X_C$ , $\Omega$	$Z$ , $\Omega$	$U_R$ , V	$U_C$ , V	$I$ , mA	$\cos\varphi$	$P$ , W	$Q$ , var	$S$ , VA
Theoretical calculation											
Experiment											

Table 4.4

Type of re-search	$U$ , V	$f$ , Hz	$X_L$ , $\Omega$	$X_C$ , $\Omega$	$Z$ , $\Omega$	$U_R$ , V	$U_L$ , V	$U_C$ , V	$I$ , mA	$\cos\varphi$	$P$ , W	$Q$ , var	$S$ , VA
Theoretical calculation													
Experiment													

### 4.3 Processing experimental results

4.3.1 For circuits in figures 4.1 – 4.3, based on the results of experiments, draw phasor diagrams of current and voltages.

4.3.2 For the circuits in figures 4.1 – 4.3, using the results of experiments, calculate the active resistance  $R$ , reactances  $X_C$ ,  $X_L$  and impedance  $Z$ . The results of

the calculation should be written down in tables 4.2, 4.3, 4.4 in the Experiment line. Draw in scale impedance triangles for the circuits in figures 4.1 – 4.3.

4.3.3 For the schemes in figures 4.1 – 4.3, use the results of experiments to calculate the  $Q$  reactive power and the  $S$  apparent power. The results of the calculation should be written down in tables 4.2, 4.3 and 4.4 in the Experiment line.

4.3.4 Verification of the ratios that are connecting the  $P$ ,  $Q$  and  $S$  powers. Draw in scale power triangles for the circuits in figures 4.1 – 4.3.

4.3.5 Verification of the Kirchhoff's voltage law using an experimental data for the schemes in figures 4.1 – 4.3.

### 4.3 Methodological guidelines

Let's consider the procedure of construction of the phasor diagram of current and voltages for the  $RL$ -circuit in figure 4.1:

- 1) Choose the scale of the current and plot the current vector  $\dot{I}$  (phasor).
- 2) Choose the scale of the voltage and plot the voltage vectors across the circuit's elements:
  - a) the voltage vector across an active resistance  $\dot{U}_R$  is plotted in the direction that coincide with the current vector, since  $\dot{U}_R$  coincides in phase with the current  $\dot{I}$ ;
  - b) the voltage vector across an inductor  $\dot{U}_L$  is plotted in counterclockwise at a  $\pi/2$  angle to the current vector, since  $\dot{U}_L$  leads in phase on the current  $\dot{I}$  by a  $\pi/2$  angle.

The phasor diagram of the current and voltages for the  $RL$ -circuit is shown in figure 4.4a. In the phasor diagram in figure 4.4a, the angle  $\varphi$ , equal to the difference between the initial phases of voltage and current:  $\varphi = \psi_u - \psi_i$ , is measured in the direction from the current vector to the voltage vector. Angle  $\varphi > 0$ , since the voltage at the input of the  $RL$ -circuit leads the current.

A triangle formed by voltage vectors with sides which is equal to  $U$ ,  $U_R$ ,  $U_L$  is called a voltage triangle (figure 4.4, a).

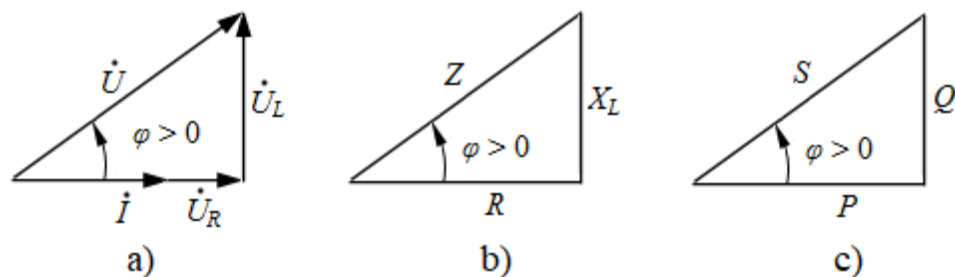


Figure 4.4 – Phasor diagram of voltages, triangles of impedance and power

Reactance  $X_L$ , magnitude  $z$  and complex impedance  $\underline{Z}$  for the  $RL$ -circuits are determined by the formulas:

$$X_L = \omega L; \quad z = \sqrt{R^2 + X_L^2}; \quad \underline{Z} = R + j\omega L = R + jX_L = ze^{j\varphi}.$$

The complex value of current in the  $RL$ -circuit and the complex values of voltages across the elements  $R$  and  $L$  are calculated by the formulas:

$$\dot{I} = \frac{\dot{U}}{R + jX_L} = \frac{\dot{U}}{\underline{Z}}; \quad \dot{U}_R = R\dot{I}; \quad \dot{U}_L = jX_L\dot{I}.$$

Resistance, reactance and impedance for the  $RL$ -circuit based on the experimental data are calculated by the formulas:

$$R = \frac{U_R}{I}; \quad X_L = \frac{U_L}{I}; \quad Z = \frac{U}{I}.$$

The impedance triangle is similar to the voltage triangle and is shown in figure 4.4b.

According to experimental data, reactive and apparent power are calculated by the formulas:

$$Q = UI \sin \varphi = I^2 X_L; \quad S = UI = I^2 Z.$$

Active, reactive and apparent power are related by:

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

The power triangle for the  $RL$ -circuit is shown in figure 4.4c.

Verification of the Kirchhoff's voltage law using an experimental data for the  $RL$ -circuit carried out by the formula:

$$U = \sqrt{U_{R1}^2 + U_L^2}.$$

Similar calculations are performed for the schemes in figures 4.2 and 4.3.

## **5 Laboratory work №5. Research of a branched electrical circuit of a single-phase sinusoidal current**

*Purposes* are to perform experimental researches of branched AC circuits and to plot the phasor diagrams of currents and voltages.

### **5.1 Preparation for work**

5.1.1 Revise topic of the Linear electrical circuits of a single-phase sinusoidal current in the Electrical engineering textbook.

5.1.2 For the scheme in figure 5.1, by the values of the parameters in accordance with your variant (table 5.1), do the following:

a) calculate the complex values of currents in each branch of the circuit and the complex values of voltages on each element of the circuit; write the effective values of currents and voltages in table 5.2 in the Theoretical calculation line;

b) calculate the  $\cos\varphi$  power factor,  $P$  active,  $Q$  reactive,  $S$  apparent power;

write the results of the calculations in table 5.2 in the Theoretical calculation line;

c) based on the results of calculations, plot phasor diagrams of currents and voltages.

For the scheme in figure 5.2, by the values of the parameters in accordance with your variant (table 5.1), do the following:

a) calculate the complex values of the currents in each branch of the circuit; write effective values of currents in table 5.3 in the Theoretical calculation line;

b) calculate the power factor  $\cos\varphi$ , active  $P$ , reactive  $Q$ , apparent  $S$  power; write the results of the calculations in table 5.3 in the Theoretical calculation line;

c) based on the results of calculations, plot phasor diagrams of currents.

5.1.3 Draw schemes (figures 5.1, 5.2) and tables 5.2, 5.3.

## 5.2 Assignment to perform the laboratory work

5.2.1 Assemble an electrical circuit according to the scheme in figure 5.1. Set the circuit parameters according to the given variant (table 5.1).

5.2.2 Measure currents at the input of the circuit and in the parallel branches, active power and power factor  $\cos\varphi$ . The results write down in table 5.2 in the Experiment line.

5.2.3 Measure voltages across each element of the circuit. The results write down in table 5.2 in the Experiment line.

5.2.4 Assemble an electrical circuit according to the scheme in figure 5.2. Set the circuit parameters according to the given variant (table 5.1).

5.2.5 Measure the currents in each branch, the voltage at the input circuit. The results write down in table 5.3 in the Experiment line.

5.2.6 Measure active power and power factor  $\cos\varphi$ . The results write down in table 5.3 in the Experiment line.

Table 5.1

Variant №	1	2	3	4	5	6
$R_1, \Omega$	100	150	80	100	75	100
$R_2, \Omega$	150	100	100	80	50	75
$C, \mu\text{F}$	5	6	4	5	7	6
$L, \text{mH}$	20	30	15	25	40	35
$f, \text{Hz}$	400	300	450	400	350	300
$U, \text{V}$	3	3	3	3	3	3

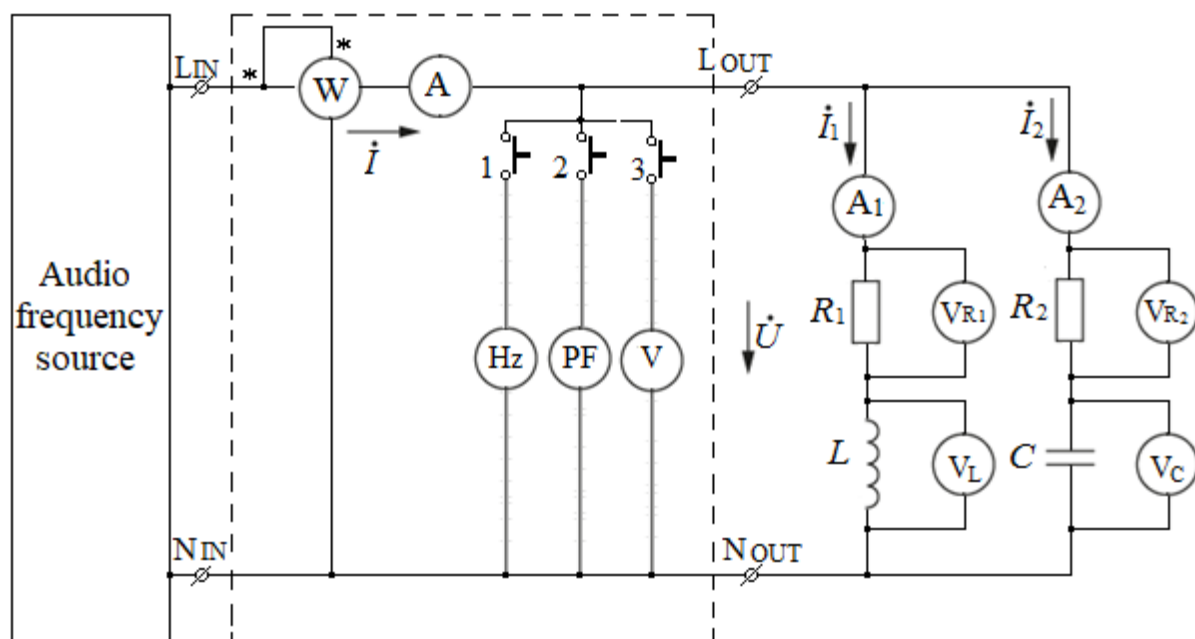


Figure 5.1 – Circuit's scheme with parallel connection of branches

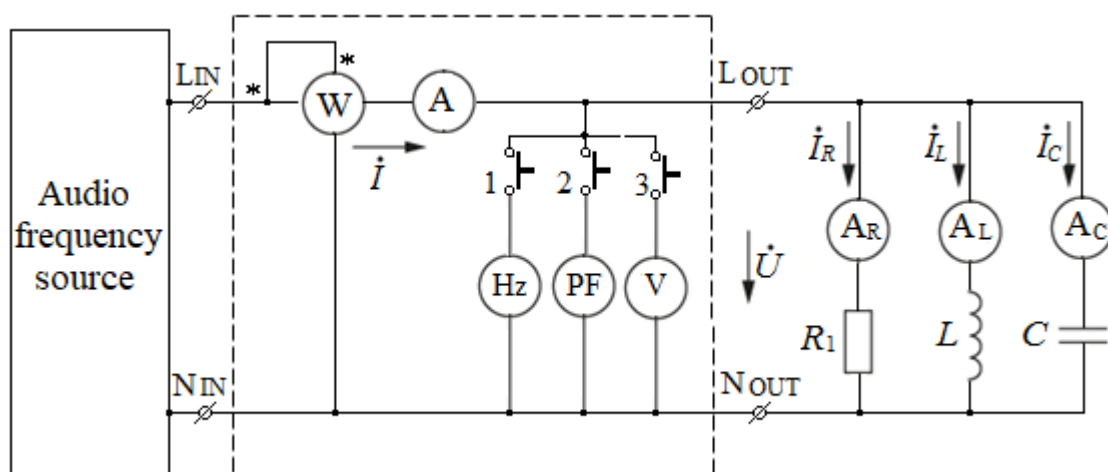


Figure 5.2 – Circuit's scheme with parallel connection of resistor, inductor and capacitor

Table 5.2

Type of research	$U$ V	$U_{R1}$ V	$U_{R2}$ V	$U_L$ V	$U_C$ V	$I$ mA	$I_1$ mA	$I_2$ mA	$\cos\varphi$	$P$ , W	$Q$ , var	$S$ , VA
Theoretical calculation												
Experiment												

Table 5.3

Type of re- search	$U$ V	$I$ mA	$I_1$ mA	$I_2$ mA	$I_3$ mA	$\cos\varphi$	$P$ , W	$Q$ , var	$S$ , VA
Theoretical calculation									
Experiment									

### 5.3 Processing experimental results

5.3.1 For the scheme in figure 5.1, based on the results of experiments, plot phasor diagrams of currents and voltages.

5.3.2 For the scheme in figure 5.1, carry out verification of the Kirchhoff's laws using an experimental data.

5.3.3 According to the experimental data, calculate the reactive  $Q$  and the apparent  $S$  powers of the circuit. The results write down in table 5.2 in the Experiment line. Check the ratios connecting the  $P$ ,  $Q$ ,  $S$  powers. Plot a power triangle.

5.3.4 For the circuit's scheme in figure 5.2, based on the results of experiments, plot in a scale a phasor diagram of currents and input voltage.

5.3.5 For the scheme in figure 5.2, carry out verification of the Kirchhoff's current law using an experimental data.

5.3.6 Using an experimental data, calculate the reactive  $Q$  power and the apparent  $S$  power of the circuit. The results write down in table 5.3 in the Experiment line. Check the ratios connecting the  $P$ ,  $Q$ ,  $S$  powers. Plot a power triangle.

### 5.4 Methodological guidelines

The procedure of construction of the phasor diagram of currents and voltages for an electrical circuit in figure 5.1:

- on the complex axes, we set aside the voltage vector at the input of the circuit  $\vec{U}$  along the real axis direction (we assume that the initial phase of the input voltage is zero);

- using the experimental data, calculate the phase difference  $\varphi_1$  between the current  $\vec{I}_1$  and the input voltage  $\vec{U}$ , and the phase difference  $\varphi_2$  between the current  $\vec{I}_2$  and the input voltage  $\vec{U}$  according to the formulas:

$$\varphi_1 = \arctg \frac{U_L}{U_{R1}}; \quad \varphi_2 = \arctg \frac{U_C}{U_{R2}};$$

- plot the current vector  $\vec{I}_1$  at an angle  $\varphi_1$  clockwise to the voltage vector  $\vec{U}$  (the current  $\vec{I}_1$  lags in phase by the angle  $\varphi_1$  from the input voltage  $\vec{U}$ );

- plot the current vector  $\vec{I}_2$  at an angle  $\varphi_2$  counterclockwise to the voltage vector  $\vec{U}$  (the current  $\vec{I}_2$  leads on the input voltage  $\vec{U}$  by the phase shift angle  $\varphi_2$ );

- by adding up of the vectors  $\vec{I}_1$  and  $\vec{I}_2$  according to the parallelogram rule, we

can determine the  $\dot{I}$  input current of the circuit in accordance with the Kirchhoff's current law:

$$\dot{I} = \dot{I}_1 + \dot{I}_2;$$

- the voltage vector across the inductor  $\dot{U}_L$  plots in counterclockwise at an angle of  $\pi/2$  to the current vector  $\dot{I}_1$ , since the voltage across the inductor  $\dot{U}_L$  leads the current  $\dot{I}_1$  by the angle of  $\pi/2$ ;

- the voltage vector at the active resistor  $\dot{U}_{R1}$  plots parallel to the current vector  $\dot{I}_1$ , since the voltage at the active resistance  $\dot{U}_{R1}$  is in phase with the current  $\dot{I}_1$ ;

- the voltage vector across capacitor  $\dot{U}_C$  plots clockwise at an angle of  $\pi/2$  to the current vector  $\dot{I}_2$ , since the voltage across capacitor  $\dot{U}_C$  lags from the phase of the current  $\dot{I}_2$  by angle of  $\pi/2$ ;

- the voltage vector across active resistor  $\dot{U}_{R2}$  plots in parallel to the current vector  $\dot{I}_2$ , since the voltage across active resistor  $\dot{U}_{R2}$  is in phase with the current  $\dot{I}_2$ .

