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ALMATY UNIVERSITY OF POWER ENGINEERING & TELECOMMUNICATIONS

Department of Theoretical electrical engineering

THEORETICAL BASES OF ELECTRICAL ENGINEERING

Methodological guidelines and assignments for laboratory works
for the 5B070200 – Automation and control baccalaureate specialty students

Almaty 2017

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Methodological guidelines and assignments for preparing, execution and design of laboratory works on "Theoretical bases of electrical engineering" (TBEE) discipline are provides.

There are six laboratory works on the main section of the TBEE discipline as following: DC linear and non-linear electric circuit analysis, single-phase and three-phase sine waveform signal linear electric circuit analysis, analysis of resonance phenomena and transient processes in the linear electric circuits, the manual is included.

Each laboratory work includes the following sections: the objective of the work, preparation for a laboratory work, an order of performance the work, analysis and design of experimental results and the conclusions of the work done.

The methodological guidelines and assignments are intended for the students, who are educated in English language on 5B070200 – Automation and control baccalaureate specialty.

25 illustrations, 18 tables, 6 items of references.

Reviewer: PhD B. I. Tuzelbayev

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Contents

Introduction

Methodological guidelines for laboratory works are part of the methodological literature complex on the “Theoretical bases of electrical engineering” (TBEE) discipline.

The laboratory researches are of great importance for increasing the quality of training and formation of students’ creative thinking and engineering skills. Performing laboratory works allows students to apply the theoretical principles in practical calculations to gain the skills of independent circuit analysis that ultimately contributes to the successful mastering of the TBEE discipline.

The manual contains descriptions of the mandatory laboratory works on “Theoretical bases of electrical engineering” discipline for the “Automation and control” specialty.

The laboratory works are complex of experimental and theoretical assignments in the study of linear and non-linear DC electric circuits, single-phase and three-phase sinusoidal current, resonance phenomena and transient processes in the linear electric circuits. All laboratory works are performed by the frontal way after the respective topics in the lecture material have been presented.

The practical implementation of the laboratory researches at the “Theoretical Electrical Engineering” department is provided by using of the “UILS-2” – universal teaching and research laboratory workbenches. The UILS-2 workbench is fixed on the table and is a metal box in which the active and passive units and a patchbay for the assembly of electrical circuits to carry out the experiment are mounted. The workbench also includes 29 external components (resistors, capacitors and inductors) and a set of connecting leads with plugs.

Active blocks are located in the left side of the stand and consist of a block of DC voltage sources and blocks of the single- and three-phase sinewave voltage sources. Passive units are located in the right side of the stand and consist of blocks of a variable resistance and a variable inductance and a variable capacitance. A patch bay is located at the center of the stand.

The DC voltage unit comprises:

– an adjustable DC stabilized voltage source with regulation range from 0.25 to 24 V;

– an unregulated DC voltage source with output voltage of 12 V or 24 V;

– “electronic switch” used to study transients.

Both DC voltage sources are provided with an electronic protection circuit against short-circuits and overloads. The current of protection activation is 1 A.

AC voltage block is a functional generator of single-phase alternating voltage of adjustable frequency of sinusoidal, rectangular and triangular shape. The unit is provided with an electronic protection circuit against short-circuits and overloads. The current of protection activation is 1 A.

The three-phase voltage unit is a source of three-phase voltage of commercial frequency f = 50 Hz. Source contains three phases electrically independent from each other.

Each phase is equipped with an electronic protection against short-circuits and overloads. The current of protection activation is 1 A.

The unit of resistances consists of three unregulated resistors R_1, R_2, R_3 and an adjustable R_4. Regulation of resistor's R_4 value is performed in the range from 0 to 999 Ω a stepwise in increments of 1 Ω by using three switches: the hundreds of (0 ... 9), the tens of (0 ... 9) and the units of (0 ... 9) Ω.

The unit of inductances includes three unregulated inductors L_1, L_2, L_3 and an adjustable inductor L_4. Value of inductance L_4 can be adjusted between 0 and 99.9 mH a stepwise of 0.1 mH by using three switches: the tens of (0 ... 9), the units of (0 ... 9) and the tenths of (0 ... 9) mH.

The unit of capacitors consists of three unregulated capacitors C_1, C_2, C_3 and an adjustable capacitor C_4. Regulation of capacitance C_4 is carried out in the range from 0 to 9.99 μF a stepwise of 0.01 μF using three switches: the units of (0 ... 9), the tenths of (0 ... 9) and the hundredths of (0 ... 9) μF.

On the front panel of the blocks the following are located: the light indicators (LEDs, light indicators), the controls (knobs of switches, toggle switches, and buttons) and measurement devices.

A patchbay is a panel with 67 jacks pairs connected with each other for plugging and mounting the components of studied electrical circuits.

The external elements are designed as the transparent plastic boxes, in which there are plugs to connect and soldering inside the elements of electric circuits: *R*, *L* and *C*.

It is necessary to switch the toggle switch "POWER" in "ON" position to turn on the active unit, at the same time on front panel the "POWER LED" lights.

Measuring devices of the units are designed to display the value of current and voltage of regulated sources. Regulation is performed by means of potentiometer handle.

The frequency is adjusted stepwise with 1 kHz step by a switch and smoothly by a "FREQUENCY SMOOTHLY" potentiometer. When the potentiometer is at the right position, the frequency of the output voltage corresponds to the value indicated on the stepwise switch with an accuracy of ± 2%.

The voltage at the output of each phase of unit of the three-phase voltage source can be adjusted stepwise from 0 to 30 V in increments 1 V using two switches: the tens of (0 ... 3) and the units of (0 ... 9) V.

In the case of a short circuit or an overload in the power supply units an electronic protection is activated, and "PROTECTION" indicator lights. After removing the causes of a short circuit or overload, it is necessary to return the power supply circuit in operating state by pressing "PROTECTION" button upon that the indicator goes out.

Requirements for performing laboratory work, procedure of carrying out laboratory works and design of report

Preliminary preparation and getting admission to perform laboratory work.

Before proceeding to the next laboratory work, the student should read the content of the laboratory work, to study theoretical material on the relevant topic.

The results of the preparation should be reflected in the report of the work, which should contain the following:

− answers to the questions of section “Preparation for a laboratory work” in written form;

− preliminary calculations;

− schemes of studied electrical circuits;

− tables for recording the results of measurements and theoretical calculations.

At the beginning of classes, the student has to defend the completely prepared report of the previous laboratory work and get admission to the next work, having a previously prepared individual report.

The teacher checks student’s readiness to perform laboratory work, asking questions to test their theoretical knowledge, familiarization with the execution order of the work and the expected results of the study. Questions can be given both orally and in writing.

During the classes, students should perform the laboratory work, namely to assemble electrical circuits, to carry out the necessary measurements and calculations, write the results of measurements and calculations in advance prepared tables.

Each student defends the report on laboratory work individually at the current or following laboratory classes, or at the consultations.

The students, who have not defended the previous laboratory work and have not get an admission to the next one, as well as students whose theoretical training is recognized as unsatisfactory, are not allowed to the work.

Students who are not admitted to the work must use the remaining time to study the theory, as well as to accomplish and to defend the works made before.

The works, which were not done in time, students do in an allotted time, specified by the teacher. The admission to the laboratory work student gets in a general order.

Work in a laboratory.

For work in the laboratory, students are combined into subgroups of 3 ... 4 people or work individually. The members of the subgroup make the experimental part of the work together, but finalization and defense of report on the performed work are done individually.

Each subgroup works on a separate workbench, where all the equipment necessary for work is located.

Students perform an external inspection of measuring instruments and equipment, before starting work. The defects should be reported immediately to the teacher.

Members of subgroups are responsible for damage caused due to non-compliance with the rules of the carrying out laboratory works or safety rules, as well as for improper using of equipment.

Students assemble the studied electrical circuit for the carrying out of experimental part of the laboratory work by themselves. The electrical circuit should be as simple as possible and easily accessible at any point.

At the very beginning of the experiment all rheostats and other adjustable devices should be adjusted so that minimum values of currents and voltages are in the circuit. The measuring instruments should be switched to the maximum measuring range. After a rough determination of the measured value, the instrument should switch to a convenient measuring range.

It is necessary to invite the teacher to check the assembled electrical circuit before turning on the power sources of the studied circuit.

The electrical circuit should be alive only during the experiment. The power supply should be turned off immediately after finishing the experiment.

Readings on the measuring instruments are written down in the “Experiment” row of the pre-prepared table in the “Experiment” row and the results of theoretical calculations are written down in the “Theory” row. By the end of carrying out of measurements the results should be shown to teacher who gives permission for disassemble scheme.

Finalization and defense of a report on laboratory work.

Each student must present the finalized complete report on the work carried out by the laboratory work to defense. The report should contain the title page and the following sections:

− an objective of the work;

− a preparation for the work;

− basic theoretical principles and answers to questions of preparation for a laboratory work;

− brief information about the experiment;

− the scheme of analyzed electric circuit;

− tables for writing down measurement results and theoretical calculations;

− the formulas, and the results of theoretical calculations for specific modes of the electric circuit;

− results of the study: tables, graphs, diagrams, numerical values of the circuit parameters, electric currents and voltages, etc.

− a comparison between theory and experiment results, the conclusions of the work done.

Template of the title page is presented on the next page.

Reports should be performed only on a one side of white sheet or of lined paper with size of A4 (210x297 mm) with margins: left is 25 mm, right is 18 mm, top is 20 mm, bottom is 25 mm. The text should be written neatly or by applying computer applications. When writing the text is permitted to use only generally accepted abbreviations or designations, decrypted at the first mention.

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Department of Theoretical electrical engineering

R E P O R T
on laboratory work No ____

on the "Theoretical bases of electrical engineering" discipline

____

(Title of the laboratory work)

____

5B070200 – "Automation and control" baccalaureate specialty

Done by ____________________________________ Group _____________
(Student's Surname & Initials) (Academic group code)

Checked by ____
(Teacher's academic degree, Academic title, Initials & Surname)

_____________ ____________________ «____» _____________ __20___ y.
(Score) (Teacher's signature) (Date)

Almaty 20___ y.

1 Laboratory work № 1. Analysis of the DC linear electric circuits

Objectives of work are the following: obtaining the skills of an experimental study of DC linear electric circuits, an experimental verification of the Ohm's and Kirchhoff's laws, also calculation methods.

1.1 Preparation for the laboratory work

Repeat section "Linear electric DC circuits" of TBEE discipline.

Answer the questions in writing and do the following assignments:

1) Write down the formulations of Ohm's law and Kirchhoff's laws.

2) According to the assignment option, draw the scheme of researched circuit, see figures 1.1…1.6, and arbitrarily specify the directions of currents in all branches of the scheme.

3) Make a system of equation for researched circuit by applying Kirchhoff's laws.

4) Make a system of equation applying mesh analysis; also write down the equations for the calculation of the currents in each branch, using the calculated values of the mesh currents.

5) Make a system of equation applying nodal analysis; also write down the equations for the calculation of the currents in each branch, using the calculated values of the potentials of nodes.

6) Write down the formulas for calculation of the potentials of all the points of the outer loop of the circuit.

7) How to measure the magnitude and sign of the potential of any point of the circuit with respect to a point, the potential of which is assumed to be zero?

8) Draw a sketch of the potential diagram for the outer loop of the circuit.

9) Write down the formulas to calculate the equivalent resistance of the circuit in the case of serial, parallel and mixed connection of resistances, as well as formulas for equivalent transformation of the triangle of resistances (Δ – delta connection) to the star of resistances (Y – connection) and vice versa.

1.2 Procedure of carrying out the work

1.2.1 Measure the resistance of the resistors $R_1 \ldots R_6$ and write down the values to the table 1.1.

Table 1.1

Resistors	R_1	R_2	R_3	R_4	R_5	R_6
Resistance R, Ω						

1.2.2 Assemble the electric circuit using the resistors, which resistances has been measured in preceding section, according to the one of the schemes shown in figures 1.1…1.6. Scheme's number corresponds to assignment option. As a voltage sources you should use a regulated and unregulated DC voltage sources. When assembling circuit provide the jacks for connecting measuring instruments. Ammeter and voltmeter should be connected in accordance with the pre-chosen directions of the currents.

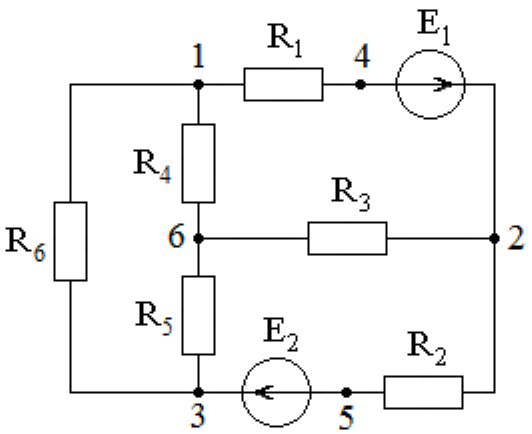


Figure 1.1

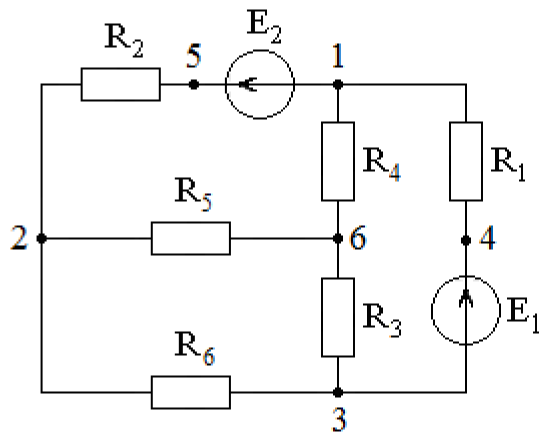


Figure 1.2

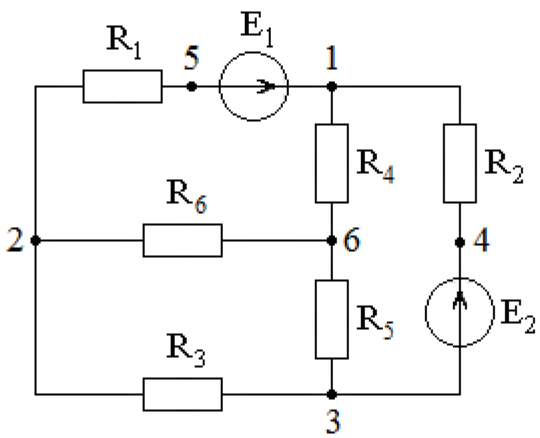


Figure 1.3

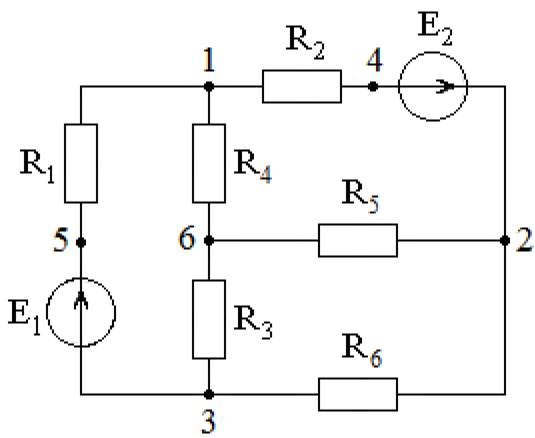


Figure 1.4

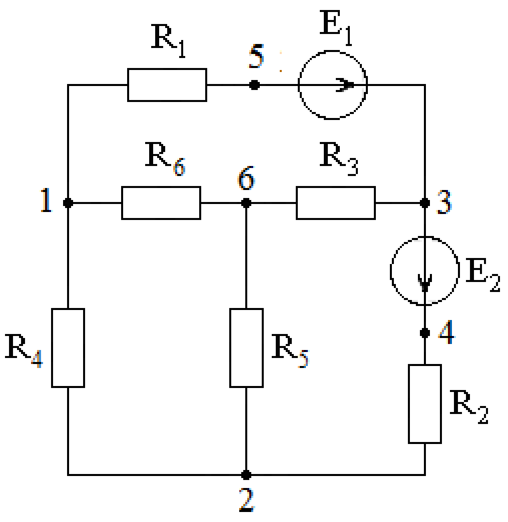


Figure 1.5

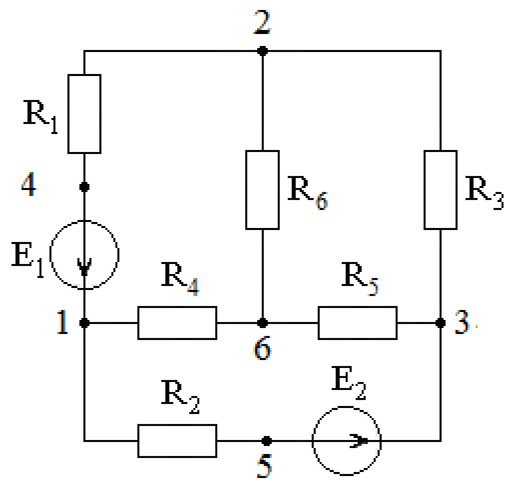


Figure 1.6

1.2.3 Measure the currents in all branches of the circuit and the values of source EMF. Write down the measured values in table 1.2 to the “Experiment” row.

Table 1.2

Currents & EMF	I_1, mA	I_2, mA	I_3, mA	I_4, mA	I_5, mA	I_6, mA	E_1, V	E_2, V
Experiment								
Calculation								

1.2.4 Assume the potential of the 1st node of circuit is zero. Measure the potentials of all points indicated in the scheme relative to the first node and write down the values in table 1.3 to the “Experiment” row.

Table 1.3

Potentials	φ_1, V	φ_2, V	φ_3, V	φ_4, V	φ_5, V	φ_6, V	φ_7, V
Experiment							
Calculation							

1.3 Processing the results of experiment and calculation

1.3.1 Check the Kirchhoff’s Current Law (KCL). Calculate the inaccuracy of KCL implementation for each node of the researched circuit.

$$\delta_1 = \frac{\sum I_k}{|I_{\max}|} \cdot 100\% ,$$

where I_{max} – the largest of the currents that converge at a given node. The calculation results write down in table 1.4.

Table 1.4

Nodes	1	2	3
Sum of the currents, mA			
The largest of the currents, mA			
Inaccuracy δ_I, %			

1.3.2 Check the Kirchhoff's Voltage Law (KVL). Calculate the inaccuracy of KVL implementation for each independent loop of the researched circuit.

$$\delta_U = \frac{\sum U_{Ri} - \sum E_i}{\left|U_{R\max}\right|} \cdot 100\% \ ,$$

where $U_{\max}$ – the largest of the voltages across elements of given particular loop. The calculation results write down in table 1.5.

Table 1.5

Independent loops	1	2	3
Sum of the voltages, V			
The largest of the voltage, V			
Inaccuracy δ_U, %			

1.3.3 Calculate the branch currents of the circuit using mesh analysis or nodal analysis. Write down the obtained values in table 1.2 to the "Calculation" row. Compare the calculated values with ones are obtained in experiment. Make a conclusion.

1.3.4 Assume the potential of the 1st node of circuit is zero. Calculate the potentials of all points indicated in the scheme relative to the first node and write down the values in table 1.3 to the "Calculation" row.

1.3.5 Plot the potential diagram for the external circuit loop.

1.4 Methodological guidelines

To construct a potential diagram it is necessary choose the closed loop. This loop divides into sections so that each section itself includes only one element, a resistor or a power source. The border points must be marked by letters or numbers. Assume a potential of one of the points is zero. Moving along loop by clockwise starting from the point of zero potential, determine the potentials of each successive point as the algebraic sum of the potential of preceding point and the voltage drop across the current circuit element.