The voltage vector at the circuit's input is related to the voltages across the circuit's elements using the Kirchhoff's voltage law:

$$\dot{U} = \dot{U}_L + \dot{U}_{R1} = \dot{U}_C + \dot{U}_{R2}.$$

Kirchhoff's voltage law for 5.1 scheme can be verified using the formulas:

$$U = \sqrt{U_{R1}^2 + U_L^2}; \quad U = \sqrt{U_{R2}^2 + U_C^2}.$$

Kirchhoff's current law for 5.1 scheme can be verified using a phasor diagram.

The phasor diagram of currents for 5.2 circuit's scheme is plotted for the case when the current through the branch with the capacitor is more than the current through the branch with inductor  $\dot{I}_C > \dot{I}_L$  (figure 5.3).

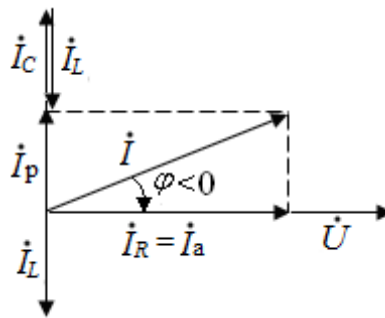


Figure 5.3 – Vector (phasor) diagram of currents for 5.2 scheme

Kirchhoff's current law for 5.2 scheme can be verified using the formula:

$$I = \sqrt{I_R^2 + (I_L - I_C)^2} = \sqrt{I_a^2 + I_r^2},$$

where  $\dot{I}_a = \dot{I}_R$  is active component of the current  $\dot{I}$ ;

$\dot{I}_r = \dot{I}_L - \dot{I}_C$  is reactive component of the current  $\dot{I}$ .



## 6 Laboratory work №6. Research of the voltage resonance

*Purpose* is an experimental study resonance properties series resonant circuit.

### 6.1 Preparation for work

Revise topic of the voltage resonance in the linear electric circuits section of an Electrical engineering textbook.

Answer the questions and do the following:

- 1) What is mode in an electrical circuit called resonance?
- 2) Where do electric circuit and under what condition the voltage resonance occur?
- 3) Calculate, according to a given variant (table 6.1), the resonant frequency  $f_0$ , the characteristic impedance of the circuit  $\rho$ , the active resistance of the circuit  $R_1$  and  $R_1$  for two values of the quality factor  $Q_1 = 2$  and  $Q_2 = 4$ , the absolute and relative bandwidth for two values of quality factor  $Q_1 = 2$  and  $Q_2 = 4$ .
- 4) Calculate the current  $I_0$ , the voltage  $U_{L0}$  and  $U_{C0}$  at resonance for two values of Q-factor  $Q_1 = 2$  and  $Q_2 = 4$ .
- 5) Plot a phasor diagram of the current and voltage of a series oscillatory circuit at resonance for  $Q_1 = 2$ .
- 6) Plot the frequency characteristics of the serial oscillatory circuit  $X_L(f)$ ,  $X_C(f)$ ,  $X(f) = X_L(f) - X_C(f)$ ,  $\varphi(f)$ .
- 7) Construct the resonance curves  $I/I_0 = F(f/f_0)$  for two different Q factors, show how the bandwidth is determined and how it depends on the quality factor of the circuit.
- 8) Draw a scheme in figure 6.1 and table 6.2.

Table 6.1

Variant №	$U$ , V	$L$ , mH	$C$ , $\mu\text{F}$
1	3	15	0.07
2	4	10	0.09
3	5	20	0.04
4	3	25	0.03
5	4	14	0.05
6	5	12	0.06

### 6.2 Assignment to perform the laboratory work

6.2.1 Assemble the serial oscillation circuit (figure 6.1). Provide measuring instruments for measuring the current and voltages across the circuit's elements. Set the input voltage and the parameters of the elements, according to the variant of the assignment (table 6.1), the resistor  $R_1$ , corresponding to the quality factor  $Q_1 = 2$ .

6.2.2 By changing the frequency of the input voltage from  $0,2 \cdot f_0$  to  $2 \cdot f_0$  (including  $f_0$ ), measure approximately 15<sup>th</sup> points of dependencies  $I(f)$ ,  $U_R(f)$ ,  $U_L(f)$ ,  $U_C(f)$  for a circuit with a quality factor  $Q_1 = 2$ . The results write down in table 6.2.

6.2.3 Set the resistance value of the resistor  $R_2$  for the quality factor  $Q_2 = 4$ . Changing the frequency of the input voltage from  $0,2 \cdot f_0$  to  $2 \cdot f_0$ , measure approximately 15<sup>th</sup> points of the  $I(f)$  dependence. The results write down in table 6.2.

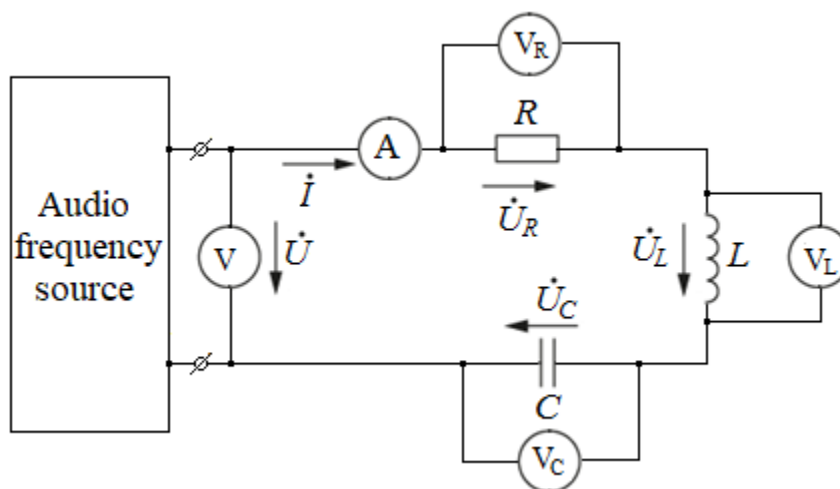


Figure 6.1 – Series oscillation circuit

Table 6.2

experience №	$f$ , Hz	$I$ , mA	$Q_1 = 2$				$\varphi_{in}, ^\circ$	$I$ , mA
			$U_R$ , V	$U_L$ , V	$U_C$ , V			
1								
2								
3								
...								
14								
15								

### 6.3 Processing experimental results

6.3.1 According to the experimental data (table 6.2), plot the resonance curves  $I(f)$ ,  $U_R(f)$ ,  $U_L(f)$ ,  $U_C(f)$  and compare them with the theoretical curves. Experimentally determine the resonant frequency  $f_0$ . Mark the current  $I_0$  and voltage  $U_{R0}$ ,  $U_{L0}$ ,  $U_{C0}$  in the resonance mode on the graph.

6.3.2 Plot in a graph the dependencies  $I/I_0 = F(f/f_0)$  for both  $Q$ -factors  $Q_1$  and  $Q_2$  according to the data in table 6.2. Determine from them the half-power frequencies  $f_1, f_2$ , absolute and relative bandwidth.

6.3.3 Using an experimental data calculate and plot the dependence  $\varphi_{in}(f)$ . Compare it curve with theoretical one  $\varphi_{in}(f)$ .

6.3.4 According to the experimental data, determine the  $Q$ -factor of the  $Q_1$  circuit and compare it with the given value.

6.3.5 Plot in scale phasor voltage diagrams using experimental values for frequency  $f_0$  and half-power frequencies  $f_1, f_2$  for  $Q$ -factor  $Q_1 = 2$ .

6.3.6 Make a conclusion about of the influence of  $Q$ -factor on the amount of bandwidth, on the character of the circuit in the resonant mode and at the half-power frequencies.

## 6.4 Methodological guidelines

6.4.1 In a circuit with a series connection of elements  $R, L, C$  in the resonance mode, the phase difference between voltage and current at the input of the circuit is zero  $\varphi = 0$ . Voltage resonance occurs when the input reactance is equal to zero:

$$X_0 = X_{L0} - X_{C0} = 0 \rightarrow X_{L0} = X_{C0} \rightarrow \omega_0 L = \frac{1}{\omega_0 C}.$$

6.4.2 Resonance frequency  $\omega_0$  or  $f_0$ :

$$\omega_0 = \frac{1}{\sqrt{LC}}; \quad f_0 = \frac{1}{2\pi\sqrt{LC}}.$$

6.4.3 The characteristic resistance  $\rho = X_{L0} = X_{C0}$  is determined by the formula:

$$\rho = \sqrt{\frac{L}{C}}.$$

6.4.4 The  $Q$ -factor and attenuation  $d$  of a circuit with a series connection of the  $R, L, C$  elements are determined by the expressions:

$$Q = \frac{U_{L0}}{U} = \frac{U_{C0}}{U} = \frac{\omega_0 L}{R} = \frac{1/\omega_0 C}{R} = \frac{\rho}{R}; \quad d = \frac{1}{Q} = \frac{R}{\rho}.$$

6.4.5 The minimum impedance of the circuit:  $Z_0 = R$ , the maximum current in the resonance mode:

$$I_0 = \frac{U}{R}.$$

6.4.6 In the resonance mode, the voltages across the inductor  $U_{L0}$  and capacitor  $U_{C0}$  are equal and opposite in phase:

$$U_{L0} = U_{C0} = \rho I_0; \quad \dot{U}_{L0} = j\rho \dot{I}_0; \quad \dot{U}_{C0} = -j\rho \dot{I}_0.$$

6.4.7 The frequency response  $\varphi_{in}(\omega)$  (or  $\varphi_{in}(f)$ ) is calculated by the formula:

$$\varphi_{in}(\omega) = \arctg \frac{\omega L - 1/\omega C}{R} = \arctg \frac{U_L - U_C}{U_R}.$$

6.4.8 Absolute bandwidth is calculated by the formula:

$$S_A = \frac{f_0}{Q} = f_0 d.$$

6.4.9 The resonance curve of the current  $I(f)$  is shown in figure 6.2.

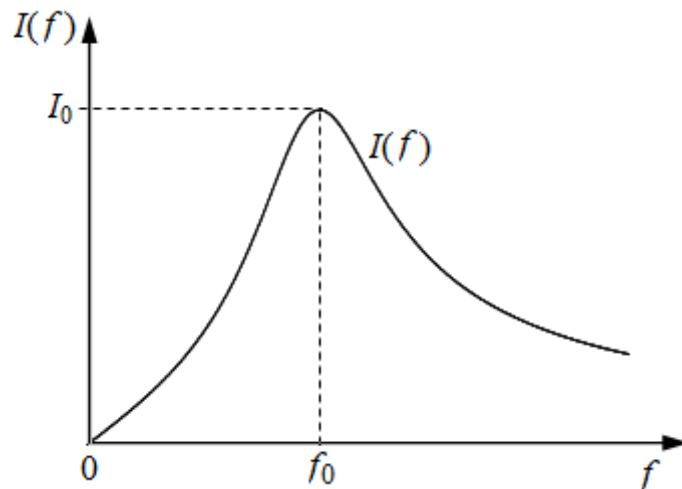


Figure 6.2 – Resonance curve of current  $I(f)$

6.4.10 The resonance curves  $U_R(f)$ ,  $U_L(f)$ ,  $U_C(f)$  are shown in figure 6.3.

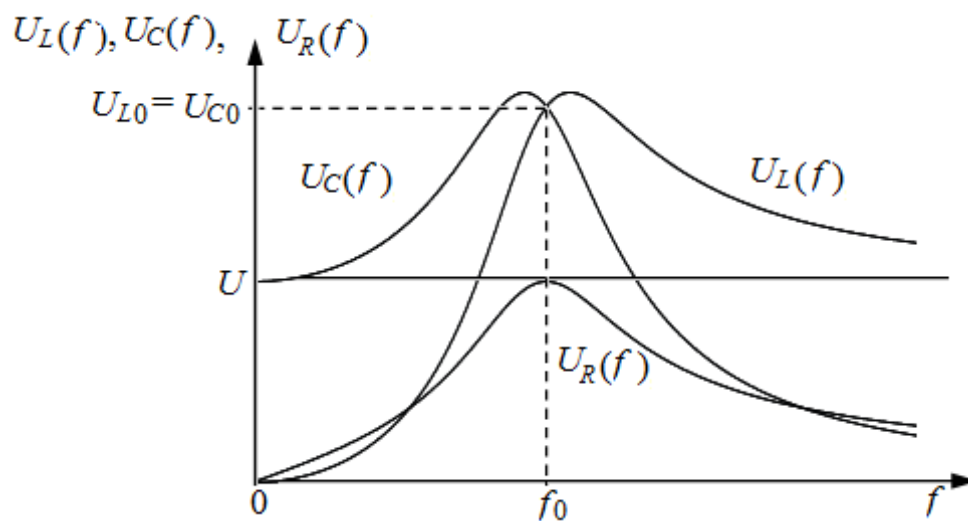


Figure 6.3 – Resonance curves  $U_L(f)$ ,  $U_C(f)$  and  $U_R(f)$

## 7 Laboratory work №7. Research of the current resonance

*Purpose* is experimental study of the resonant properties of a parallel oscillatory circuit.

### 7.1 Preparation for work

Revise topic of the current resonance in the linear electric circuits section of an Electrical engineering textbook.

Answer the questions and do the following:

1) In which electrical circuits and under what condition does current resonance occur?

2) Calculate the resonant frequency  $\omega_0$  and  $f_0$ , characteristic impedance  $\rho$  and characteristic (wave) conductivity of the circuit  $\gamma$ ,  $Q$ -factor and attenuation  $d$  of the resonant circuit for the parallel oscillation circuit (figure 7.1) according to a given variant (table 7.1).

3) Calculate the currents in the branches of the  $I_0$ ,  $I_{R0}$ ,  $I_{L0}$ ,  $I_{C0}$  and active power at the resonance mode.

4) Plot the frequency characteristics of the parallel oscillatory circuit (figure 7.1):  $B_L(f)$ ,  $B_C(f)$ ,  $B(f) = B_L(f) - B_C(f)$ ,  $\varphi_{in}(f)$ .

5) Plot resonance curves  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$ , for a parallel oscillatory circuit (figure 7.1).

6) Plot a phasor diagram in the resonance mode for a parallel oscillatory circuit (figure 7.1).

7) Draw scheme in a figure 7.1 and table 7.2.

### 7.2 Assignment to perform the laboratory work

7.2.1 Assemble an electrical circuit according to the scheme in figure 7.1. Set the input voltage of the circuit and the parameters of the elements according to the variant of the assignment (table 7.1).

7.2.2 Changing the frequency of the input voltage from  $0.1 \times f_0$  to  $2 \times f_0$ , measure the dependencies  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$ . The results write down in table 7.2.