Changing of potential along the loop depends on the type of the circuit element between adjacent points. If the current portion of loop is the energy consumer (resistor), the changing of potential is numerically equal to the voltage drop across this resistor. In case of coincidence of the true direction of the current with the move direction along loop the potential decreases, otherwise it increases. If the current portion of loop is the energy source, the changing of potential is numerically equal to the value of the source EMF. In case coincidence of the direction of the source EMF and direction of moving along loop the potential increases, otherwise it decreases.

Construct the potential diagram for the external circuit loop in the rectangular coordinate system after calculation of the potentials of all loop points. The *x*-axis represents the accumulating loop resistance, accumulative value of the individual element resistances in the sequence in which one they are located at the loop is in a pre-chosen scale m_R. On the ordinate axis put the value of potentials of corresponding loop points in scale m_φ. The potential diagram begin to construct from the point with zero potential and end after cover the loop at the same point.

The potential diagram represents the dependences of potential changing along the circuit, starting from a point, the potential of which is assumed to be zero.

A current is determined from potential diagram by the formula:

$$I = \left(m_\varphi / m_R\right) \cdot tg\alpha \,,$$

where α is the slope angle to the horizontal axis of the corresponding section of polyline of potential diagram.

2 Laboratory work №2. Analysis of linear electric circuits at single-phase sinusoidal current

Objective is obtaining the skills of an experimental research of the unbranched and branched linear electric circuits at single-phase sinusoidal current.

2.1 Preparation for a laboratory work

Study the sections of the TBEE course relating to the circuits at single-phase sinusoidal current.

In writing do the following assignments:

1) Write down Ohm’s law in a complex form and for the RMS (root means square) values for the linear electric *R*, *L*, *C* circuit shown in figure 2.1.

2) Write down KVL equation in a complex form and for the RMS values for the unbranched electric *R*, *L*, *C* circuit shown in figure 2.1.

3) Write down KCL equation in a complex form and for the RMS values for the electric circuit with parallel connection of *R*, *L*, *C* elements shown in figure 2.2.

4) Make up the equations in the complex form using Kirchhoff’s laws for one of the circuits in figures 2.3…2.8, in accordance with the assignment option (as directed by the teacher).

5) Construct the phasor diagrams of currents and voltages for the circuits shown in figures 2.1, 2.2, and for one of the circuits in figures 2.3…2.8 in accordance with the assignment option (as directed by the teacher).

6) Build phasor diagram of currents and voltages for one of the schemes in figures 2.3…2.8 qualitatively, in accordance with the assignment option (as directed by the teacher).

7) Write down formulas for the calculation of active, reactive and apparent power, as well as the equations of balance of active and reactive power in the circuits of sinusoidal current.

2.2 Procedure of carrying out the work

2.2.1 Assemble the electric circuit as shown in figure 2.1. Set the source voltage U of 5 to 15 V and a frequency f of about 1000 Hz.

The parameters of circuit's elements choose in specified ranges: resistance R = 50…200 Ω, coil of inductance L = 10…30 mH, capacity of capacitor C = 1…3 μF.

Measure the current and voltages across all elements. In addition, measure the active resistance of coil R_{coil}. Write down the measurement results to the table 2.1.

The voltage across coil of inductance (inductor) $U_{coil} = \sqrt{(I \cdot \omega L)^2 + (I \cdot R_{coil})^2}$

Table 2.1

U, V	f, Hz	R, Ω	L, mH	R_{coil}, Ω	C, μF	I, mA	U_R, V	U_{coil}, V	U_C, V

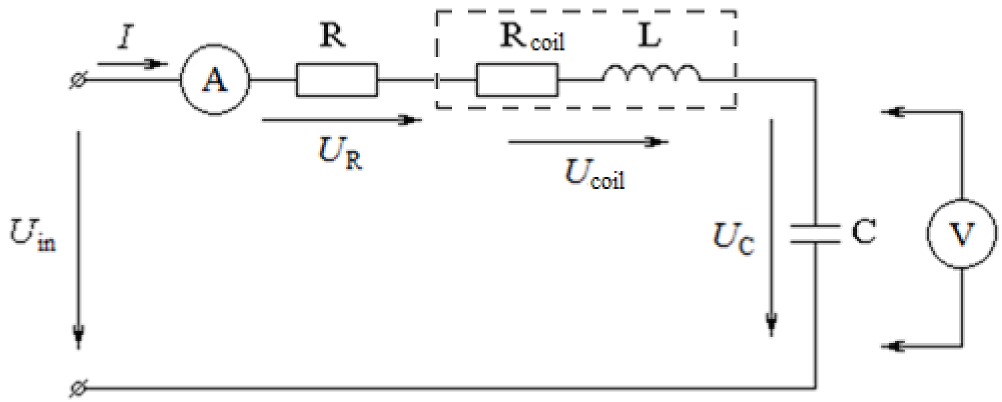


Figure 2.1

2.2.2 Assemble the electric circuit as shown in figure 2.2. Use the voltage and frequency of the source selected in the preceding paragraph, as well as the parameters of the circuit elements.

Measure the voltage across circuit elements and all currents.

Write down the measurement results to the table 2.2.

Table 2.2

U, V	f, Hz	R, Ω	L, mH	C, μF	I, mA	I_R, mA	I_L, mA	I_C, mA

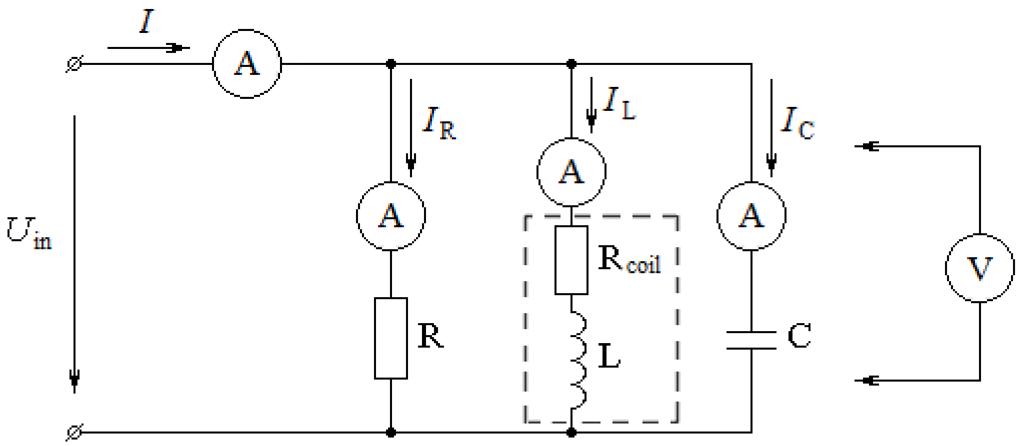


Figure 2.2

2.2.3 Assemble the electric circuit in accordance with the assignment option (as directed by the teacher) according to one of the schemes shown in figures 2.3 ... 2.8. Use the voltage and frequency of the source selected in the preceding paragraphs. The parameters of circuit's elements choose in specified ranges: active resistances R = 50 ... 200 Ω, inductors L = 10 ... 30 mH and capacitors C = 1 ... 3 μF.

Measure the currents in all branches, the voltages across all circuit elements and across the parallel circuit portion U_{ab}. The measurement results should be written in tabular form.

In table should be specified the source voltage and frequency, parameters of all elements (resistors, inductors and capacitors), the value of the currents in all branches and the voltages across all circuit elements and across parallel portion U_{ab}.

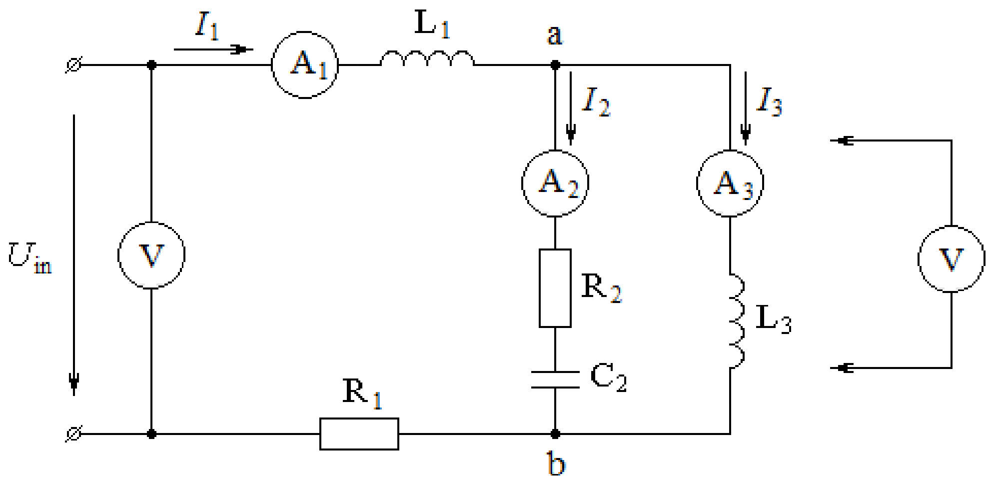


Figure 2.3

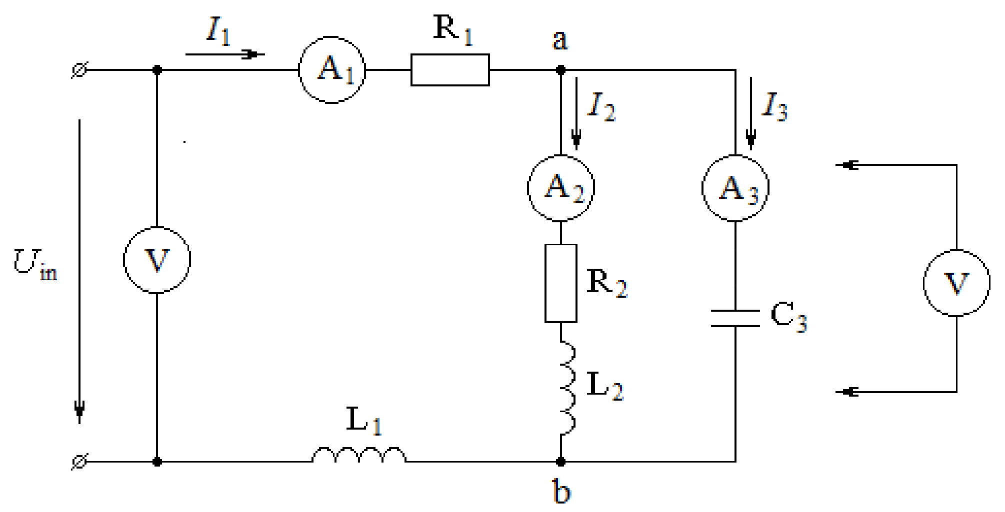


Figure 2.4

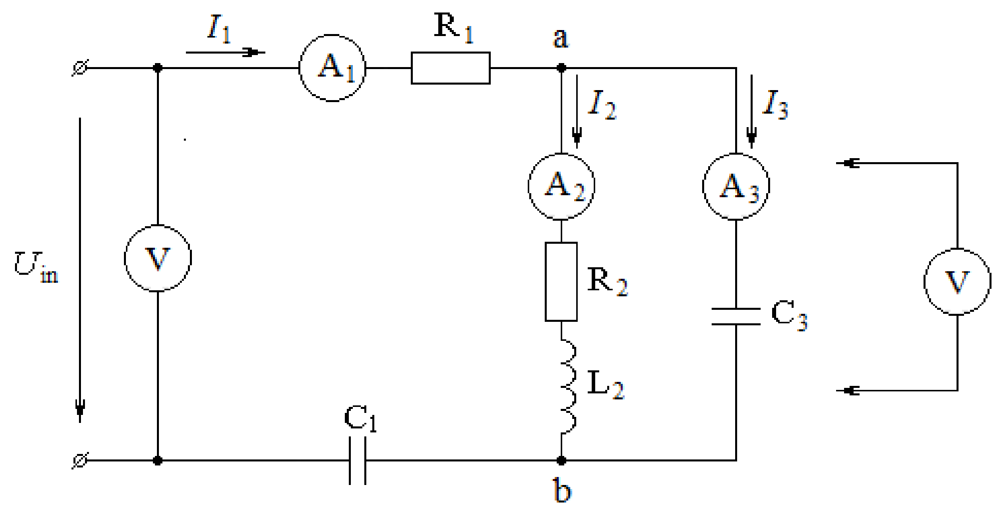


Figure 2.5

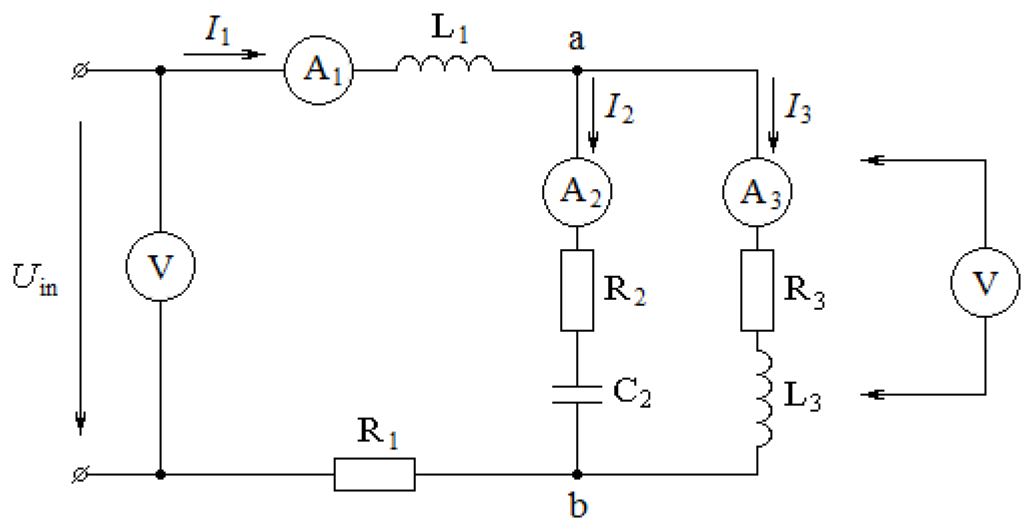


Figure 2.6

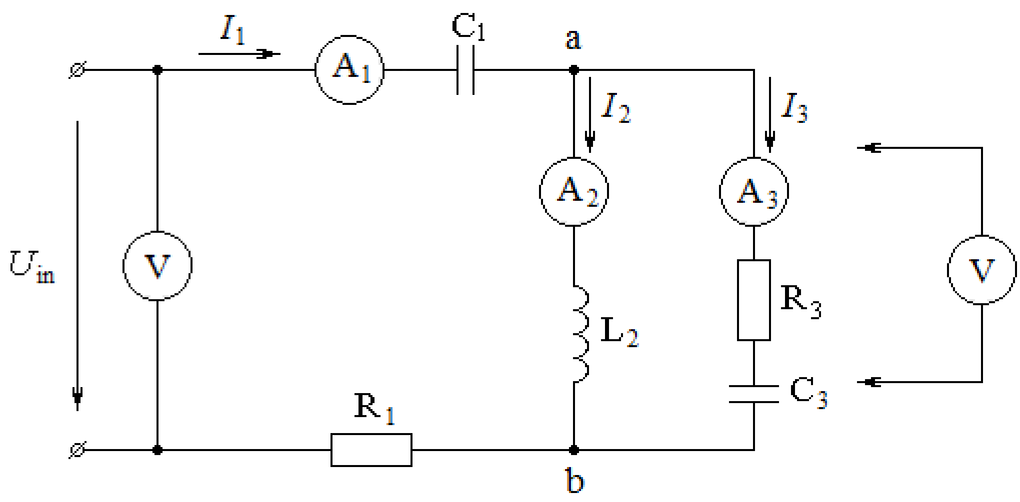


Figure 2.7

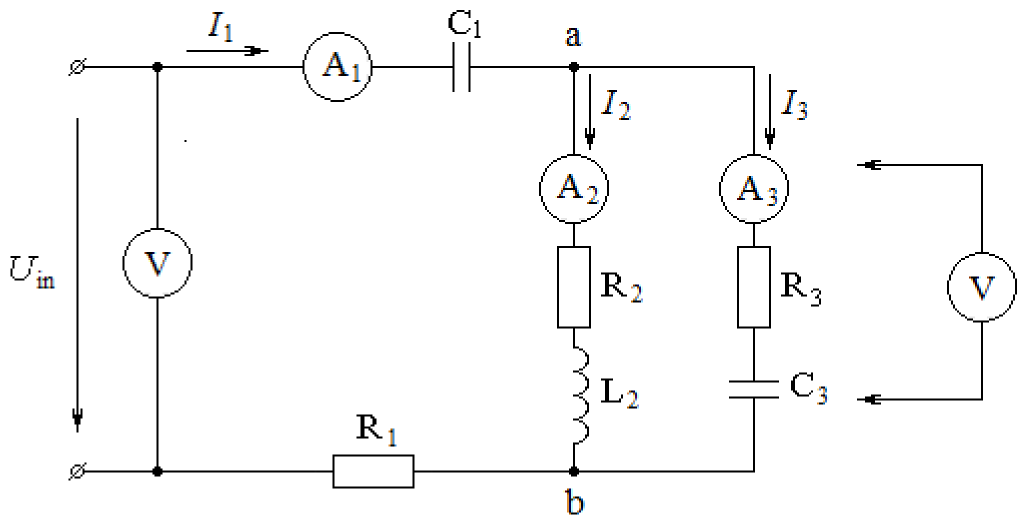


Figure 2.8

2.3 Processing the results of experiments

2.3.1 According to the data of the table 2.1 construct the phasor diagram of current and voltages for the scheme in figure 2.1. Check the implementation of the Kirchhoff's voltage law (KVL) using phasor diagram.

2.3.2 Using the data of the table 2.2 construct the phasor diagram of voltage and currents for the scheme in figure 2.2. Check the implementation of the Kirchhoff's current law (KCL) using phasor diagram.

2.3.3 Using the data in paragraph 2.2.3 should be done following:

1) Construct phasor diagram of currents and voltages for the analyzed circuit.

2) Calculate active, reactive and apparent powers of the source. Check the relation that connecting these powers: $S = \sqrt{P^2 + Q^2}$.

3) Make up an equation of balance of active power for the analyzed circuit. Check the implementation of it.

2.3.4 Make conclusions by using the results of research.

2.4 Methodological guidelines

Active power – it is the intensity of the transformation of electromagnetic energy into other forms of energy. For linear electric circuits with sinusoidal curve of current and voltage the active power P is determined by expression:

$$P = UI\cos\varphi,$$

where U and I – RMS values of the voltage and current;

$\varphi = \varphi_u - \varphi_i$ – the phase shift angle between voltage and current;

$\cos\varphi$ – power factor.

The unit of active power measurement – Watt (W).

Reactive power – it is the intensity of the exchange of energy between the electric and magnetic fields of electrical circuit elements, as well as the intensity of the exchange of energy between the energy source and the receiver. For linear electric circuits with sinusoidal curve of current and voltage the reactive power Q is determined by expression:

$$Q = UI\sin\varphi.$$

The unit of reactive power is Volt-Amps reactive (var).

Apparent power – it is the overall power of electrical equipment AC circuit, which characterizes its maximum throughput. For linear electric circuits with sinusoidal curve of voltage and current the apparent power S is determined by expression:

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

The unit of apparent power is Volt-Amps (VA).

3 Laboratory work №3. Analysis of voltage resonance phenomenon

Objective is obtaining the skills of an experimental study of resonance phenomena in linear electrical circuits of sinusoidal current.

3.1 Preparation for a laboratory work

Repeat section “The phenomenon of resonance in electric circuits” of TBEE course.

Answer the questions in writing and do the following assignments:

1) What phenomenon in electric circuit is called resonance?

2) At what connections of an inductor and a capacitor are possible a voltage resonance and a current resonance? Draw the circuit diagrams.

3) Under what condition in the electrical circuit a resonance phenomenon does occur? Write down the condition of resonance.