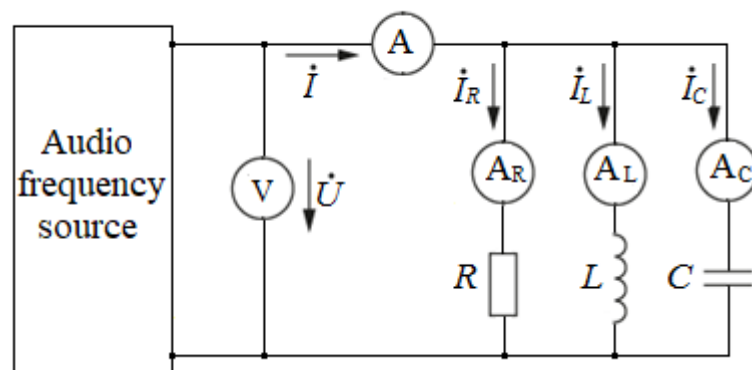


Figure 7.1 – Parallel oscillation circuit

Table 7.1

Variant №	$U, V$	$L, mH$	$C, \mu F$	$R, \Omega$
1	3	10	0,5	250
2	3	5	0,8	200
3	3	8	0,7	220
4	3	6	0,4	240
5	3	7	0,9	200
6	3	3	0,6	150

Table 7.2

experience №	$f, Hz$	$I, mA$	$I_R, mA$	$I_L, mA$	$I_C, mA$	$\varphi_{in}, deg$
1						
2						
3						
...						
14						
15						

### 7.3 Processing experimental results

7.3.1 According to the experimental data, plot the resonance curves  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$ .

7.3.2 Using the experimental curves  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$ , determine the resonant frequency  $f_0$ , currents in the branches of the circuit  $I_0$ ,  $I_{R0}$ ,  $I_{L0}$ ,  $I_{C0}$  in the resonance mode. Compare with calculated data.

7.3.3 From the experimental curves  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$ , determine the quality factor  $Q$  and the attenuation  $d$  of the loop. Compare with calculated data.

7.3.4 Based on the found  $Q$  factor, determine the characteristic conductivity  $\gamma$ . Compare with the calculated value of  $\gamma$ .

7.3.5 According to the experimental data, calculate  $\varphi_{in}(f)$ , write down the calculation results in table 7.2. Plot a graph  $\varphi_{in}(f)$ .

7.3.6 According to the experimental data to plot a phasor diagram of currents in the resonance mode.

### 7.4 Methodological guidelines

7.4.1 In the oscillatory circuit with parallel connection of the elements  $R$ ,  $L$ ,  $C$  (figure 7.1) a current resonance occurs. In the resonance mode, the phase difference between the voltage and the current at the circuit input is zero  $\varphi = 0$ . The condition of resonance currents  $\varphi = 0$  means the zero input reactive conductivity:

$$B_0 = B_{L0} - B_{C0} = 0 \rightarrow B_{L0} = B_{C0} \rightarrow \frac{1}{\omega_0 L} = \omega_0 C.$$

The total input conductance of the circuit is equal to the active conductivity  $\underline{Y} = g$ .

7.4.2 The *resonant frequency*  $\omega_0$  and  $f_0$  are determined by the expressions:

$$\omega_0 = \frac{1}{\sqrt{LC}}; \quad f_0 = \frac{1}{2\pi\sqrt{LC}}.$$

7.4.3 The *characteristic (wave) conductivity* of the contour  $\gamma$  is equal to:

$$\gamma = \frac{1}{\omega_0 L} = \omega_0 C = \sqrt{\frac{C}{L}}.$$

7.4.4 The *Q-factor* of the parallel circuit (figure 7.1) determines how many times the current in the inductor and in the capacitor exceeds the current at the circuit's input in the resonance mode and is calculated by the formula:

$$Q = \frac{I_{L0}}{I_0} = \frac{I_{C0}}{I_0} = \frac{U}{\omega_0 L U g} = \frac{U \omega_0 C}{U g} = \frac{\gamma}{g}.$$

7.4.5 The current in the common branch  $I_0$  and in the parallel branches  $I_{R0}$ ,  $I_{L0}$ ,  $I_{C0}$  in the resonance mode is calculated by the formulas:

$$I_0 = I_{R0} = \frac{U}{R} = U g; \quad I_{L0} = U \frac{1}{\omega_0 L} = U \frac{1}{2\pi f_0 L}; \quad I_{C0} = U \omega_0 C = U 2\pi f_0 C.$$

7.4.6 The currents in the inductor and capacitor in the resonance mode (figure 7.1) are equal to each other and opposite in phase: the current in the inductor lags in phase from the voltage by  $90^\circ$ , and the current in the capacitor leads the voltage by  $90^\circ$ . The current at the input of the parallel circuit (figure 7.1) at resonance is in phase with the voltage and is equal to the current at the active resistor:

$$\dot{I}_{L0} + \dot{I}_{C0} = 0 \rightarrow \dot{I}_0 = \dot{I}_{L0} + \dot{I}_{C0} + \dot{I}_R = \dot{I}_R.$$

The phasor diagram of currents for a parallel circuit (figure 7.1) in the resonant mode is shown in figure 7.2.

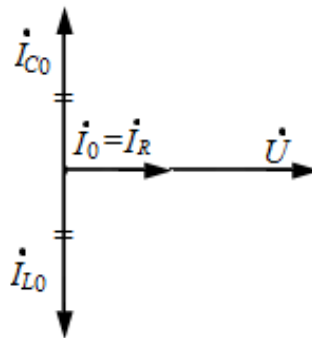


Figure 7.2 – Phasor diagram of current in resonance mode

7.4.7 Plot the resonance curves  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$ , the following expressions are used:

$$I(f) = U \sqrt{g^2 + \left( \frac{1}{2\pi fL} - 2\pi fC \right)^2}; \quad I_R(f) = Ug; \quad I_L(f) = \frac{U}{2\pi fL}; \quad I_C(f) = U 2\pi fC.$$

The resonance curves  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$  are presented in figure 7.3.

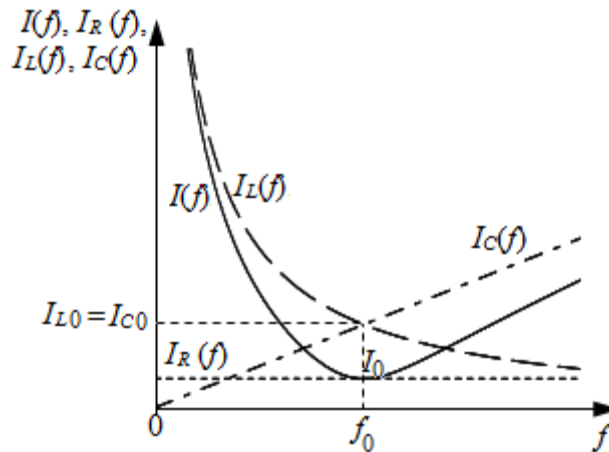


Figure 7.3 – Resonance curves  $I(f)$ ,  $I_R(f)$ ,  $I_L(f)$ ,  $I_C(f)$

## 8 Laboratory work №8. The study of the three-phase circuits when the source's and consumer's phases are connected in a star

*Purpose* is to obtain skills of the theoretical and experimental researches of the three-phase circuits with neutral wire and without one, when the source's and consumer's phases are connected in a star.

### 8.1 Preparation for work

Revise the section of three-phase electrical circuits of an Electrical engineering textbook.

Answer the questions and do the following:

- 1) What is electrical circuit called a three-phase circuit?
- 2) Which is three-phase EMF system called symmetrical system? For a symmetrical EMF system, write the instantaneous ( $e_A$ ,  $e_B$ ,  $e_C$ ) and complex effective values ( $\dot{E}_A$ ,  $\dot{E}_B$ ,  $\dot{E}_C$ ).
- 3) Plot a phasor diagram of a symmetrical three-phase EMF system.
- 4) What is connection of the phase windings of a three-phase generator called star connection? Draw a connection scheme of the phases of a three-phase generator in a star.



5) Which are voltages called phase voltages and which ones line voltages? How are phase and line voltages related?

6) What is mode of a three-phase circuit called symmetrical mode?

7) What are the relationships related to phase voltages and line voltages in a symmetric mode?

8) What are wires called line wires? Which is wire called neutral wire?

9) Which are currents called phase currents and which ones line currents? How are the phase and line currents connected in a three-phase circuit when the phases of the source and consumer are connected in a star?

10) How is the current in the neutral wire determined? What is the current in the neutral wire in a symmetrical mode?

11) Calculate the currents and voltages, according to a given variant (table 8.1), in a three-phase circuit when connecting the source and consumer phases of the star in a symmetric mode with a neutral wire (figure 8.1). The results of the theoretical calculation should be written down in table 8.2 in the line of Theoretical calculation. Symmetric mode.

12) Calculate the currents and voltages, according to a given variant (table 8.1), in a three-phase circuit when the phases of the source and consumer are connected in a star in a symmetric mode without a neutral wire (figure 8.2). The results of the theoretical calculation should be written down in table 8.3 in the line of Theoretical calculation. Symmetric mode.

Table 8.1

Variant №	Phase voltages of generator $U_{AN} = U_{BN} = U_{CN} = U_{ph}, \text{ V}$	Consumer's phase resistances $R_a = R_b = R_c = R, \Omega$	Open phase of consumer
1	10	75	<i>an</i>
2	15	100	<i>bn</i>
3	20	150	<i>cn</i>
4	18	200	<i>an</i>
5	12	100	<i>bn</i>
6	25	300	<i>cn</i>

13) According to the calculation results, plot a phasor (topographic) voltage diagram and a phasor current diagram for a three-phase circuit when the phases of the source and consumer are connected in a star in a symmetric mode.

14) Calculate the active and apparent powers of the three-phase circuit when the phases of the source and consumer are connected in a star in a symmetric mode.

15) Plot a phasor (topographic) voltage diagram and a phasor current diagram for a three-phase circuit when connecting the source and consumer phases with a star with a neutral wire when one of the consumer phases is open, according to a given variant (table 8.1).

From the diagram, determine the line and phase voltages of the consumer, the currents in the three-phase line and the current in the neutral wire.

The results should be written down in table 8.2 in the line of Theoretical calculation. Open consumer's phase.

16) Plot a phasor (topographic) voltage diagram and a phasor current diagram for a three-phase circuit when connecting the source and consumer phases with a star without a neutral wire if one of the open consumer's phases, according to a given variant (table 8.1).

From the diagram, determine the line and phase voltages of the consumer, the bias voltage of the neutral  $U_{nN}$ , the currents in the three-phase line.

The results should be written in table 8.3 in the line of Theoretical calculation. Open consumer's phase.

17) Draw schemes 8.1, 8.2 and tables 8.2, 8.3.

## 8.2 Assignment to perform the laboratory work

8.2.1 Assemble the three-phase circuit according to the scheme in figure 8.1. Set the generator phase voltages  $U_{AN} = U_{BN} = U_{CN} = U_{ph}$  and the consumer's phase resistances  $R_a = R_b = R_c = R$  according to the assignment variant (table 8.1).

8.2.2 Measure line voltages  $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ ; consumer phase voltages  $U_{an}$ ,  $U_{bn}$ ,  $U_{cn}$ ; currents in line  $I_A$ ,  $I_B$ ,  $I_C$  and current in the neutral wire  $I_N$  in a symmetrical mode.

The results should be written in table 8.2 in the line of Experimental researches. Symmetrical mode.

8.2.3 In a three-phase circuit (figure 8.1), open one of the phases of the consumer, according to a given variant (table 8.1).

8.2.4 Measure line voltages  $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ ; consumer phase voltages  $U_{an}$ ,  $U_{bn}$ ,  $U_{cn}$ ; currents in line  $I_A$ ,  $I_B$ ,  $I_C$  and current in the neutral wire  $I_N$  at the open of one of the phases of the consumer.

The results should be written in table 8.2 in the line of Experimental researches. Open consumer's phase.

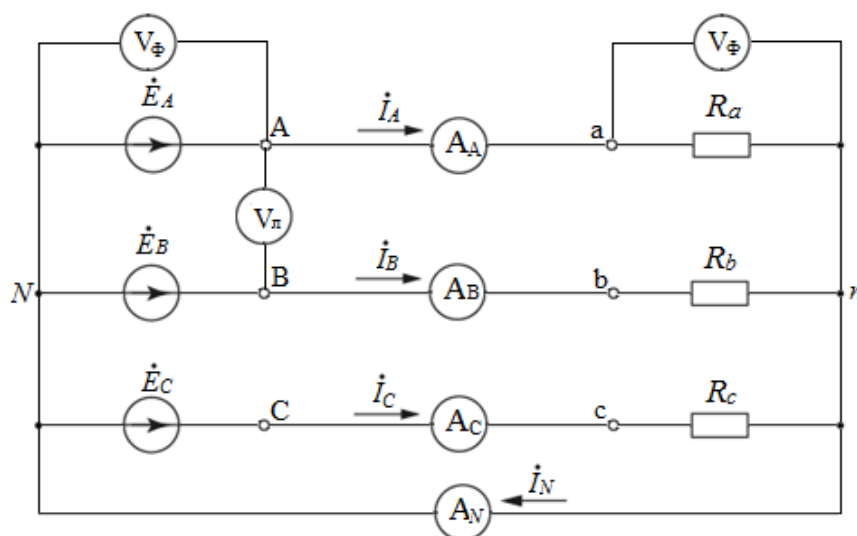


Figure 8.1 – Scheme of a three-phase star-to- star circuit with a neutral wire

Table 8.2

Operation mode	$U_{AN}$ , V	$U_{BN}$ , V	$U_{CN}$ , V	$U_{AB}$ , V	$U_{BC}$ , V	$U_{CA}$ , V	$U_{an}$ , V	$U_{bn}$ , V	$U_{cn}$ , V	$I_A$ , mA	$I_B$ , mA	$I_C$ , mA	$I_N$ , mA
Theoretical calculation													
Symmetrical													
Open phase													
Experimental researches													
Symmetrical													
Open phase													

8.2.5 Assemble the circuit according to the scheme (figure 8.2). Set the generator phase voltages  $U_{AN} = U_{BN} = U_{CN} = U_{ph}$  and the consumer's phase resistances  $R_a = R_b = R_c = R$  according to the variant of the assignment (table 8.1).

8.2.6 Measure line voltages  $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ ; consumer phase voltages  $U_{an}$ ,  $U_{bn}$ ,  $U_{cn}$ ; neutral bias voltage  $U_{nN}$ ; currents in line  $I_A$ ,  $I_B$ ,  $I_C$  in symmetric mode.

The results should be written in table 8.2 in the line of Experimental researches. Symmetric mode.

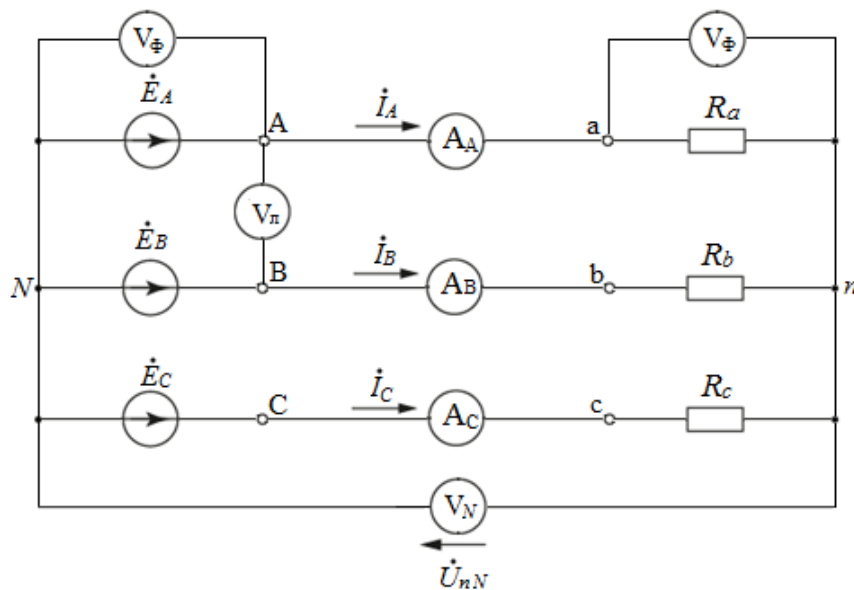


Figure 8.2 – Scheme of a three-phase star-to-star circuit without a neutral wire

8.2.7 In a three-phase circuit (figure 8.2), open one of the phases of the consumer, according to a given variant (table 8.1)

8.2.8 Measure line voltages  $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ ; consumer phase voltages  $U_{an}$ ,  $U_{bn}$ ,  $U_{cn}$ ; neutral bias voltage  $U_{nN}$ ; currents in line  $I_A$ ,  $I_B$ ,  $I_C$  at the open of one of the phases of the consumer.