4) How to calculate the resonant angular frequency ω_0 and frequency f_0?

5) What value is called the characteristic impedance of the resonant circuit?

6) Write down formulas to calculate the impedance and current of the circuit at the mode of voltage resonance.

7) How to calculate the voltage across an inductance and a capacitance at mode of voltage resonance?

8) How to determine the quality-factor Q of the serial oscillating circuit? How many times does the voltage across an inductance and a capacitance exceed the input voltage in resonance mode, if the Q-factor is equal to 2.5 or 5?

9) Construct a phasor diagram of voltages and current for the electric circuit with a series connection of R, L, C for the following cases:

a) when the source frequency is equal to the resonant frequency;

b) when the source frequency is less than resonant frequency;

c) when the source frequency is more than resonant frequency.

10) How to calculate the phase angle φ_{in} between current and voltage at the input of the serial oscillating circuit?

11) Plot a graph of $\varphi_{in}(\omega)$. What is the value of the phase angle φ_{in} at resonant frequency?

12) Plot the curves of frequency characteristics of the circuit: $X_L(\omega)$, $-X_C(\omega)$ and $X_{in}(\omega) = X_L(\omega) - X_C(\omega)$.

13) Plot the graphs of the resonant curve $I(f)$ and curves $U_L(f)$, $U_C(f)$.

14) Plot the resonant curves in relative units $I/I_0 = F(f/f_0)$ for the series resonant circuits with different quality-factors.

15) How to determine the bandwidth of the serial oscillating circuit?

According to option of assignment (table 3.1) calculate the resonant frequencies ω_0 and f_0, the characteristic impedance of the circuit ρ and the total active resistances of the circuit $R_{\Sigma 1}$ and $R_{\Sigma 2}$ for two quality factors $Q_1 = 2.5$ and $Q_2 = 5.0$.

Table 3.1

Option	L, H	C, μF
1	0.02	1.0
2	0.01	3.0
3	0.01	4.0
4	0.02	2.0
5	0.01	2.0
6	0.02	3.0

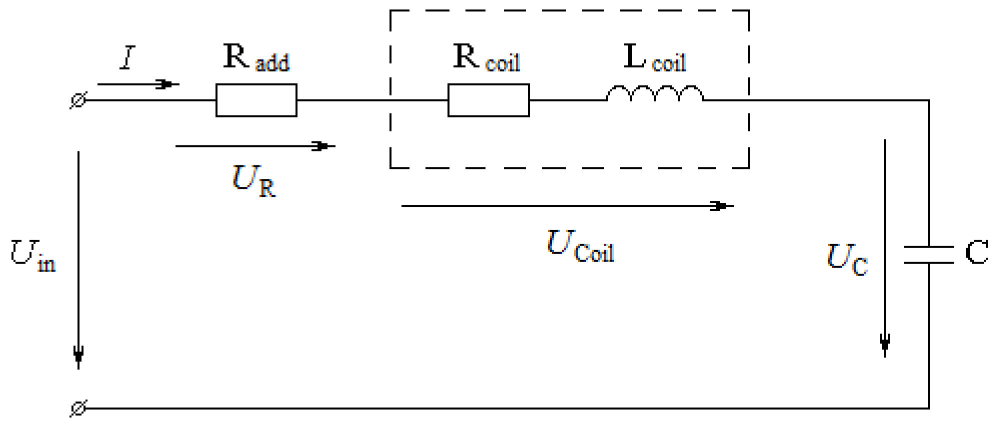


Figure 3.1 – Scheme of serial oscillating circuit

3.2 Procedure of carrying out the work

3.2.1 Assemble a serial oscillating circuit as shown in figure 3.1. Set the input voltage about 3...5V. It is convenient to use blocks of variable resistance, inductance and capacitance, respectively, or the external elements as a resistor, an inductor and a capacitor. Set the parameters according to the option of assignment (table 3.1). Measure the value of resistance of the coil of inductance R_{coil}. Value of additional resistance R_{add1} is determined by the formula $R_{add1} = R_{\Sigma 1} - R_{coil}$, where R_{Σ} is total loop active resistance calculated for the quality factor $Q_1 = 2.5$; R_{coil} is active resistance of the coil of inductance.

3.2.2 By changing the frequency of the input voltage, measure and write down the values of the frequency characteristics $I(f)$, $U_{coil}(f)$ and $U_C(f)$ for circuit with a quality-factor $Q_1 = 2.5$ to the table 3.2. Throughout the experiment, the RMS value of input voltage is kept unchanged.

3.2.3 Set the value of the additional resistor $R_{add2} = R_{\Sigma 2} - R_{coil}$ in the circuit to the quality factor $Q_2 = 5.0$. By changing the frequency of the source, measure and write down the values of the resonant curve $I(f)$ for this quality factor to the table 3.2.

Table 3.2

f, Hz	Quality-factor					
	$Q = 2.5$					$Q = 5.0$
	I, mA	U_C, V	U_{coil}, V	U_L, V	φ_{in}, deg	I, mA
1						
…						
9						

3.3 Processing the results of experiments

3.3.1 According to the measurement results, written in table 3.2, plot resonant curve $I(f)$ and frequency characteristics of the $U_L(f)$ and the $U_C(f)$. Calculate the voltage U_L by the formula: $U_L = \sqrt{U_{coil}^2 - \left(R_{coil} \cdot I\right)^2}$.

Compare the experimental curves with the theoretical ones. Make a conclusion.

3.3.2 Calculate the dependencies $I/I_0 = F(f/f_0)$ for the $Q_1 = 2.5$ and $Q_2 = 5.0$ according to the table 3.2. Plot the graphs of resonant curves $I/I_0 = F(f/f_0)$ for the two quality-factors. Determine the cut-off frequencies $f_{1\text{cut}}$ and $f_{2\text{cut}}$ for the correspondence resonant curve $I/I_0 = F(f/f_0)$, make a conclusion about the bandwidth of the circuit.

3.3.3 Determine by the experimental data (table 3.2) the resonant frequency f_0, corresponding to the maximum value of current in the circuit at fixed input voltage.

3.3.4 Calculate and plot the graph of dependence the phase angle between voltage and current at input of circuit φ_{in} versus frequency f:

$$\varphi_{in}(f) = arctg\left(\frac{U_L(f) - U_C(f)}{R_\Sigma \cdot I(f)}\right).$$

Compare the resulting curve with theoretical one. Make a conclusion.

3.3.5 Calculate the apparent and active power at resonant mode using the experimental data. Make a conclusion.

3.3.6 Determine the quality-factor of the oscillating circuit using the graphs of the frequency characteristics $U_L(f)$, $U_C(f)$ and resonant curves $I(f)$ by formulas:

$$Q = \frac{\rho}{R} = \frac{U_{L0}}{U} = \frac{U_{C0}}{U} = \frac{f_0}{f_{2cut} - f_{1cut}}.$$

Compare those values with the pre-calculated ones.

3.4 Methodological guidelines

Resonance curves $I(f)$ for two values of the Q-factor is needed to construct in relative units on the same figure. This makes it easy to compare the two curves and make a conclusion about the connection between the value of Q-factor and the width of the oscillating circuit bandwidth.

Parameters of an equivalent circuit can be calculated from the resonance curve:

$$Q = \frac{f_0}{f_{2cut} - f_{1cut}}; \quad R_\Sigma = \frac{U}{I_{0(\max)}}; \quad \rho = Q \cdot R_\Sigma; \quad L = \frac{\rho}{\omega}; \quad C = \frac{1}{\omega \cdot \rho}.$$

4 Laboratory work №4. Transients analysis in linear electric circuits of the first and second order

Objective is obtaining the skills of experimental research of transients in an electrical circuit with a single energy storage element – with capacitor and with two elements – with inductor and capacitor.

4.1 Preparation for a laboratory work

Repeat section "Transients in the first and second order linear electric circuits" of TBEE course.

Answer the questions in writing and do the following assignments:

1) What is the transient process, and what are its causes? In which of electrical circuits can occur transients?

2) Write down the commutation laws.

3) What are named as steady and free components of the transient time function, for example, of the current or of the voltage?

4) What is the physical sense of the time constant of the circuit? What is the value of *RC* - circuit time constant?

5) What is named as damping factor of the circuit?

6) Write down the expressions of instantaneous values of $u_C(t)$ and $i_C(t)$ at short circuit of *RC* - network, plot the graphs of $u_C(t)$ and $i_C(t)$.

7) Write down the equation by Kirchhoff's voltage law (KVL) for the free components of voltages across elements of *RLC* - circuit and the corresponding characteristic equation of the circuit.

8) Which roots of the characteristic equation of *RLC* - circuit corresponds to the overdamped character of discharge of the capacitor? Write down the expressions for the instantaneous values of the $u_C(t)$, $i(t)$ and $u_L(t)$ at overdamped character of discharge of the capacitor. Draw graphs of these time functions.

9) Which roots of the characteristic equation of *RLC* - circuit corresponds to the critical overdamped character of discharge of the capacitor? Write down the expressions for the instantaneous values of the $u_C(t)$, $i(t)$ and $u_L(t)$ at critical overdamped character of discharge of the capacitor.

10) Write down the expression for the calculation of the critical resistance of *RLC* - circuit.

11) Which roots of the characteristic equation of *RLC* - circuit corresponds to the underdamped character of discharge of the capacitor? Write down the expressions for the instantaneous values of the $u_C(t)$, $i(t)$ and $u_L(t)$ at underdamped character of discharge of the capacitor. Draw graphs of these time functions.

12) What is called logarithmic damping decrement?

4.2 Procedure of carrying out the work

4.2.1 Assemble the electric circuit as shown in figure 4.1.

Set values of the EMF E_0, the resistor R and the capacitor C according to the assignment option, table 4.1. Set value of R_1 in the range of 100...300 Ω. Plug in the voltage across capacitor to the oscilloscope input. Copy the voltage curve $u_C(t)$ in a scale from the oscilloscope screen or take a screenshot.