The results should be written in table 8.2 in the line of Experimental researches. The open consumer's phase.

Table 8.3

Operation mode	$U_{AN},$ V	$U_{BN},$ V	$U_{CN},$ V	$U_{AB},$ V	$U_{BC},$ V	$U_{CA},$ V	$U_{an},$ V	$U_{bn},$ V	$U_{cn},$ V	$I_A,$ mA	$I_B,$ mA	$I_C,$ mA	$U_{nN},$ V
Theoretical calculation													
Symmetrical													
Open phase													
Experimental researches													
Symmetrical													
Open phase													

### 8.3 Processing experimental results

8.3.1 According to the results of experimental researches of 8.2.2 section (table 8.2), plot a phasor (topographic) voltage diagram and a phasor current diagram.

Check the relation between the line voltages and phase voltages.

Calculate the currents from the measured phase voltages and phase resistances of the consumer and compare with those ones found experimentally.

According to the phasor diagram of the currents to show that the current in the neutral wire in the symmetric mode is zero  $I_N = 0$ .

Compare the values of voltages and currents found by calculation (table 8.2, the line of Theoretical calculation, symmetric mode) with experimental values (table 8.2, the line of Experimental researches, symmetric mode).

8.3.2 According to the results of experimental researches of section 8.2.4 (table 8.2, the line of Experimental researches, open consumer's phase) to plot a phasor (topographic) voltage diagram and phasor current diagram.

Calculate the currents from the measure phase voltages and phase resistances of the consumer and compare with those ones found experimentally.

Using the phasor diagram of currents ( $I_L = I_{ph}$ ), determine the current in the neutral wire  $I_N$  when one of the consumer phases is cut off and compare with the measured current  $I_N$  (table 8.2, the line of Experimental researches. Open consumer's phase).

Compare the values of voltages and currents found by calculation (table 8.2, the line of Theoretical calculation. Open consumer's phase) with the experimental values (table 8.2, the line of Experimental researches. Open consumer's phase).

8.3.3 Compare the calculated (table 8.2, line of Theoretical calculation. Symmetric mode) and experimental (section 8.2.6, table 8.3, the Symmetric mode line) voltages and currents in a symmetric mode in a three-phase circuit without a neutral wire.

8.3.4 Compare the values of voltages and currents in a symmetric mode, found experimentally for a three-phase circuit with a neutral wire of 8.2.2 section and without a neutral wire of 8.2.6 section (tables 8.2 and 8.3, the line of Experimental researches. Symmetric mode).

8.3.5 According to the results of experimental researches, 8.2.8 section (table 8.3, the line of Experimental researches. Open consumer's phase) plot a phasor (topographic) voltage diagram and a phasor current diagram.

On the topographic voltage diagram, show the neutral points of the generator  $N$  and the consumer  $n$ . Using the diagram determine the neutral bias voltage, voltage and current across the resistors  $R_b$  and  $R_c$  and compare with those ones found experimentally.

To show how many times the voltages and currents across the resistors  $R_b$  and  $R_c$  are reduced in comparison with the symmetric mode.

8.3.6 Compare the results of theoretical and experimental researches in a three-phase circuit with a neutral wire and without a neutral wire in a symmetric mode and with the open of one of the phases of the consumer.

Make a conclusion about the role of the neutral wire.

## 8.4 Methodological guidelines

A system with three sinusoidal EMFs of the same frequency, with equal amplitudes and shifted in phase relative to each other at an angle of  $120^\circ$  is called a symmetrical three-phase system of EMF.

The instantaneous and complex effective values of a symmetrical EMF system are written as:

$$e_A = E_m \sin \omega t; \quad e_B = E_m \sin(\omega t - 120^\circ); \quad e_C = E_m \sin(\omega t + 120^\circ);$$

$$\dot{E}_A = \frac{E_m}{\sqrt{2}} = E; \quad \dot{E}_B = \frac{E_m}{\sqrt{2}} e^{-j120^\circ} = E e^{-j120^\circ}; \quad \dot{E}_C = \frac{E_m}{\sqrt{2}} e^{j120^\circ} = E e^{j120^\circ}.$$

8.4.1 Phasor (topographic) diagram of line ( $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ ) and phase ( $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ ) voltages combined with the phasor current diagram in a symmetric mode for a three-phase circuit with neutral and without the neutral wire is shown in figure 8.3.

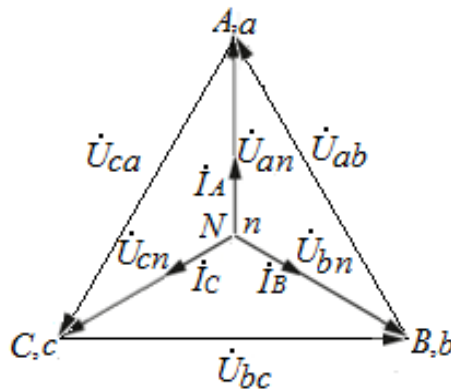


Figure 8.3 – Topographic voltage diagram and current phasor diagram in symmetric mode for a three-phase circuit with a neutral wire and without a neutral wire

From the phasor diagram of currents, it follows that the current in the neutral wire in the circuit with a neutral wire (figure 8.1) is zero:

$$\dot{I}_N = \dot{I}_A + \dot{I}_B + \dot{I}_C = 0.$$

In the scheme without a neutral wire (figure 8.2) in a symmetric mode, the phasor (topographic) voltage diagram and phasor current diagram will not change. bias voltage of neutral  $U_{nN} = 0$ .

When one of the consumer phases is open, for example, *an* phase (figure 8.4, a), the potentials of the points *N* and *n* are the same in a three-phase circuit with a neutral wire, and the topographic voltage diagram remains the same as in the symmetrical mode.

Current  $I_A = 0$ , currents  $I_B$  and  $I_C$  are the same as in the symmetrical mode. The current in the neutral wire is determined from the phasor current diagram (figure 8.4, b) according to the first Kirchhoff law (Kirchhoff's current law):

$$\dot{I}_N = \dot{I}_B + \dot{I}_C.$$

When one of the consumer phases opens, for example, the *an* phase (figure 8.5a), in the three-phase circuit without a neutral wire, the potentials of points *N* and *n* become different. The resistors in phases *b* and *c* are connected in series and for each of these resistors there is half the line voltage  $\dot{U}_{BC}$ . On the topographic diagram, point *n* is located in the middle of the segment *BC*. Topographic voltage diagram is presented in figure 8.5, b.

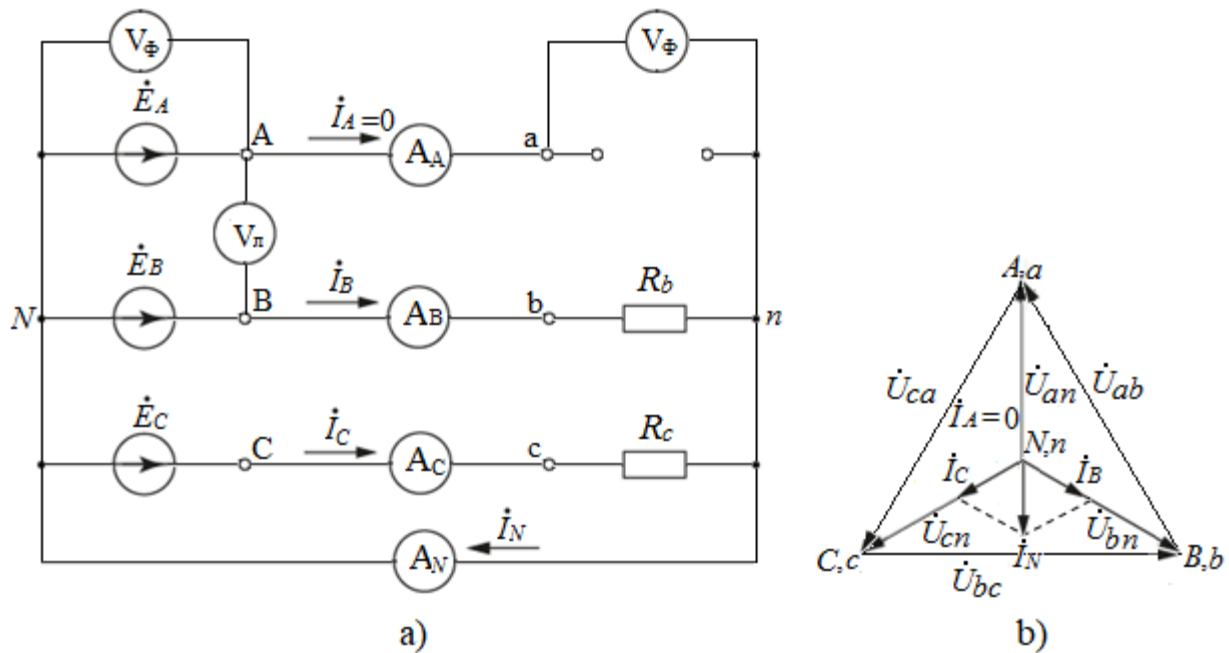


Figure 8.4 – Three-phase circuit with a neutral wire when the consumer phase *an* is opened



## 9 Laboratory work №9. The study of the three-phase circuit when connecting the phases of the consumer by triangle

*Purpose* is obtaining the skills of theoretical and experimental research of the symmetric mode of a three-phase circuit when connecting the phases of a consumer by triangle.

### 9.1 Preparation for work

Revise the section of three-phase electrical circuits of an Electrical engineering textbook.

Answer the questions and do the following:

1) Which is phase connection of a three-phase consumer called a delta connection?

2) Which are voltages called phase voltages and which ones line voltages? How are the phase and line voltages of a delta-connected consumer?

3) Which are currents called phase currents and which ones line currents? How are the phase and line currents in the three-phase circuit when the phases of the consumer are connected in a triangle? What is the ratio of phase and line currents in a symmetrical mode?

4) What is symmetrical mode of a three-phase circuit called?

5) For a three-phase circuit when connecting the phases of a three-phase generator by a star, and the consumer phases by a triangle (figure 9.1), calculate the line voltages  $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ , phase currents  $I_{ab}$ ,  $I_{bc}$ ,  $I_{ca}$  in consumer phases, line currents  $I_A$ ,  $I_B$ ,  $I_C$  in symmetric mode, according to a given variant (table 9.1). The results of the theoretical calculation should be written down in table 9.2 in the line of Theoretical calculation. Symmetric mode.

6) According to the results of calculations, plot a phasor voltage diagram and a phasor current diagram in a symmetric mode.

7) Draw figure 9.1 and table 9.2.

Table 9.1

Variant №	Phase voltage of generator $U_{AN} = U_{BN} = U_{CN} = U_{\phi}$	Consumer's phase resistances $R_{ab} = R_{bc} = R_{ca} = R$
1	10	75
2	15	100
3	20	150
4	18	200
5	12	100
6	24	300



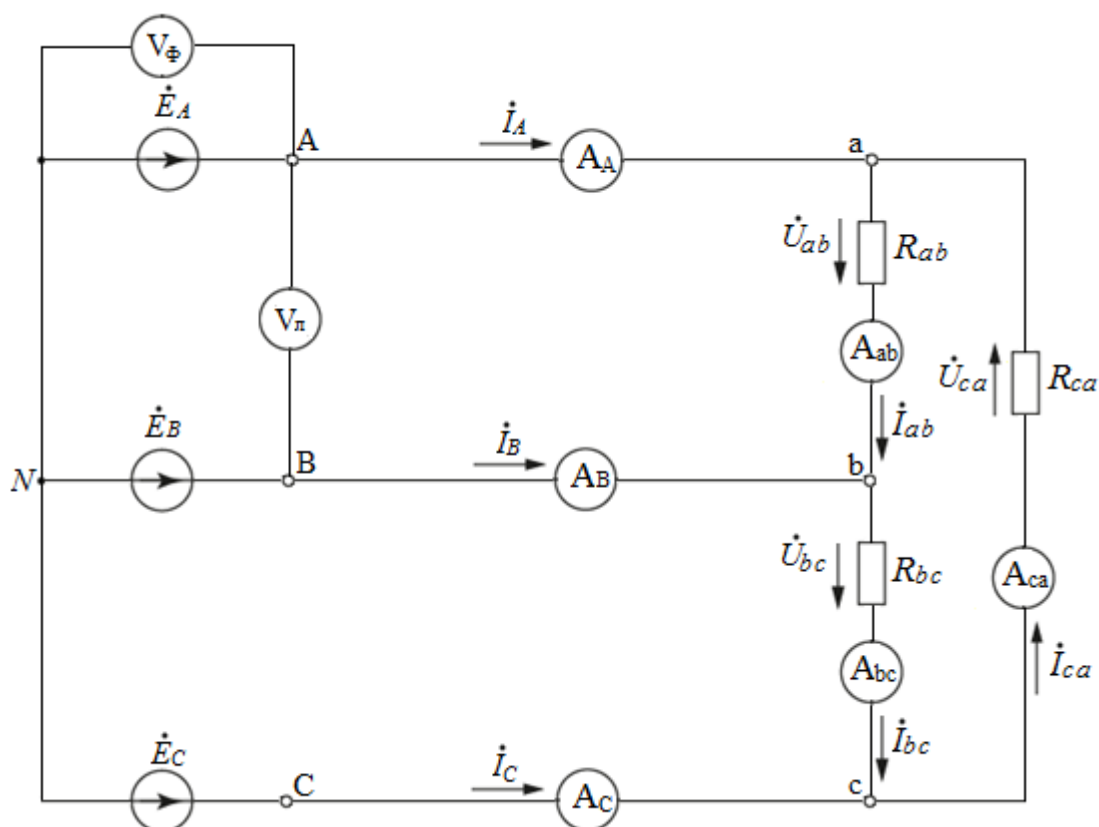


Figure 9.1 – Three-phase circuit when the phases of the consumer are connected in a delta

Table 9.2

Operation mode	$U_{AB}$ , V	$U_{BC}$ , V	$U_{CA}$ , V	$I_A$ , mA	$I_B$ , mA	$I_C$ , mA	$I_{ab}$ , mA	$I_{bc}$ , mA	$I_{ca}$ , mA
Theoretical calculation									
Symmetrical									
Experimental researches									
Symmetrical									

## 9.2 Assignment to perform the laboratory work

9.2.1 Assemble the three-phase circuit according to the scheme (figure 9.1). Set the generator phase voltages  $U_{AN} = U_{BN} = U_{CN} = U_{ph}$  and the consumer's phase resistances  $R_{ab} = R_{bc} = R_{ca} = R$  according to the variant of the assignment (table 9.1).

9.2.2 Measure line voltages  $U_{AB} = U_{ab}$ ,  $U_{BC} = U_{bc}$ ,  $U_{CA} = U_{ca}$ ; currents in line  $I_A$ ,  $I_B$ ,  $I_C$  and phase currents in the phases of the consumer  $I_{ab}$ ,  $I_{bc}$ ,  $I_{ca}$  in a symmetric mode.

The results write in table 9.2 in the line of Experimental researches. Symmetrical mode.

### 9.3 Processing the experimental data

9.3.1 According to the results of experimental researches of the 9.2.2 section (table 9.2), plot a phasor voltage diagram and a phasor current diagram. Vectors of line currents plot as the difference of the corresponding phase currents:

$$\dot{I}_A = \dot{I}_{ab} - \dot{I}_{ca}; \quad \dot{I}_B = \dot{I}_{bc} - \dot{I}_{ab}; \quad \dot{I}_C = \dot{I}_{ca} - \dot{I}_{bc}.$$

9.3.2 From the phasor diagram, find the line currents and compare them with the values of the line currents determined experimentally (table 9.2).