Change one of the circuit parameters according to assignment option (table 4.2). Copy new curve of $u_C(t)$ in a scale from the oscilloscope screen or take a screenshot, aligning it with the first curve. Compare the obtained curves.

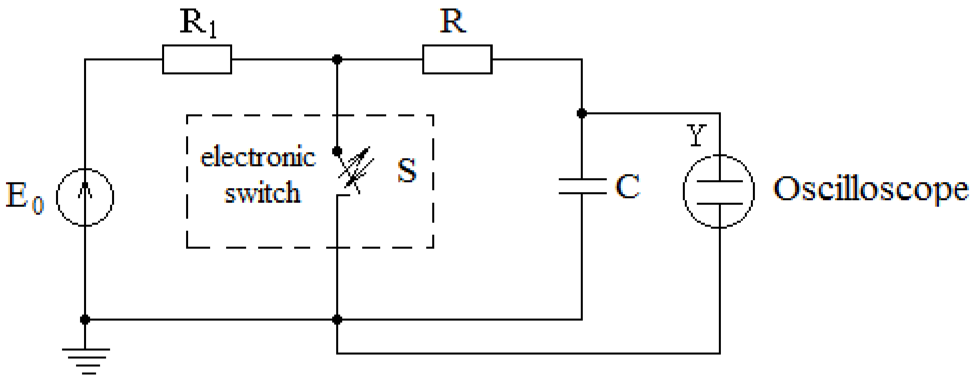


Figure 4.1 – Scheme of research the *RC*-circuit

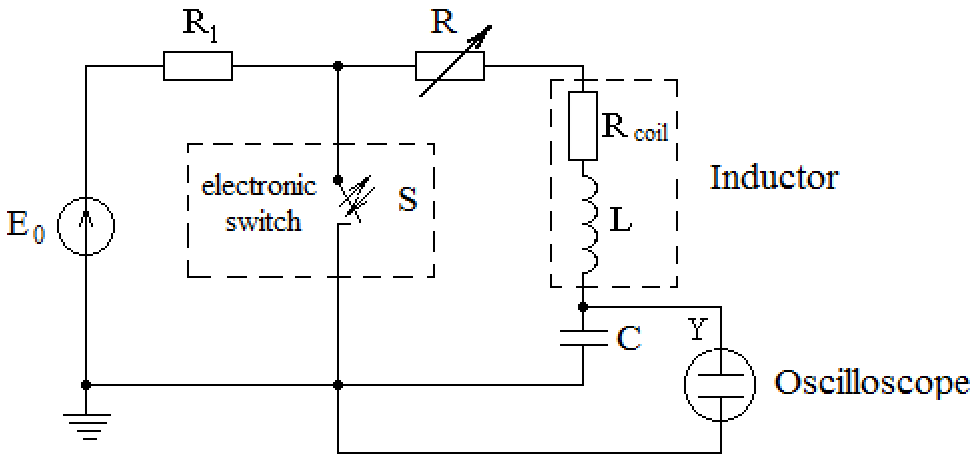


Figure 4.2 – Scheme of research the *RLC*-circuit

Table 4.1

Option	E_0, V	R, Ω	C, μF
1	10	300	4
2	15	400	2
3	20	200	5
4	10	600	5
5	15	500	3

Table 4.2

Option	E_0, V	R, Ω	C, μF
1	10	600	4
2	15	400	4
3	20	400	5
4	10	300	5
5	15	500	6

Table 4.3

Option	R, Ω	L, mH	C, μF
1	1	10	4
2	1	20	3
3	1	20	2
4	1	15	2
5	1	10	3

4.2.2 Assemble the electric circuit as shown in figure 4.2.

Set values of the resistor R, the inductor L and the capacitor C according to the assignment option, table 4.3. Measure the coil resistance R_{coil}. Set values of the R_1 in the range of 100...300 Ω and of the EMF E_0 = 15…20 V.

Plug in the voltage across capacitor to the oscilloscope input. Copy the voltage curve $u_C(t)$ in a scale from the oscilloscope screen or take a screenshot.

By increasing the resistance of the resistor R to achieve the disappearance of fluctuations on the voltage curve $u_C(t)$ that corresponds to the critical overdamped character of the capacitor discharge. Write down the value of obtained critical resistance $R_{cr.exp.}$ of circuit with taking into account the coil resistance R_{coil}. Compare the value of critical resistance obtained in the experiment with the calculated.

Enlarge total resistance of the circuit R_Σ in two times in comparison with the critical. Copy the obtained voltage curve $u_C(t)$ from the oscilloscope screen for the overdamped character of the capacitor discharge.

4.3 Processing the results of experiments

Calculate the time constants τ and damping factors α of the circuit shown in figure 4.1 for two given options of the circuit parameters (tables 4.1 and 4.2): τ_{RC1}, α_{RC1} и τ_{RC2}, α_{RC2}.

Determine the time constant τ_{RC} and the damping factor α_{RC} of the circuit by the image of the voltage curve at the capacitor $u_C(t)$.

Theoretically calculate voltage function $u_C(t)$ by the known parameters of the circuit according to assignment option (tables 4.1 and 4.2).

Draw graphs of the calculated and experimental curves $u_C(t)$ on the same figure.

Make a conclusion about the impact of the value of resistance R or capacitance C on the time constant τ of the circuit and consequently on the rate of transient process; determine the time of discharge of the capacitor.

For the circuit in figure 4.2 theoretically calculate the damping factor $\alpha_{theory.}$ and the natural frequency $\omega_{0theory}$ by using given values of total resistance $R_{\Sigma} = R + R_{coil}$, L and C.

Calculate the experimental values of the damping factor $\alpha_{exp.}$ and the natural frequency $\omega_{0exp.}$ of the circuit by using the experimentally obtained image of voltage waveform across the capacitor $u_C(t)$ (see point 4.2.2).

Theoretically calculate the critical resistance $R_{cr.theory}$ of circuit by using given values of L and C according to the assignment option (table 4.3).

Make conclusions on the done work: compare the theoretically calculated values of α, ω_0 and R_{cr} with ones obtained experimentally. Analyze the impact of the total resistance of the circuit on the character of discharge of the capacitor.

4.4 Methodological guidelines

The scale of the time axis is determined from the condition that the electronic switch (S) commutes with a frequency f = 50 Hz and a period of T = 20 ms. During a first half of the period (10 ms), the electronic switch is opened, the capacitor is charged. And during a second half of the period (10 ms), the electronic switch is closed, the capacitor discharges.

The time constant of the circuit τ_{RC} is determined by experimental curve of $u_C(t)$ as a subtangent a-b (figure 4.3).

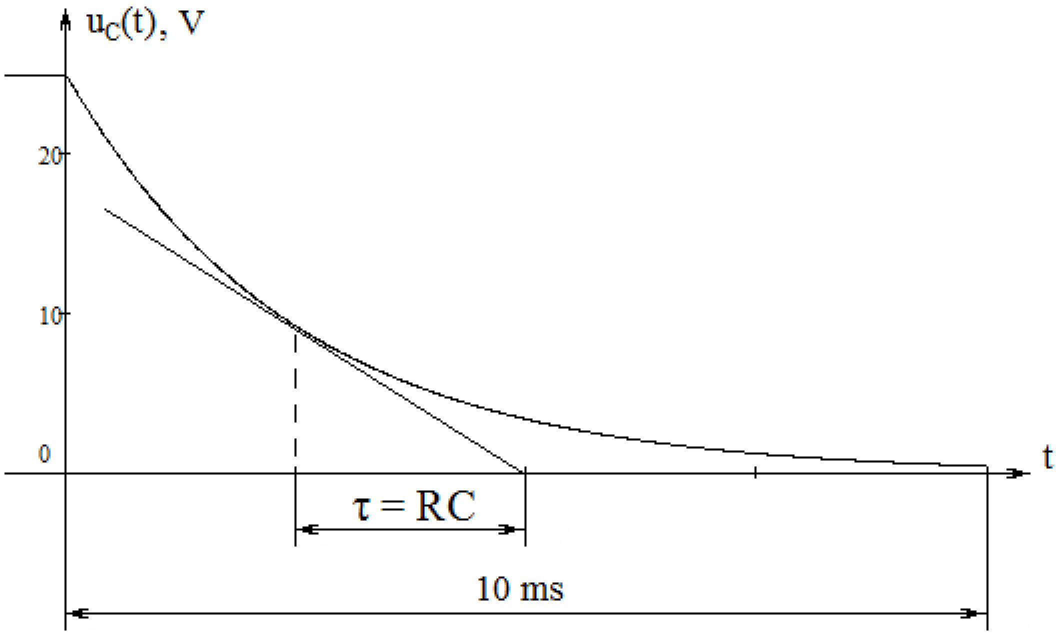


Figure 4.3 – Determination the time constant τ_{RC} of RC-circuit

Theoretical values of the damping factor α_{theory}, the natural frequency $\omega_{0\text{theory}}$ and the critical resistance $R_{\text{cr.theory}}$ are determined by the formulas:

$$\alpha_{theory}=\frac{R_{\Sigma}}{2L};\quad \omega_{0theory}=\sqrt{\frac{1}{LC}-\left(\frac{R_{\Sigma}}{2L}\right)^{2}};\quad R_{cr.theory}=2\sqrt{\frac{L}{C}}\,.$$

The experimental values of the damping factor $\alpha_{\text{theory.}}$ and the natural frequency $\omega_{0\text{theory}}$ are determined by the voltage curve $u_C(t)$ which obtained from the oscilloscope screen, as shown in figure 4.4.