9.3.3 Check the relation between the line currents and the phase currents in the phases of the consumer in a symmetrical mode.

9.3.4 Calculate the currents in the phases of the consumer from the experimentally determined voltages  $U_{ab}$ ,  $U_{bc}$ ,  $U_{ca}$  and the phase resistances of the consumer  $R_{ab} = R_{bc} = R_{ca} = R$  and compare with those found experimentally.

9.3.5 Compare the values of voltages and currents found by calculation (table 9.2, the line of Theoretical calculation. Symmetric mode), with experimental values (table 9.2, the line of Experimental researches. Symmetric mode).

### 9.4 Methodological guidelines

A three-phase consumer connected in a triangle is attached to a symmetric system of line voltages of the generator, the windings of which are connected in a star (figure 9.1). Line voltages of the generator are related to the phase voltages of the generator by the ratio:

$$U_L = \sqrt{3}U_{ph}.$$

The value of the phase voltage of the generator  $U_{ph}$  is given in table 9.1.

Since the phases of the consumer are connected in a triangle, the line voltages  $U_L$  are equal to the phase voltages on the phases of the consumer:  $U_{ab} = U_{bc} = U_{ca} = U_L$ . Take the initial phase voltage  $\dot{U}_{ab}$  equal to zero, we get:

$$\dot{U}_{ab} = U_L e^{j0^\circ}; \quad \dot{U}_{bc} = U_L e^{-j120^\circ}; \quad \dot{U}_{ca} = U_L e^{j120^\circ}.$$

The currents in the phases of the consumer are determined by Ohm's law. Since the mode in the three-phase circuit is symmetrical ( $R_{ab} = R_{bc} = R_{ca} = R$ ), it is enough to calculate the current in only one phase:

$$\dot{I}_{ab} = \frac{\dot{U}_{ab}}{R_{ab}}.$$

The phase currents of the consumer  $I_{ab}$ ,  $I_{bc}$ ,  $I_{ca}$  have the same values and are in phase with the corresponding voltages.

Line currents  $I_A$ ,  $I_B$ ,  $I_C$  are determined as the difference of phase currents:

$$\dot{I}_A = \dot{I}_{ab} - \dot{I}_{ca}; \quad \dot{I}_B = \dot{I}_{bc} - \dot{I}_{ab}; \quad \dot{I}_C = \dot{I}_{ca} - \dot{I}_{bc}.$$

In the symmetric mode, the phase and line currents are connected in the relation:

$$I_L = \sqrt{3} I_{ph}.$$

The phasor diagram of voltages and currents is shown in figure 9.2.

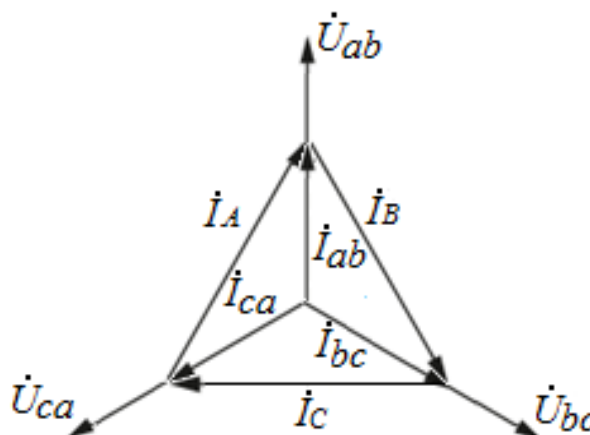


Figure 9.2 – The phasor diagram of voltages and currents of a three-phase circuit when the phases of a consumer are connected in a triangle

## 10 Laboratory work №10. The study of transients in a linear electrical circuit of the first and second orders

*Purpose* is experimental verification of the commutation laws and calculated ratios for the time constant of the electric circuit  $\tau$ , the attenuation coefficient  $\alpha$ , the angular frequency  $\omega_0$  and the period  $T_0$  of free oscillations, as well as the study of the influence of the parameters of the electric circuit on the character of the transient process.

### 10.1 Preparation for work

Answer the *test questions* and prepare a report on the performance of the laboratory work, where the research schema and tables should be drawn to enter the experimental data.

Test questions:

- 1) What process is called transient and in what circuits are transient processes observed?
- 2) What is the meaning of commutation laws?
- 3) What value is called the time constant of an electrical circuit?
- 4) How does the time constant depend on the parameters of the  $RC$  or  $RL$

circuit?

5) What is the duration of the transition process, theoretically and in practice, when solving most engineering problems with an accuracy of 3%?

6) Which of the transition processes is called oscillatory and which is aperiodic? What are the conditions of their occurrence?

7) How does the critical resistance of the  $RLC$  circuit calculate?

8) How are attenuation coefficient  $\alpha$ , angular frequency  $\omega_0$  and period  $T_0$  of free oscillations calculated and determined experimentally?

9) How does the time constant of the electric circuit  $\tau$  in cases of aperiodic and oscillatory character of the transition process calculate?

10) Write the equations of change in  $u_C(t)$ ,  $u_L(t)$  and  $i(t)$  in the process of discharging a capacitor with an oscillatory character, an aperiodic and critical case of an aperiodic character of the transition process.

11) How does the time constant of the circuit  $\tau$  determine using the graph of  $u_C(t)$ ?

## 10.2 Assignment to perform the laboratory work

Units of adjustable DC voltage, variable capacity, variable inductance and variable resistance, an electronic key, elements of a typesetting field and an oscilloscope are used in work. The electronic key (EK) switches with a frequency of 50 Hz (with internal synchronization) and creates a periodically repeating transient process. This allows you to observe the curves of instantaneous voltage values in the transient process on the oscilloscope screen.

10.2.1 Research the transient process in the first-order circuit using the example of the discharge of a capacitor to an active resistor ( $RC$ -circuit). The resistances of resistors  $R_1$  and  $R_2$  and the capacitance of capacitor  $C$  used in the work are shown for the three variants in table 10.1. Power supply voltage  $U = 20$  V.

Table 10.1 – Variants for the parameters  $R_1$ ,  $R_2$  and  $C$

Variant	$R_1, \Omega$	$R_2, \Omega$	$C, \mu F$
1	100...200, to measure	200	9.99
2	100...200, to measure	300	6
3	100...200, to measure	250	8

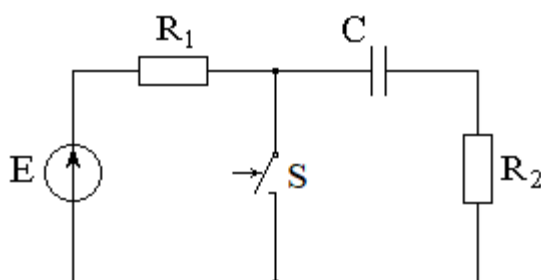


Figure 10.1 – Scheme for the study of  $RC$ -circuit

10.2.2 Assemble the circuit as shown in figure 10.1. Use a variable capacitor unit (0.01... 9.99  $\mu\text{F}$ ) as a capacitor, resistor unit  $R_1$  as a resistor  $R_1$ , and a variable resistance unit (1... 999  $\Omega$ ) as a resistor  $R_2$ . Research the transient process in the circuit, observing curves of the voltage  $u_C(t)$  and the current  $i_C(t)$  of the capacitor.

Directly, the curve of the instantaneous values of the current using an oscilloscope is impossible to observe, since the latter has a large input resistance and connects on as a voltmeter, parallel to the circuit element for measuring the voltage. We take advantage of the fact that the active resistance of the laws of voltage and current changes over time coincide with the accuracy of a constant factor, namely:  $i_R = u_R/R$ . Thus, by connecting the voltage across the resistor  $R_2$ , which is connected in series with the capacitor, to the oscilloscope input, you can observe the curve of the instantaneous values of the capacitor current on the scale  $m_y/R_2$ , where  $m_y$  is the vertical division value of the oscilloscope (V/div.).

It is necessary to obtain voltage curves  $u_C(t)$  and current  $i_C(t)$  of the capacitor in a convenient scale for observation. Using the oscilloscope vertical scale  $m_y(\text{V/div.})$  and horizontal  $m_x(\text{ms/div.})$ , determine the initial value of the discharge current of the capacitor  $i_C(0)$ , the voltage on the capacitor at the beginning of the discharge process  $u_C(0)$ , and also discharge circuit time  $\tau$ .

The capacitor is charged through resistors  $R_1$  and  $R_2$  with the open key  $S$ . In figure 10.2, this state of the circuit corresponds to the time interval to the left of  $t = 0$ , equal to 10 ms, corresponding to half the switching frequency period of the keys  $f = 50 \text{ Hz}$ .

The capacitor discharge circuit is formed when the key  $S$  is closed. In figure 10.2, this state of the circuit corresponds to the time interval to the right of  $t = 0$ , equal also to 10 ms.

There are two way of the time constant  $\tau$  determining from an experiment:

a)  $\tau$  is equal to the time interval between two instantaneous values of voltage or current, differing by a factor of  $e$ , where  $e = 2.718$  is the base of the natural logarithm;

b)  $\tau$  is equal to the length of the subtangent exponent taken on the asymptote. This method is shown in figure 10.2.

The measurement results are recorded in table 10.2 in the Experiment line.

Table 10.2 – The results of the study of the RC-circuit in figure 10.1

Value	Calculation	Experiment	Error
$i_C(0)$ , mA			
$u_C(0)$ , V			
$\tau$ , ms			

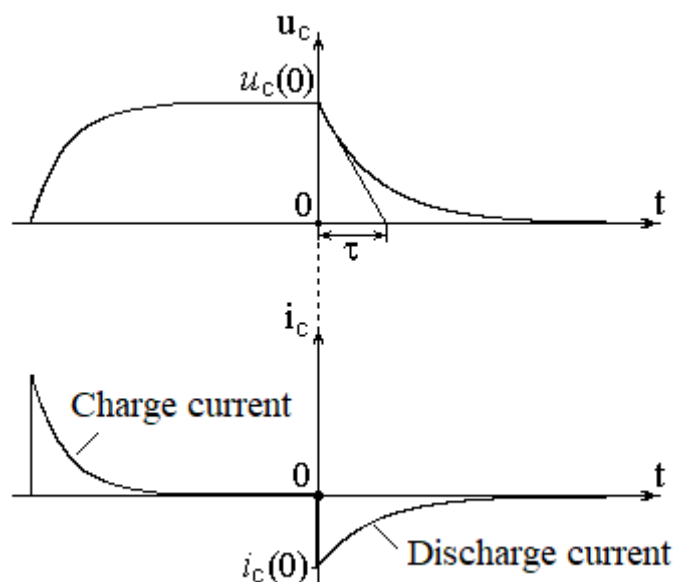


Figure 10.2 – Curves of instantaneous values of  $u_C(t)$  and  $i_C(t)$  in the  $RC$ -circuit

10.2.3 Take a picture or draw from the oscilloscope screen on the tracing paper the dependences  $u_C(t)$  and  $i_C(t)$  of the capacitor and present them in the report in the form of graphs like the curves shown in figure 10.2.

10.2.4 Calculate the values of  $i_C(0)$ ,  $u_C(0)$  and  $\tau$  from the known supply voltage  $U$ , the resistance of the resistor  $R_2$  and the capacitance of the capacitor  $C$ . The found values are written in the corresponding lines of table 10.2 in the column “Calculation”. Determine the error of the discrepancy between the calculation results and the experiment  $\delta$ , %.

10.2.5 Research the transient process in the second order circuit using the example of the discharge of a capacitor to an active resistor connected in series with the inductor. The research scheme is shown in figure 10.3.

Calculate the critical active resistance  $R_{cr.}$ , which determines the limiting case of the aperiodic character of the transient process. The values of  $L$  and  $C$  are given for the three variants in table 10.3.

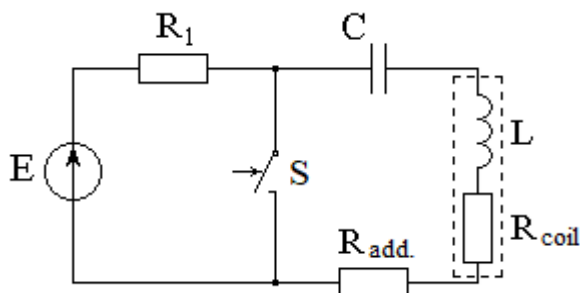


Figure 10.3 – Scheme for the research of  $RLC$ -circuit

Table 10.3 – variants of assignment

Variant	$L$ , mH	$C$ , $\mu\text{F}$
1	20	9.99
2	40	8
3	60	6

10.2.6 For the value  $R_{\Sigma} = 0,1R_{cr}$ , calculate the attenuation coefficient  $\alpha$ , the time constant of the electric circuit  $\tau$ , the angular frequency  $\omega_0$  and the period  $T_0$  of free oscillations, where  $R_{\Sigma}$  is the total active resistance of the discharge circuit, taking into account the active resistance of the coil of inductance  $R_{coil}$  and additional resistance  $R_{add}$ . Thus, it is necessary to measure  $R_{coil}$  and calculate  $R_{add} = R_{\Sigma} - R_{coil}$ .

10.2.7 Assemble the circuit under study and set the specified parameters of its elements:  $R_{add}$  – on the unit of variable resistance,  $L$  and  $C$  – on the units of variable inductance and capacitance, respectively.

Get on the oscilloscope screen image of the researched curves  $u_C(t)$  and  $i(t)$ . Connecting the oscilloscope to the input voltage across the resistor  $R_{add}$ , which is connected in series with the capacitor, you can observe the curve of the instantaneous values of the current of the capacitor on the scale of  $m_y/R_{add}$ , where  $m_y$  is the value for dividing the oscilloscope vertically (V/div.).

From the curves obtained, determine the attenuation coefficient  $\alpha$ , the period  $T_0$ , and the angular frequency of the free oscillations  $\omega_0$ . When determining  $\alpha$ , it is necessary to measure two adjacent amplitudes of the same sign  $A_1$  and  $A_2$  of the curve under study. It is also necessary to take into account that two adjacent amplitudes of the same sign are separated from each other on a time interval equal to the oscillation period  $T_0$  (figure 10.4). Then the experimental values of the attenuation coefficient  $\alpha_{exp.}$  and the angular frequency of free oscillations  $\omega_{0exp.}$  can be calculated by the formulas:

$$\alpha_{exp.} = \frac{1}{T_0} \ln \left( \frac{u_c(t_1)}{u_c(t_1 + T_0)} \right) = \ln \left( \frac{A_1}{A_2} \right) \quad \text{and} \quad \omega_{0exp.} = \frac{2\pi}{T_0}.$$

Using the obtained  $\alpha$  value, calculate the experimental value of the time constant of the electric circuit  $\tau$ . The results of the calculation and the experiment write in table 10.4. Determine the error of the results discrepancy  $\delta$ , %.

Table 10.4 – The results of the study  $RLC$ -circuit

Value	Calculation	Experiment	Error $\delta$ , %
$\alpha$ , 1/s			
$T_0$ , s			
$\omega_0$ , rad/s			
$R_{cr}$ , $\Omega$			

10.2.8 Photograph or draw the curves of  $u_C(t)$  and  $i(t)$  with the oscillatory character of the transient process and present them in the report in the form of graphs like the curve shown in figure 10.4. Using the curves of  $u_C(t)$  and  $i(t)$  to check the fulfillment of the laws of commutation.

10.2.9 Increasing the resistance  $R_{add}$ , determine the critical transient mode from the voltage image across the capacitor  $u_C(t)$  on the oscilloscope screen. This mode is characterized by the fact that the  $u_C(t)$  voltage during the discharge of the capacitor ceases to change sign, that is, decreases monotonically, without changing sign.

Write the corresponding value of  $R_{cr.} = R_{ad} + R_{coil}$  and compare with one calculated in section 10.4.5. The results of the calculation and the experiment write in table 10.4.

10.2.10 Set the value of  $R_{add} = R_{cr.} - R_{coil}$  and photograph or draw the curves of  $u_C(t)$  and  $i(t)$  with the aperiodic character of the transient process. Present them in the report in the form of graphs, like shown in figure 10.4.

### 10.3 Conclusions on work

Make conclusions about the influence on the character of the transient process the values of the parameters  $R$ ,  $L$  and  $C$ , as well as about the accuracy of the measurements.

It is also necessary to pay attention to the conditions for the occurrence of an oscillatory or aperiodic transient process, as well as to an experimental verification of the laws of commutation.

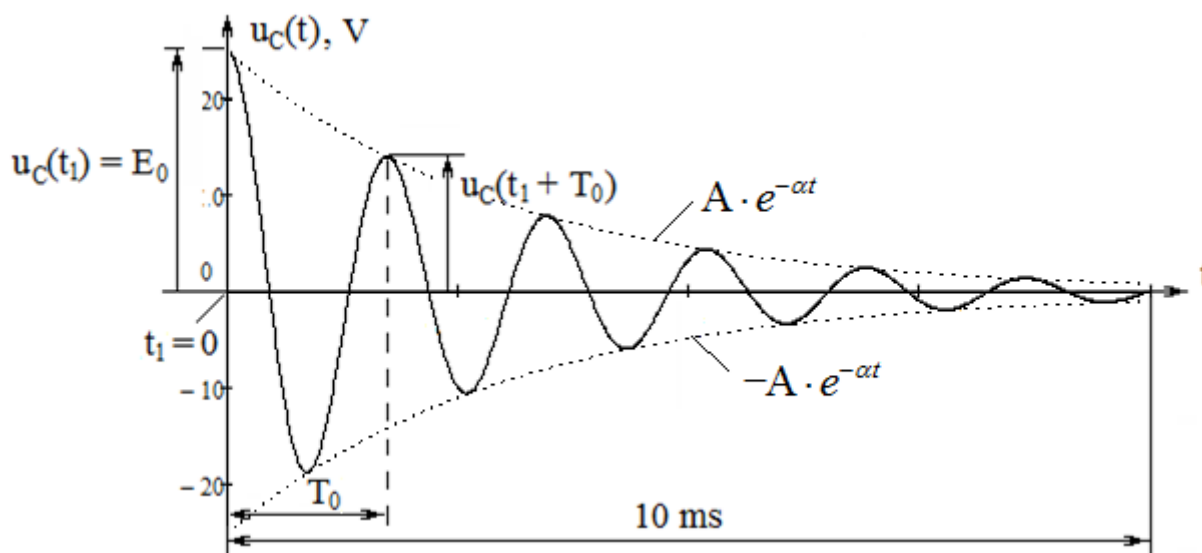


Figure 10.4 – Curve of instantaneous values of the voltage  $u_C(t)$  across the capacitor at discharge mode in the  $RLC$  circuit



## 11 Laboratory work №11. Single Phase Transformer Test

*Purpose* is familiarization with the device, the principle of operation, characteristics and methods of research of single-phase transformers.

### 11.1 Preparation for work

Answer the test questions and prepare a report on the performance of the laboratory work, where the studied scheme and tables should be drawn to enter the experimental data.

Test questions:

- 1) Purpose of the transformer.
- 2) Design and principle of operation of a single-phase transformer.
- 3) How and for what purpose is the open circuit (OC, no-load) test of a transformer performed?
- 4) What is the difference between short circuit (SC) test and an emergency short circuit?
- 5) Why can we neglect the power losses in the magnetic core of the transformer in the test of short circuit (SC)?
- 6) How do the parameters of the  $T$ -section equivalent circuit of a transformer determine?
- 7) Explain power losses in the transformer and give their definitions.
- 8) What is the impact of the character of the load on the external characteristic of the transformer?

### 11.2 Assignment to perform the laboratory work

11.2.1 Familiarize yourself with the instruments and equipment of the workbench used in carrying out the work, and record in the report the nominal technical data of the transformer under study.

11.2.2 Transformer idling experience.

11.2.3 In accordance with the circuit diagram in figure 11.1, assemble an electrical circuit for conducting the experience of idling the transformer. The test transformer is powered from a controlled source of sinusoidal voltage - a laboratory autotransformer (LATR).

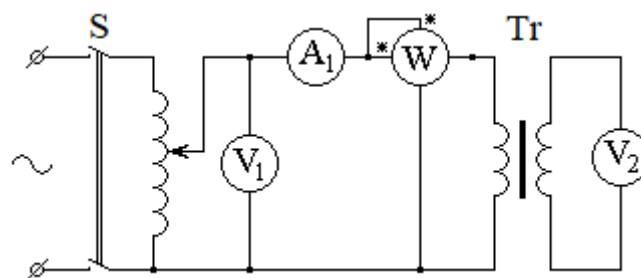


Figure 11.1 – Transformer idle work circuit

Set the rated voltage on the primary winding of the transformer and write the readings of the devices in table 11.1.

Table 11.1 – The results of measurements in the experience of idling

Measurements				Calculations							
$U_1, V$	$U_2, V$	$I_0, A$	$P_0, W$	$S_0, VA$	$Q_0, var$	$z_0, \Omega$	$r_0, \Omega$	$x_0, \Omega$	$\cos \varphi_0$	$i_0, \%$	$k$

According to the results of measurements of the experience of idling need to determine:

- transformer transformation ratio:

$$k = U_1/U_2; \quad (11.1)$$

- transformer power factor at idle:

$$\cos \varphi_0 = P_0/(U_1 \cdot I_0); \quad (11.2)$$

- parameters of the magnetizing circuit (ignoring the voltage drops on  $r_1$  and  $x_1$  from the current  $I_0$ ):

$$z_0 = U_1 / I_0; \quad r_0 = P_0 / I_0^2; \quad x_0 = \sqrt{z_0^2 - r_0^2}; \quad (11.3)$$

- the relative value of the no-load current:

$$i_0, \% = (I_0/I_{nom}) \cdot 100\%. \quad (11.4)$$

At the end of the idling experience, set the voltage  $U_1$  to zero and switch off the workbench power supply.

#### 11.2.4 Transformer short circuit experience.

The experiment is carried out at a reduced voltage on the primary winding of the transformer  $U_{1sc}$ . The voltage must be gradually increased, starting from zero, to a value at which the currents in the primary and secondary windings of the transformer take on nominal values, that is:

$$I_{1sc} = I_{1nom} \quad \text{and} \quad I_{2sc} = I_{2nom}.$$

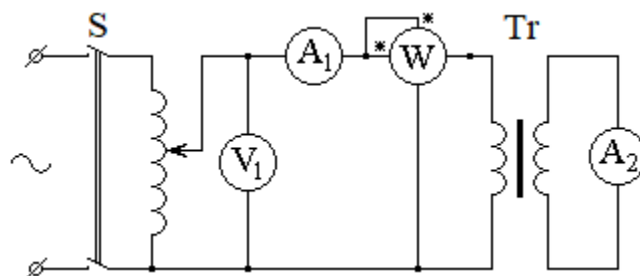


Figure 11.2 – Circuit experience short circuit

To conduct a short circuit experiment, assemble an electrical circuit, the cir-

cuit diagram of which is shown in figure 11.2. Set on the LATR voltage of the transformer to zero. Turn on switch B and conduct the experiment in accordance with the above. Write the values of the measured values in table 11.2.

Table 11.2 – Measurement results in short circuit experience

Measurements				Calculations							
$U_{1sc}, V$	$I_{1sc}, A$	$I_{2sc}, A$	$P_{sc}, W$	$S_{sc}, VA$	$Q_{sc}, var$	$Z_{sc}, \Omega$	$R_{sc}, \Omega$	$X_{sc}, \Omega$	$\cos \varphi_{sc}$	$U_{sc}, \%$	

Based on the measurement results of short circuit experience, determine:

– electrical power loss in the transformer:

$$P_e \approx P_{sc}; \quad (11.5)$$

– apparent  $S_{sc}$  and reactive  $Q_{sc}$  short circuit power:

$$S_{sc} = I_{1sc} \cdot U_{1sc}; \quad Q_{sc} = \sqrt{S_{sc}^2 - P_{sc}^2}; \quad (11.6)$$

– transformer equivalent circuit parameters:

$$Z_{sc} = U_{1sc}/I_{1sc}; \quad r_{sc} = r_1 + r_2' = P_{sc} / I_{1sc}^2; \quad x_{sc} = x_1 + x_2' = \sqrt{Z_{sc}^2 - r_{sc}^2}; \quad (11.7)$$

– transformer power factor:

$$\cos \varphi_{1sc} = P_{sc}/(U_{1sc} \cdot I_{1sc}); \quad (11.8)$$

– voltage of short circuit in percent:

$$u_{sc}, \% = (U_{1sc}/U_{1nom}) \cdot 100. \quad (11.9)$$

#### 11.2.5 Test transformer under load.

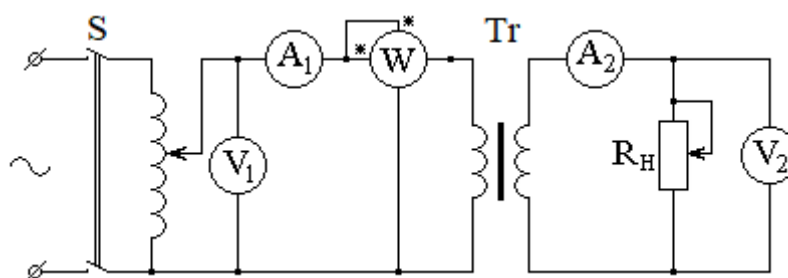


Figure 11.3 – Scheme of tests transformer under load

For the experience to assemble the electrical circuit, the scheme of which is shown in figure 11.3.

As a load, connect the resistor  $R_{Load}$  to the terminals of the secondary winding of the transformer. Turn on switch B and install the nominal voltage  $U_1 = U_{1N}$  on the

transformer primary winding. Changing the load resistance, make four to five measurements at different values of  $R_{Load}$ .

In this case, the voltage at the terminals of the primary winding of the transformer to maintain unchanged.

The measurement results write in table 11.3.

Table 11.3 – Test of transformer under load

№	Measurements					Calculations				
	$U_{1N}, V$	$I_1, A$	$P_1, W$	$U_2, V$	$I_2, A$	$S_1, VA$	$P_2, W$	$\cos \varphi_1$	$\eta$	$\beta$
1										
2										
3										
4										
5										

Based on the measurement results, determine:

– transformer load factor:

$$\beta = I_2/I_{2N}; \quad (11.10)$$

– active load power:

$$P_2 = U_2 \cdot I_2 \cos \varphi_2, \quad (11.11)$$

where the power factor  $\cos \varphi_2 = 1$ , taking into account the active character of the load resistance;

– apparent power at the input of the transformer:

$$S_1 = U_{1N} \cdot I_1; \quad (11.12)$$

– transformer power factor:

$$\cos \varphi_1 = P_1/S_1; \quad (11.13)$$

– transformer efficiency:

$$\eta = \frac{P_2}{P_1} = \frac{P_2}{P_2 + P_M + P_\Sigma} = \frac{\beta \cdot U_2 \cdot I_{2N} \cdot \cos \varphi_2}{\beta \cdot U_2 \cdot I_{2N} \cdot \cos \varphi_2 + P_0 + \beta^2 \cdot P_K}. \quad (11.14)$$

According to the calculated and measured data, plot in a single coordinate system the external  $U_2 = f(I_2)$  and the operating characteristics of the transformer:

$$I_1 = f(I_2); \quad \eta = f(I_2); \quad \cos \varphi_1 = f(I_2). \quad (11.15)$$

To draw the equivalent circuit of the loaded transformer with indication of its elements.

## 12 Laboratory work №12. The study of the DC generator with independent excitation

*Purpose* is to study the device of the DC generator with independent excitation, to obtain the main characteristics of the generator by experience.

### 12.1 Description of the electrical circuit of connections

The electrical circuit scheme of connections is shown in figure 12.1.

Source G1 – a three-phase source of sinusoidal voltage of industrial frequency  $f = 50$  Hz is used to power the drive motor of the generator.

The G2 source is an adjustable DC voltage source, which is used to supply a DC voltage to the excitation winding of a G/M DC machine operating in a generator with independent excitation.

The angular displacement converter G5 generates pulses whose frequency is proportional to the speed of rotation of the generator shaft. The pulses are fed to the input of the indicator of the rotation frequency of the relay shaft of the armature of the generator.

The asynchronous motor with a short-circuited rotor M1, which rotates the generator's armature, receives power from the source G1 through the switch A6.

The unit of multimeters P1 is used to measure the excitation current  $I_e$ , EMF  $E_0$ , as well as the current  $I$  and voltage  $U$  of the test generator G/M.


The list of used equipment is given in table 12.1.

Table 12.1 – List of equipment used

Designation	Name	Type	Parameters
G1	Three phase source	202.2	$\sim 400$ V / 16 A
G2	Adjustable DC voltage source	206.1	$= 0 \dots 250$ V / 3 A (armature)
G/M	DC machinery	104.2	90W/ 220V/ 0,56 A (armature) / 2x110V / 0,25 A (excitation)
G5	Converter of an angular displacements	104	6 output channels / 2500 pulses per turn
M1	Asynchronous squirrel cage motor	106	$\sim 380$ V / 120 W 1500 rev/min
A16	Three-pole switch	301.1	$\sim 400$ V / 10 A
A10	Active load	306.1	220 V / 3x0...50 W
A11	Rheostat for adjusting of excitation current of DC machine	308.1	0...2000 $\Omega$ / 0,3 A
A13	Rheostat	323.2	2x0...100 $\Omega$ / 1 A
P1	Unit of the multimeters 3 multimeters	508.2	$\sim 0 \dots 700$ V / 0...10 A $= 0 \dots 1000$ V / 10 A 0...20 M $\Omega$
P3	Indicator of rotation frequency	506.2	$- 2000 \dots 0 \dots 2000$ rev/min

## 12.2 Methodological guidelines for the preparation and carrying out of experiments

12.2.1 Make sure that the devices used in the experiment are disconnected from the power supply.

12.2.2 Connect the protective grounding jacks «» of the devices used in the experiment with the «PE» socket of the three-phase power source G1.

12.2.3 Connect the equipment in accordance with the wiring diagram shown in figure 12.1.

12.2.4 Switches the operating mode of the source G2 and the switch A6 to set the *manual* position.

12.2.5 Turn the adjustment knob of the source G2 counterclockwise until it stops (position 0).

12.2.6 Turn on the POWER switches of the multimeter unit P1 and the speed indicator P3. Turn on the multimeters of the P1 unit and set the necessary modes and limits of the measured value.