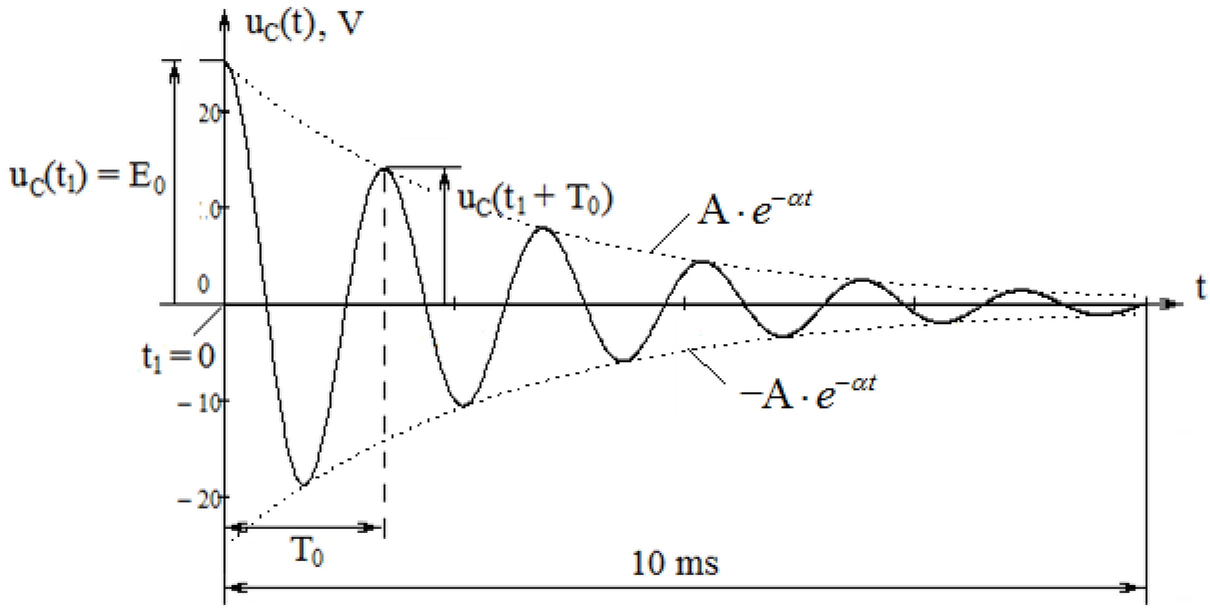


Figure 4.4 – Determination the $\alpha_{\text{exp.}}$, T_0 and $\omega_{0\text{theory}}$ of *RLC*-circuit

The natural frequency $\omega_{0\text{theory}}$ can be calculated by the formula:

$$\omega_0 = 2\pi f_0 = \frac{2\pi}{T_0},$$

where T_0 is period of free oscillations is determined by the voltage curve $u_C(t)$ as shown in figure 4.4.

The experimental value of the damping factor $\alpha_{\text{exp.}}$ can be calculated by the logarithmic decrement and period of natural oscillation by the formula:

$$\alpha_{\text{exp.}} = \frac{1}{T_0}\ell n\frac{u_c(t_1)}{u_c(t_1+T_0)},$$

where $u_C(t_1) = E_0$ – amplitude of the voltage oscillation across capacitor at the moment $t_1 = 0$. In denominator the value of amplitude of the voltage oscillations across capacitor after the period T_0.

5 Laboratory work №5. Analysis of three-phase electric circuits at star connection of source and load phases

Objectives are obtaining the skills of the experimental study of three-phase electric circuits at star connection of source and load phases, experimentally obtain fundamental relations between the phase and the line voltages and currents in the balanced and unbalanced modes, as well as to evaluate the role of a neutral wire.

5.1 Preparation for a laboratory work

Repeat section “Three-phase circuits” of the TBEE course.

Answer the questions in writing and do the following assignments:

1) What is called a “connection in star” of the source and the load phases?

2) What points of the three-phase circuit are called as neutrals? What wire is called as neutral (a null) wire?

3) What wires are called the line wire, which values of the current and the voltage are called the line current or the line voltage and which called the phase one?

4) What mode in the three-phase circuit is called balanced?

5) What relations are between the phase and line currents and voltages in a balanced mode at connection the phase in star, what values are equal I_{N}, U_{nN}?

6) Write down formula for calculating the bias voltage U_{nN} by the method of two nodes.

7) Construct the phasor diagram of currents and the topographical diagram of voltages for three-phase electrical circuit without a neutral wire in the following modes:

− balanced mode (the equal resistances are connected in the load’s phases);

− emergency mode, when open circuit and short-circuit of one of the load phases according to assignment option, the resistances of the other two phases are active and equal.

8) By using the topographical and the phasor diagrams determine the changing of currents and voltages in emergency mode in comparison with the values in the balanced mode.

9) Construct the phasor diagram of currents and the topographical diagram of voltages for three-phase electrical circuit with a neutral wire in the following modes:

− balanced mode (in the load phases are connected the equal resistances);

− emergency mode, when open circuit of one of the load phases according to assignment option, the resistances of the other two phases are active and equal.

10) By using the topographical and phasor diagrams determine the changing of currents and voltages in unbalanced mode in comparison with the values in the balanced mode.

11) Draw schemes of three-phase circuit when phases are connected according to the “Star – Star” with and without the neutral wire, see figures 4.1 and 4.2.

12) Draw the table 5.2 and the table 5.3.

5.2 Procedure of carrying out the work

5.2.1 Choose the resistors with equal values of resistance: $R_1 = R_2 = R_3$.

5.2.2 Assemble the phases of three-phase source and load in a star. Connect the neutral points of the source and the load by the neutral wire.

Experimentally study a balanced mode. The resistances of load phases are an active and equal to each other: $R_A = R_1$, $\mathrm{R_B} = R_2$, $R_C = R_3$.

5.2.3 Turn on a block of three-phase voltage source and set the phase EMF values of three-phase source in accordance with the assignment option (table 5.1). Measure the phase currents of the load, the current in the neutral wire I_N and the line and phase voltages of the load. Write down the measurement results to the table 5.2.

5.2.4 Study experimentally an emergency operation mode that occur in the circuit with a neutral wire at breakage of one of the phases of the load in accordance with the assignment option (table 5.1). The resistances in other two phases of load are the same as in point 5.2.2. Measure the phase currents of the load, the current in the neutral wire I_N and the phase and line voltages of the load. Write down the measurement results to the table 5.2.

5.2.5 Study experimentally an unbalanced mode in a three-phase circuit with a neutral wire at reduced twice the value of resistance in one of the load phases, in accordance with the assignment option (table 5.1). The resistances in other two phases of load are the same as in point 5.2.2. Measure the phase currents of the load, the current in the neutral wire I_N and the phase and line voltages of the load. Write down the measurement results to the table 5.2.

5.2.6 Disconnect the neutral wire. Study a balanced mode in a circuit without a neutral wire experimentally. The resistances of load phases are an active and equal to each other: $R_A = R_1$, $\mathrm{R_B} = R_2$, $R_C = R_3$. Measure the load phase currents, the phase and line voltages of the load and U_{nN} neutral displacement voltage between the neutral nodes of source and load. Write down the measurement results to the table 5.3.

5.2.7 Study experimentally an emergency operation mode that occur in the circuit without neutral wire at breakage of one of the phases of the load. The phase is the same as in point 5.2.4 (“open circuit” mode). The resistances in other two phases of load are the same as in point 5.2.2. Measure the phase currents of the load, the phase and line voltages of the load and the voltage of neutral displacement U_{nN}. Write down the measurement results to the table 5.3.

5.2.8 Study experimentally an emergency operation mode that occur in the circuit without neutral wire at short circuit of one of the phases of the load. The phase is the same as in point 5.2.4. The resistances in other two phases of load are the same as in point 5.2.2. Measure the phase currents of the load, the phase and line voltages of the load as well as the voltage of neutral displacement U_{nN}. Write down the measurement results to the table 5.3.

5.2.9 Study experimentally the potential displacement of neutral node of the load in the circuit without neutral wire at reduced twice the value of resistance in one of the load phases. The phase is the same as in point 5.2.4. The resistances in other two phases of load are the same as in point 5.2.2. Measure the phase currents of the load, the phase and line voltages of the load as well as the voltage of neutral displacement U_{nN}. Write down the measurement results to the table 5.3.

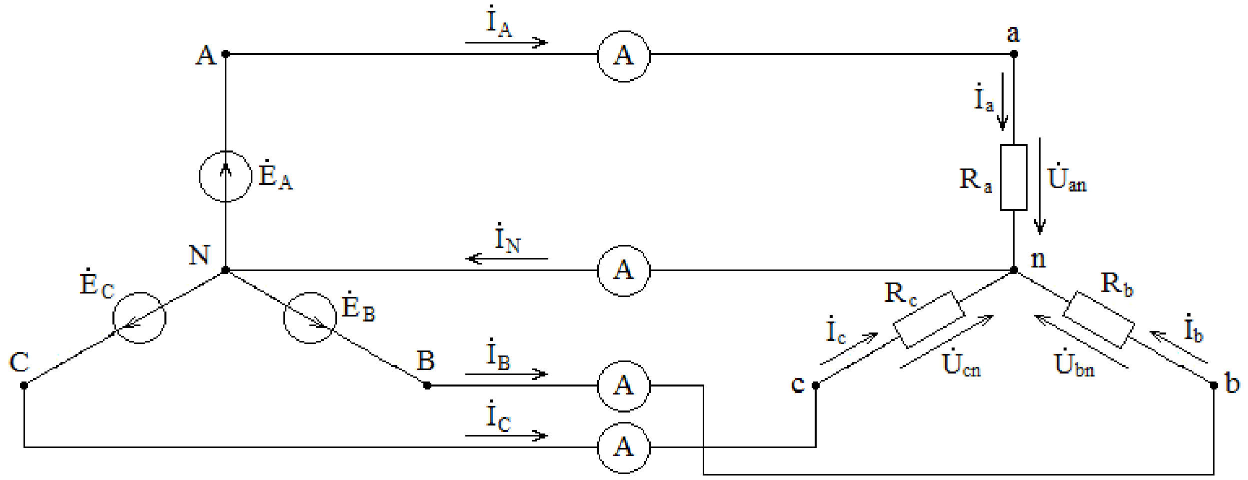


Figure 5.1 – Scheme with neutral wire of star connection of source’s and load’s phases