12.2.7 Turn on G1 source. Luminous lights should signal the presence of phase's voltage at its output.

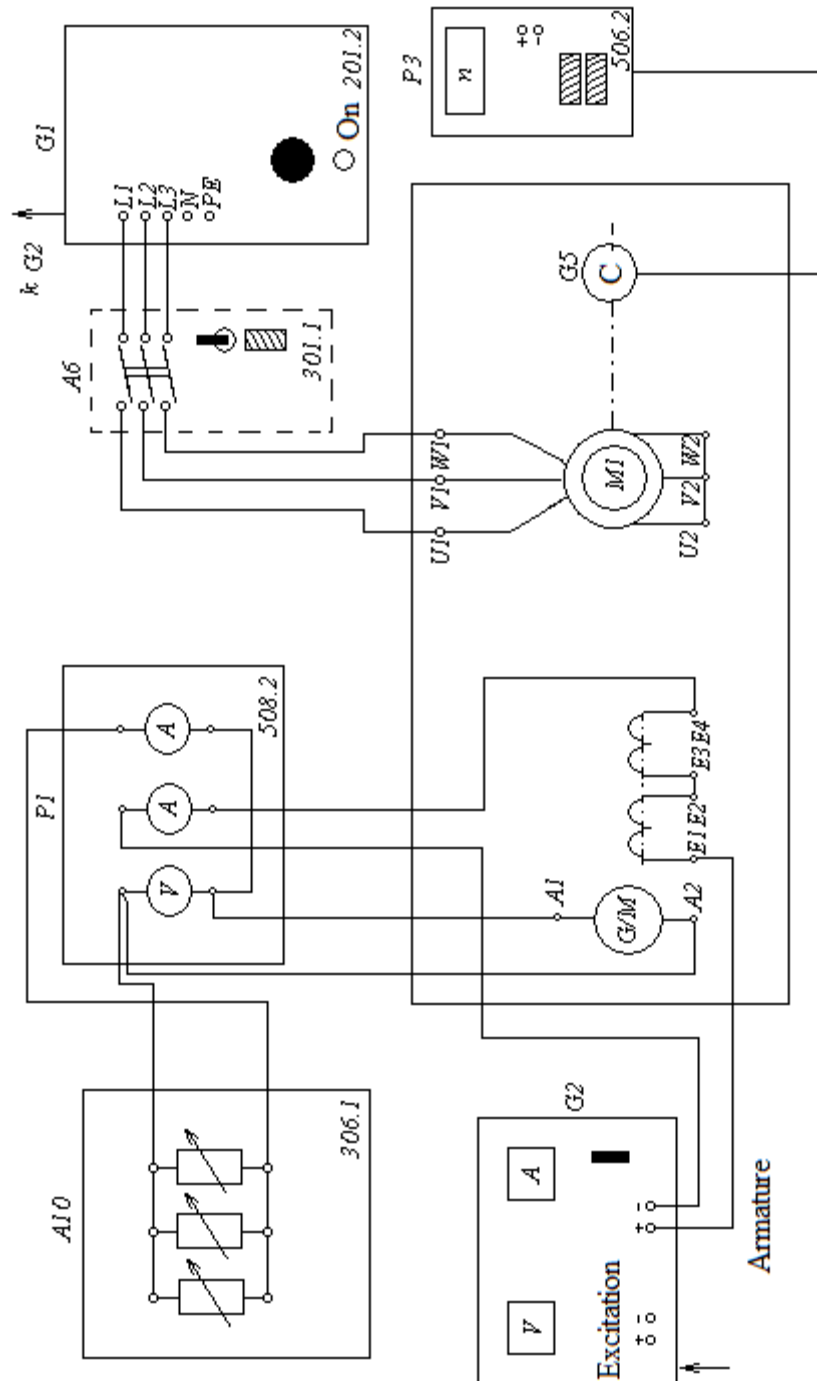


Figure 12.1 – Electrical circuit of connections for the study of the DC generator

12.2.8 Turn on the A6 switch with the ON button. In this case, the engine M1 should start to rotate.

12.2.9 Turn on the POWER switch and press the ON button of the G2 source.

### 12.3 Measurement characteristics of idling $E_0 = f(I_e)$

12.3.1 Disconnect the active load A10 from the generator.

12.3.2 Gradually rotating the adjustment knob of the source G2, increase the excitation current  $I_e$  of the generator G/M in the range from 0 to 0.2 A. Make six to seven measurements and record the readings of the ammeter P1.1 (excitation current  $I_e$ ) and the voltmeter P1.2 (EMF  $E_0$  of the generator) in table 12.2.

12.3.3 Rotating the adjustment knob of the source G2 in the opposite direction, reduce the current  $I_e$  in the range from 0.2 to 0 A. Make six to seven measurements and write the readings of the ammeter P1.1 (excitation current  $I_e$ ) and the voltmeter P1.2 in table 12.2.

Table 12.2 – Characteristic of idling of the generator

$I_e, A$ (ascending)							
$E_0, V$							
$I_e, A$ (descending)							
$E_0, V$							

According to the table 12.2 to plot the ascending and descending branches of the characteristics of idling generator  $E_0 = f(I_e)$ .

### 12.4 Measurement of external $U=f(I)$ and adjusting $I_e=f(I)$ characteristics of the generator

12.4.1 Connect the active load A10 to the generator.

12.4.2 Rotating the adjusting knob of the G2 source, set and keep constant the excitation current  $I_e$  during the experiment, for example, 0.1 A.

12.4.3 At the same time, switching the adjustment knobs of the A10 load from 0 to 100%, increase the current of the generator armature. Make six to seven measurements and write the readings of the ammeter R.1.1 (current  $I$ ) and the voltmeter P.1.2 (voltage  $U$  of the armature winding of the generator) in table 12.3.

Table 12.3 – External generator characteristic

$I, A$							
$U, V$							

12.4.4 Return the adjustment knobs of the active load A10 to the 0% position.

12.4.5 Set, by regulating the excitation current  $I_e$ , the voltage  $U$  in the armature winding of the generator is approximately 140 V.

12.4.6 Moving the A10 active load adjustment knobs clockwise and maintaining by adjusting the excitation current  $I_e$ , the voltage  $U$  is constant and equal to



140 V, measure the current  $I_a$  of the generator armature winding and write the readings of ammeters P.1.1 (current  $I_a$ ) and P.1.3 (excitation current  $I_e$ ) in table 12.4.

Table 12.4 – Adjusting characteristic of the generator

$I_a, A$							
$I_e, A$							

12.4.7 At the end of the experiment, at the G2 source, turn the adjustment knob counterclockwise until it stops, press the OFF button and turn off the POWER switch. Turn off the A6 and press the OFF button. Turn off the G1 source: press the button «mushroom» and turn off the packet switch. Turn off the POWER switch of the A6 switch, the P1 multimeter unit and the P3 rotation frequency indicator.

12.4.8 According to the data in tables 12.3 and 12.4, to plot for the generator:

- external characteristic  $U=f(I)$  with  $n=const$ ,  $I_e = const$ . (table 12.3);
- adjusting characteristic  $I_e=f(I_a)$  at  $U_a=const$ . (table 12.4).

### 13 Laboratory work №13. Investigation of a DC motor with independent excitation

*Purpose* is the study of the device of a DC motor with independent excitation, the plot of engine characteristics according to experimental data

#### 13.1 Description of the electrical circuit

Scheme of the electrical connections is shown in figure 13.1.

Source G1 - source of sinusoidal voltage of industrial frequency.

The power source G2 of the DC motor is used to power the excitation voltage of the excitation winding of the DC machine operating in motor mode.

The angular displacement converter G5 generates pulses fed to the input of the rotational speed indicator P3.

The asynchronous motor with a squirrel-cage rotor M1 plays the role of an electromagnetic brake, the stator winding of which is powered by direct current through the rectifier A18 from the adjustable autotransformer A1.

Using the multimeters of the P1 unit, the current and voltage of the armature winding of the M2 motor are monitored.


The list of used equipment is given in table 13.1.

Table 13.1 – List of equipment used

Designation	Name	Type	Parameters
G1	Three phase source	201.2	$\sim 400\text{ V} / 16\text{ A}$
G2	DC motor power supply	206.1	$= 0 \dots 250\text{ V} / 3\text{ A}$ (armature)
G5	Converter of an angular displacements “B”	104	6 output channels / $2500\text{ rpm}$
M1	Asynchronous motor with squirrel cage rotor	106	$\sim 120\text{ V} / 380\text{ V} / 1500\text{ rpm}$
M2	DC machine	101.2	$90\text{ W} / 220\text{ V} / 0,56\text{ A}$ (armature) $2 \times 110\text{ V} / 0,25\text{ A}$ (excitation)
A1	Adjustable autotransformer	318.1	$\sim 0 \dots 240\text{ V} / 2\text{ A}$
A18	Rectifier	322	$\sim 400\text{ V} / 2\text{ A}$
P1	Unit of the multimeters 3 multimeters	508.2	$\sim 0 \dots 700\text{ V} / 0 \dots 10\text{ A}$ $= 0 \dots 1000\text{ V} / 10\text{ A}$ $0 \dots 20\text{ M}\Omega$
P3	Indicator of speed of rotation	506.2	$-2000 \dots 0 \dots 2000\text{ rpm}$

## 13.2 Methodological guidelines on the preparation and implementation of experiments

13.2.1 Make sure that the devices used in the experiment are disconnected from the power supply.

13.2.2 Connect the protective grounding jacks of the devices «» used in the experiment with the PE socket of the three-phase source G1.

13.2.3 Connect the equipment in accordance with the electrical scheme of connection.

13.2.4 Set the mode switches of the G2 source to “manual”.

13.2.5 The adjustment knob of the source G2 and the autotransformer A1 turn counter-clockwise until it stops.

13.2.6 Turn on the POWER switch of the multimeter unit P1 and the indicator of rotational speed P3.

13.2.7 Turn on the multimeters of the P1 unit.

13.2.8 Turn on the G1 source. The glowing bulbs should indicate the presence of voltage at its output.

13.2.9 Turn on the POWER switch and press the ON button of the G2 source.



### 13.3 Measurement of work engine characteristics and mechanical characteristic $M = f(n)$

13.3.1 Rotating the adjustment knob of the G2 source, accelerate the M2 engine to the rotational speed  $n$ , for example, equal to 1500 rpm.

13.3.2 Turn on the switch POWER of the autotransformer A1.

13.3.3 Rotating the adjustment knob of the autotransformer A1, change the armature's current  $I_a$  (the current should not exceed 1 A) of the M2 engine and write the readings of the ammeter P1.1 (the current  $I_a$ ), voltmeter P1.2 (the voltage across armature of the motor M2), ammeter P1.3 (the current of excitation  $I_e$  of the motor M2) and pointer P3 (the speed of rotational  $n$ ) in table 13.2.

Table 13.2 – DC motor characteristics

$I_a, A$									
$U_a, V$									
$I_e, A$									
$n, rpm$									

13.3.4 At the end of the experiment, turn the adjustment knob counterclockwise until it stops, first at the A1 autotransformer, then at the G2 source and turn off the POWER switches. Turn off the G1 source by pressing the red button «mushroom».

13.3.5 Using the data of table 13.2, the measured value of the active resistance of the excitation winding  $R_e$  and the excitation voltage  $U_e$  of the motor M2, for each value of the rotational speed  $n$ , calculate and write in table 13.3 the corresponding values of the work characteristics:

– power on the motor shaft M2 according to the empirical formula (valid for  $I_e = 0 \dots 0.8$  A and  $n = 500 \dots 1250$  rpm):

$$P_2 = \frac{2\pi}{60} \cdot 1150 \cdot I_e^2, W;$$

– power consumed by the M2 engine from the network:

$$P_1 = U_a + I_a + \frac{U_e^2}{R_e}, W;$$

– electromagnetic momentum of the engine M2:

$$M = \frac{60}{2 \cdot \pi \cdot n} \cdot (U_a - 65 \cdot I_a) \cdot I_a, N \cdot m;$$

– efficiency of the engine M2:

$$\eta = \frac{P_2}{P_1} \cdot 100, (\%) .$$

13.3.6 Using the data of table 13.3, plot the desired work characteristics  $P_1=f(P_2)$ ,  $M=f(P_2)$ ,  $\eta=f(P_2)$  and the mechanical characteristic  $M = f(n)$  of the DC motor.

Table 13.3 – Work characteristics DC motor

$n, rpm$									
$P_2, W$									
$P_1, W$									
$M, N\cdot m$									
$\eta, \%$									

## 14 Laboratory work №14. Research of the induction motor with squirrel cage

*Purpose* is studying the device of an asynchronous motor with a squirrel-cage rotor, construction the motor characteristics experimentally.

### 14.1 Description of the electrical circuit of connections


Electrical circuit of connections is shown in figure 14.1.

The asynchronous motor M1 under test is supplied with power through the A6 switch and the three-phase transformer groups A2, A7 from the three-phase power supply with sinusoidal voltage G1.

With the help of an ammeter and a voltmeter of the multimeter unit P1, the stator winding current and the line voltage of the tested motor M1 are monitored.

With the help of the power meter P2, the active and reactive powers consumed by one phase of the tested motor M1 are monitored.

### 14.2 Methodological guidelines on the preparation and implementation of experiments

14.2.1 Connect the protective grounding jacks of the devices «» used in the experiment with the PE socket of the three-phase power source G1.

14.2.2 Set the operating mode switches of switches A6 and A8 to the “manual” position.

14.2.3 In the transformer group A2, set the rated voltage of 220 V.

14.2.4 Turn on the switch POWER of the units involved in the experiment.

14.2.5 Turn on the multimeters of the P1 unit.

14.2.6 Turn on the G1 source. The glowing bulbs should indicate the presence of voltage at its output.

The list of used equipment is given in table 14.1.

Table 14.1 – List of equipment used

Designation	Denomination	Type	Parameters
G1	Three phase source	201.2	$\sim 400\text{ V} / 16\text{ A}$
G2	DC motor power supply	206.1	$= 0 \dots 250\text{ V} / 3\text{ A}$ (armature) $- 200\text{ V} / 1\text{ A}$ (excitation)
G4	Dc machine	101.2	90W/ 220V/ 0,55 A (armature) 2×110 V / 0,25 A (excitation)
G5	Converter of an angular displacements	104	6 output channels / 2500 rpm
M1	Asynchronous motor with squirrel cage rotor	106	$\sim 120\text{ V} / 380\text{ V} / 1500\text{ rpm}$
A2	Three Phase Transformer Group	347.1	3×80 VA; 230 V / 242, 235, 230, 226, 220, 133, 127 V
A6	Three-pole switch	301.1	$\sim 400\text{ V} / 10\text{ A}$
A10	Active load	306.1	220 V / 3×0...50 W
P1	Unit of the multimeters	508.2	3 multimeters $\approx 0 \dots 1000\text{ V} /$ $\approx 0 \dots 10\text{ A}$ 0...20 MΩ
P2	Power meter	507.2	15; 60; 150; 300;600 V / 0,05; 0,1; 0,2; 0,5 A
P3	Indicator of speed of rotation	506.2	$-2000 \dots 0 \dots 2000\text{ rpm}$

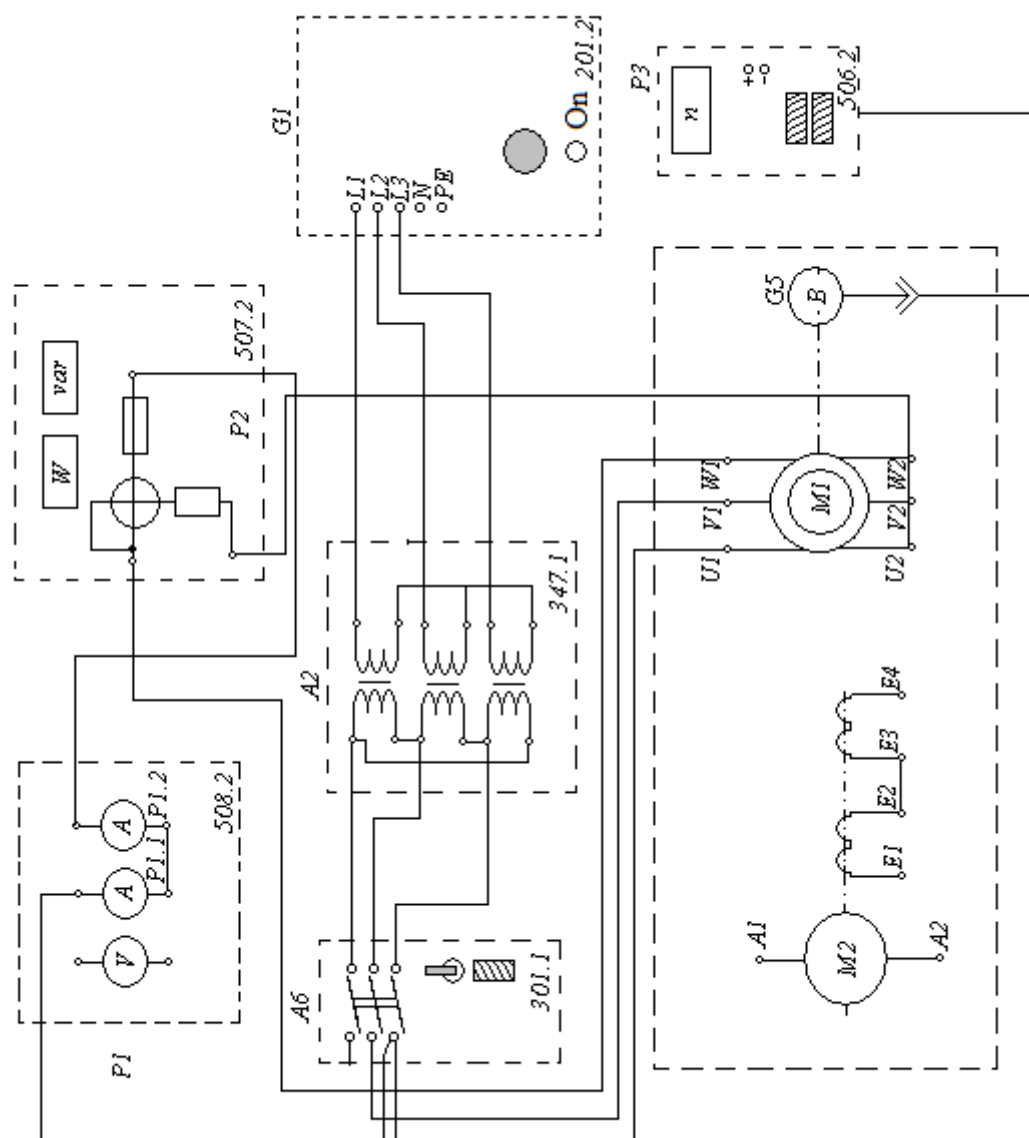


Figure 14.1 – Electrical scheme of connections for idle and short circuit

### 14.3 Experiment of the idle mode

14.3.1 Start the M1 engine by pressing the ON button of the A6 switch.

14.3.2 Changing the position of the adjustment knobs of the transformer groups A2 and A7, vary the line voltage  $U$  supplied to the motor M1 in the range from 100 to 250 V and write the readings of the voltmeter P1.1, the ammeter P1.2 (phase current  $I_0$  of the motor M1), and also wattmeter and varmeter meter P2 (active  $P_{01}$  and reactive  $Q_{01}$  power consumed by one phase of the induction motor) in table 14.2.

Table 14.2– Characteristics of a single-phase induction motor

$U_1, V$							
$I_0, A$							
$P_{01}, W$							
$Q_{01}, var$							

14.3.3 Disconnect G1 source.

14.3.4 Turn off the POWER switch of the units involved in the experiment.

14.3.5 Using the data of table 14.2, calculate the corresponding to the voltage  $U$  active  $P_0$  and reactive  $Q_0$  power consumed by the motor M1 in three phases:

$$P_0 = 3 \cdot P_{01}; \quad Q_0 = 3 \cdot Q_{01}.$$

Write the results in table 14.3.

Table 14.3 – Characteristics of the three phases of the asynchronous motor

$U, V$							
$P_0, A$							
$Q_0, var$							

14.3.6 Using the data of table 14.3, calculate the values of power factor corresponding to the voltage  $U$ :

$$\cos \varphi_0 = \frac{P_0}{\sqrt{P_0^2 + Q_0^2}}.$$

Write the results in table 14.4.

Table 14.4 – Asynchronous motor power factor

$U, V$							
$\cos \varphi_0$							

14.3.7 According to the data of tables 14.3 and 14.4, plot the idling characteristics of a three-phase asynchronous motor with a short-circuited rotor:  $I_0 = f(U)$ ,  $P_0 = f(U)$  and  $\cos \varphi_0 = f(U)$ .



## 14.4 Experiment of the short-circuit

14.4.1 Remove the cover covering the coupling connecting the shaft of the DC machine M2 to the shaft of the motor M1, and fasten the locking device on it.

14.4.2 By pressing the ON button of the A6 switch, connect the M1 motor to the electrical network.

14.4.3 Quickly (in less than 10 seconds) count and record in table 14.5 the readings of voltmeter P1.1 (line voltage  $U$  of a motor M1), ammeter P1.2 (current  $I_{sc}$  of the stator winding of a motor M1), and wattmeter P2 (active power  $P_{sc1}$  that is consumed by one phase of the motor M1) and immediately thereafter, by pressing the OFF button of the switch A6, disconnect the motor M1 from the power source.

14.4.4 Repeat the required number of times the procedure for connecting the motor M1 to the electrical network, reading the readings of the measuring devices and its disconnection from the electrical network at several lower values of the secondary voltage of the transformer group A2.

Table 14.5 – Data of short circuit experience

$U, V$							
$I_{sc}, A$							
$P_{sc1}, W$							

14.4.5 Disconnect  $G1$  source.

14.4.6 Turn off the switches POWER of the units involved in the experiment.

14.4.7 Using the data of table 14.4, calculate the values of the apparent active power  $P_{sc}$  consumed by the M1 motor and the short-circuit impedance corresponding to the voltage  $U$ :

$$P_{sc} = 3 \cdot P_{sc1}; \quad z_{sc} = \frac{U}{I_{sc}}.$$

The results obtained, write in table 14.6

Table 14.6 – The results of the calculation in the experience of short circuit

$U, V$							
$P_{sc}, W$							
$Z_{sc}, \Omega$							

14.4.8 Using the data of tables 14.5 and 14.6, plot the characteristics of a short circuit of a three-phase asynchronous motor with a short-circuited rotor:

$$I_{sc} = f(U); P_{sc} = f(U) \quad \text{and} \quad z_{sc} = f(U).$$



## 14.5 Determination of mechanical and operating characteristics of a squirrel cage induction motor

Electrical circuit of connections is shown in figure 14.2.

The power source of the DC motor G2 is used to power the excitation winding of the DC machine G4. The DC machine G4 operates in a generator mode with independent excitation and acts as a loading machine.

Turn the adjustment knob of the G2 source to the stop counterclockwise, and adjust the active load knob A10 - clockwise.

The active load A10 is used as the load of the generator G4.

The order of the experiment.

14.5.1 Start the asynchronous motor with the ON button.

14.5.2 Rotating the source G2 knob, increase the current  $I$  of the stator winding of the M1 motor and write the readings of the ammeter P1.1 (current  $I$ ), wattmeter of the power meter P2 (active power  $P$  of the phase of the motor M1) and pointer P3 (the rotational speed  $n$  of the motor M1) in table 14.7.

Table 14.7 – Engine under load test data

$I, A$							
$P, W$							
$n, rpm$							

14.5.3 After completing the experiment, turn off switch A6 and source G1.

14.5.4 Turn off the POWER switch of the units involved in the experiment.

14.5.5 Calculate the electromagnetic moment  $M$  of the motor M1 for each value of current  $I$  from table 14.7 using the formula:

$$M = \frac{3}{50\pi} (P - 80 I^2), N \cdot m$$

and write the calculation results in table 14.8.

Table 14.8 – Mechanical characteristic of asynchronous motor

$M, N \cdot m$							
$n, rpm$							

14.5.6 Using the data of table 14.8, plot the mechanical characteristic  $n = f(M)$  of a three-phase asynchronous motor.

14.5.7 Turn on the G1 source.

14.5.8 Start the engine M1 by pressing the ON button of the switch A6.

14.5.9 Rotating the adjustment knob of the G2 source, change the current  $I$  of the stator winding of the M1 engine and enter the readings of the ammeter P1.1 (the current), wattmeter and varmeter of the power meter P2 (the active  $P_{1.1}$  and reactive  $Q_{1.1}$  power of one phase of the motor M1), pointer P3 (the frequency of rotation  $n$  of the motor's M1 armature), ammeter and voltmeter P1.3 (the current  $I_a$  and voltage  $U$  of the armature winding of the generator G4) in table 14.9.

Table 14.9 – Data for calculating work characteristics of the motor

$I, A$							
$P_{11}, W$							
$Q_{11}, var$							
$n_1, rpm$							
$I_a, A$							
$U_a, V$							

14.5.10 At the end of the experiment, turn off switch A6 and source G1.

14.5.11 Turn off the POWER switch of the units involved in the experiment.

14.5.12 Using the data of table 14.9, calculate for each current's value  $I$  the effective active power  $P_2$ , the total active power consumed from the network  $P_1$ , the mechanical moment  $M$ , the power factor  $\cos\varphi$ , the slip  $s$  and the efficiency  $\eta$  of the asynchronous motor:

$$P_2 = U_a I_a ; \quad P_1 = 3 P_{1.1} ; \quad M = \frac{3}{50\pi} (P - 80 I^2) ; \quad \cos\varphi = \frac{P_{1.1}}{\sqrt{P_{1.1}^2 + Q_{1.1}^2}} ;$$

$$s = \left( 1 - \frac{n}{1500} \right) \cdot 100 ; \quad \eta = \frac{P_2}{3 P_{1.1}} \cdot 100 .$$

The results of the calculation, write in the table 14.10

Table 14.10 – Work characteristics of asynchronous motor

$I, A$							
$P_2, W$							
$P_1, W$							
$M, N \cdot m$							
$\cos\varphi$							
$s, \%$							
$\eta, \%$							

14.5.13 Using the data of table 14.10, plot the work characteristics of a three-phase asynchronous motor with a squirrel cage:

$$I = f(P_2) ; P_1 = f(P_2) ; s = f(P_2) ; \cos\varphi = f(P_2) ; M = f(P_2) ; \eta = f(P_2) .$$

## **Appendix A**

### **Requirements for the performing and design of laboratory works reports**

#### **1 Preliminary preparation and admission to the work**

1.1 Before proceeding with the next classes, the student should become familiar with the content of the laboratory work, study the theoretical material on the relevant topic.

1.2 The results of the training should be reflected in the report of the work being done, which should contain:

- a) working electrical schemes;
- b) written answers to questions in the Preparation for the work section;
- c) tables for writing down the measurement results;
- d) preliminary calculations.

1.3 At the beginning of the class, the student must:

- a) defend a fully executed previous work;
- b) to get the admission to the following work, having the individual report.

During the class, the student must carry out the work (assemble the electrical circuit schemes, make the necessary measurements and write the results in the tables prepared in advance).

1.4 The readiness of students to perform the work is checked by the teacher, asking test questions on the theory, the procedure of performance of this work, the principle of operation of the devices, the formulas used and the expected results. Questions may be asked verbally or in writing.

1.5 Students who have not fulfilled the requirements of the third paragraph, as well as those students whose theoretical training is considered unsatisfactory, are not allowed to work.

1.6 Students who are not allowed to work should use the remaining time to study the theory, as well as to design and defense the work done earlier.

1.7 Laboratory work that was not have been done on time should be done by students in the time allotted for working off. To do this, the student must pre-register with the teacher. An admission to work a student receives on a general basis.

#### **2 Work in the laboratory room**

2.1 For work in the laboratory, the teacher divides the group into teams (2-3 students) or assigns the student to work individually. The team members do the experimental part of the work together, but each draws up its own report and defends it individually.

2.2 Each team works in an individual workplace, where all the necessary equipment for work is mounted.

2.3. It is necessary at the beginning of the work to inspect the equipment and instruments. Any defects noted should be reported immediately to the teacher.

2.4 For damage caused to the laboratory due to non-compliance with the rules of work carrying out or safety, as well as improper handling of equipment, team members are responsible.

2.5 Electrical schemes for the work the students assemble by their own. Measurement instruments, auxiliary and adjustable devices should be placed so that the scheme turned out simple, visual and easily accessible at each point.

2.6 At the beginning of the experiment, the rheostats and other adjustable devices must be adjusted so that the circuit has the minimum values of currents and voltages, the measuring instruments must be switched to the maximum range. Approximately having determined the measuring value, switch the device to a convenient measuring range.

2.7 The circuit must be checked by the teacher and only with his permission the circuit can be turned on the power supply voltage. The circuit should be energized only while observing its operation and when taking experimental data. At the end of the experiment, the power supply voltage should be immediately turned off.

2.8. The readings of the measuring instruments are recorded in the previously prepared report tables. At the end of the measurements, the results should be shown to the teacher, who gives permission to disassemble the scheme. Prior to this, the scheme should not be disassembled, so that, if necessary, it was possible to make additional or repeated measurements.

### **3 Drawing up report of laboratory work and its defense**

3.1 The student must provide a completely prepared report to defense of each work done.

3.2 A drawn up report of the previous work should be presented at the beginning of the next lesson and defended during the lesson.

3.3 The report should contain a title sheet (appendix B) and the following sections:

- the purpose of the work;
- the basic theoretical principles and answers to the test questions of preparation section;
- schemes of the studied electrical circuits;
- calculation formulas, calculations, estimated graphs of the studied electrical quantities and modes of the electrical circuit;
- the results of the study (tables of data, graphs, numerical values of parameters and electrical quantities);
- conclusions on the work done.

Reports are drawn up on sheets of white or lined A4 paper, which are filled on one side. In the text, written clearly and neatly with a paste of the same color, it is allowed to use only generally accepted symbols or abbreviations, decoded at the first mention.

## Appendix B

### Sample of the title sheet

MINISTRY OF EDUCATION AND SCIENCE REPUBLIC OF KAZAKHSTAN

Non-commercial Joint Stock Company

ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS

Department of Electrical Engineering

### REPORT on laboratory work № \_\_\_\_

on the “\_\_\_\_\_” discipline

\_\_\_\_\_  
(Title of the laboratory work)

\_\_\_\_\_ specialty

Done by \_\_\_\_\_ Group \_\_\_\_\_  
(Student's Surname and Initials) (Academic group code)

Checked by \_\_\_\_\_  
(Teacher's academic degree, academic rank, Surname and Initials)

\_\_\_\_\_ «\_\_\_\_» \_\_\_\_\_ 20\_\_\_\_.  
(Grade) (Teacher's signature) (Date)

Almaty 20\_\_

## References

### Basic

- 1 Introductory Circuit Analysis / Robert L. Boylestad. – 13th edition 2015. – 1224 p.
- 2 Fundamentals of Electric Circuits / Charles K. Alexander, Matthew N. O. Sadiku. – 5th edition – 2013. – 995 p.
- 3 John Bird. Electrical Circuit Theory and Technology – Third edition 2007. – 694 p.

### Additional

- 4 Касаткин А. С. Электротехника: Учебник/А. С. Касаткин, М. В. Немцов – 12-е изд., стер. – М.: АCADEMIA, 2008. – 544 с.
- 5 Бессонов Л. А. Теоретические основы электротехники. Электрические цепи: Учебник для бакалавров / Л. А. Бессонов. – 11-е изд., перераб. и доп. – М.: Юрайт, 2013. – 701 с.: ил.
- 6 Немцов, М. В. Электротехника и электроника: Учебник. – 3-е изд., стер. – М.: Академия, 2010. – 432 с.
- 7 Данилов И. А. Общая электротехника: Учебное пособие для учащихся вузов и техникумов, бакалавров, специалистов / И. А. Данилов. – М.: Юрайт, 2010. – 673 с.: ил.
- 8 Евдокимов Ф. Е. Общая электротехника: Учебник /Ф. Е. Евдокимов. – 3-е изд., испр. – М.: Высшая школа, 2004. – 367 с.: ил.
- 9 Баймаганов А. С. Электротехника и электроника. Конспект лекций для студентов всех форм обучения специальности 050717 – Теплоэнергетика. – Алматы: АУЭС, 2008. – 85 с.
- 10 Баймаганов А.С., Светашев Г.М. Электротехника и электроника: Учебное пособие для студентов всех форм обучения специальности 5В071700 – Теплоэнергетика. – Алматы: АИЭС, 2010 – 106 с.



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## ELECTRICAL ENGINEERING

Methodological guidelines and assignments for performing laboratory works  
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5B074600 – Instrumentation specialties

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