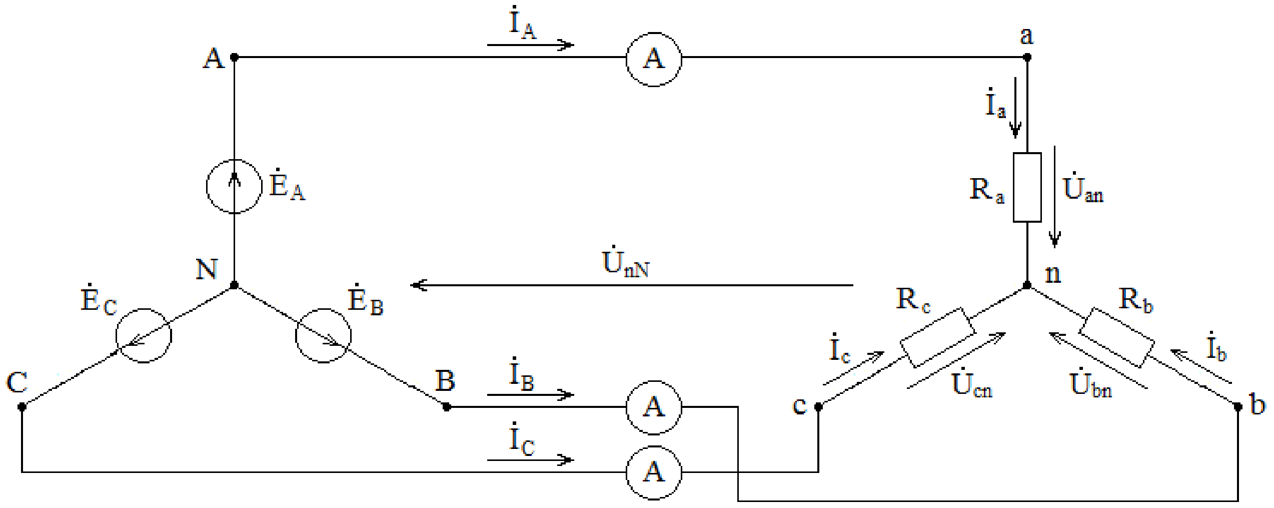


Figure 5.2 – Scheme without neutral wire of star connection of source’s and load’s phases

Table 5.1 – Assignment options

Option	Phase voltage	Open circuit, short circuit and change twice value of resistance *R* in phase
1	4	*B*
2	5	*A*
3	6	*C*

4	7	*B*
5	8	*A*
6	9	*C*

Table 5.2 – Study of three-phase circuit with neutral wire

Kind of research	Mode	Voltages, V						Currents, mA			
		U_{ab}	U_{bc}	U_{ca}	U_{an}	U_{bn}	U_{cn}	I_A	I_B	I_C	I_N
Experiment	balance										
	open phase										
	unbalance										
Theory	balance										
	open phase										
	unbalance										

Table 5.3 – Study of three-phase circuit without neutral wire

Kind of research	Mode	Voltages, V							Currents, mA		
		U_{ab}	U_{bc}	U_{ca}	U_{an}	U_{bn}	U_{cn}	U_{nN}	I_A	I_B	I_C
Experiment	balance										
	open circuit										
	short circuit										
	unbalance										
Theory	balance										
	open circuit										
	short circuit										
	unbalance										

5.3 Processing the results of experiments

5.3.1 Construct the topographical diagram of voltages and the phasor diagram of currents using experimental data of point 5.2.3. Indicate the position of the neutral nodes of source *N* and load *n* on the topographical diagram.

Check the ratio between line and phase voltages in a balanced mode.

Using the known values of the phase voltages and load impedances calculate the RMS values of currents in the load's phases. Determine the current in the neutral wire I_N using the phasor diagram and ensure that the current in the neutral wire $I_N = 0$ in the balanced mode. Write down the calculation results to the table 5.2 in "Theory" row. Compare the theoretical and experimental values.

5.3.2 Construct the topographical diagram of voltages and the phasor diagram of currents using experimental data of point 5.2.4. Determine the current in the neutral wire I_N using the phasor diagram. Compare the value obtained with the one measured in the experiment. Calculate the RMS values of the voltages and currents in the three-phase circuit at breakage of one of the load phases (a phase is the same as in point 5.2.4). Write down the results to the table 5.2 in “Theory” row. Compare the theoretical and experimental values.

5.3.3 Construct the topographical diagram of voltages and the phasor diagram of currents using experimental data of point 5.2.5. Determine the current in the neutral wire I_N using the phasor diagram. Compare the value obtained with the one measured in the experiment. Calculate the RMS values of the voltages and currents in the three-phase circuit at reduced twice the value of resistance in one of the load phases (a phase is the same as in point 5.2.4). Write down the results to the table 5.2 in “Theory” row and compare with experimental values.

5.3.4 Construct the topographical diagram of voltages and the phasor diagram of currents using experimental data of point 5.2.6. Calculate the RMS values of the voltages and currents in the three-phase circuit without a neutral wire at balanced mode. Write down results to the table 5.3 in “Theory” row and compare with experimental values.

5.3.5 Construct the topographical diagram of voltages and the phasor diagram of currents using experimental data of point 5.2.7. Calculate the RMS values of the voltages and currents in the three-phase circuit without a neutral wire at breakage of one of the phases of the load. Write down results to the table 5.3 in “Theory” row and compare with experimental values.

5.3.6 Construct the topographical diagram of voltages and the phasor diagram of currents using experimental data of point 5.2.8. Calculate the RMS values of the voltages and currents in the three-phase circuit without a neutral wire at short circuit in one of the phases of the load. Write down results to the table 5.3 in “Theory” row and compare with experimental values.

5.3.7 Construct the topographical diagram of voltages and the phasor diagram of currents using experimental data of point 5.2.9. Calculate the RMS values of the voltages and currents in the three-phase circuit without a neutral wire at reduced twice the value of resistance in one of the load phases. Write down results to the table 5.3 in “Theory” row and compare with experimental values.

5.3.8 For all the studied modes of the three-phase circuit do the following:

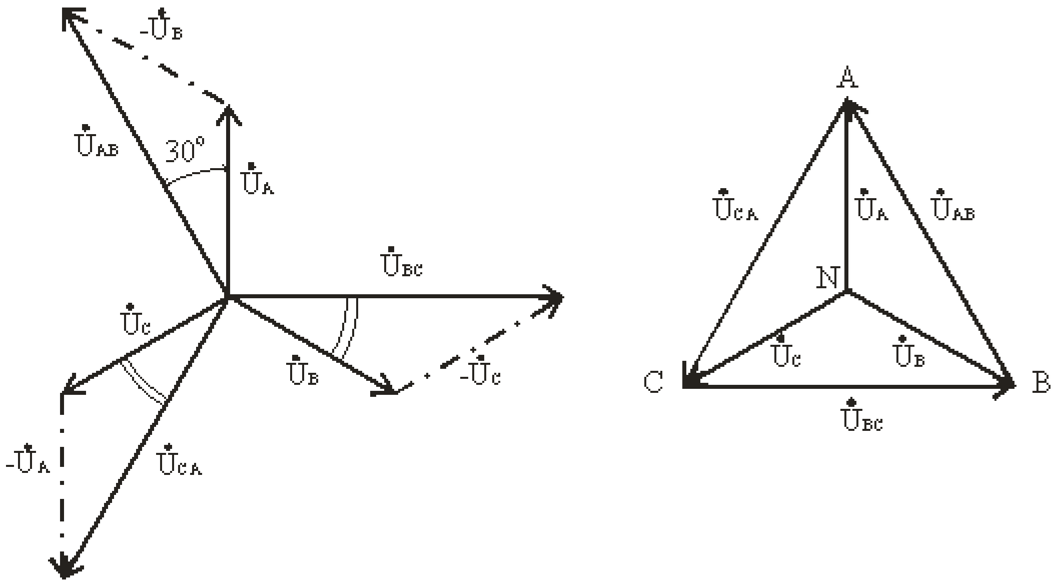
− make the conclusions about the results of the comparison of theoretical and experimental values of voltages and currents;

− compare the values of currents and voltages in three-phase circuit with neutral wire and without it, make conclusion about the role of neutral wire.

5.4 Methodological guidelines

It is seen from the vector diagram (figure 5.3 a) if the phase voltages system is balanced then the system of line voltages is also balanced. Line voltages U_{AB},

U_{BC}, U_{CA} are equal in magnitude and are phase-shifted relative to each other by 120° (general symbol is U_{line}) and gets ahead of the vectors of the phase voltages U_{A}, U_{B}, U_{C} (general symbol is U_{phase}) on an angle of 30°.



a) b)

Figure 5.3

It is convenient to construct a topographic diagram of voltages (figure 5.3 b) combined with the vector diagram of currents to analyze the operation modes of the three-phase electric circuit. Potentials of points on the topographic diagram correspond to potentials of points in the circuit in magnitude and phase. Vector that connects two points on the topographic diagram expresses the magnitude and phase of voltage between the same points of the circuit.

6 Laboratory work №6. Analysis of electric DC circuit with nonlinear elements

Objective is to obtain the skills of experimental research of electrical DC circuits with nonlinear elements.

6.1 Preparation for a laboratory work

Repeat section “Nonlinear electric DC circuits” of the TBEE course.

Answer the questions in writing and do the following assignments:

1) What kind of non-linear elements are called symmetric and what ones asymmetric? Show their current-voltage characteristics.
2) What is the difference between the static and the differential resistances of nonlinear elements?
3) Draw a scheme for getting the readings required for the construction of the current-voltage characteristics of the nonlinear element. As the source, you must use a regulated DC power supply. Provide necessary measuring instruments in the scheme.
4) Give an example of the graphical calculation method of electrical circuit with a single source of EMF and with two nonlinear resistors connected in series.
5) Give an example of the graphical calculation method of electrical circuit with a single source of EMF and with two nonlinear resistors connected in parallel.
6) Give an example of the graphical calculation method of electrical circuit with a combined connection of three nonlinear resistors.
7) Give an example of the graphical calculation method of the electric circuit with nonlinear elements by applying method of two nodes.

6.2 Procedure of carrying out the work

6.2.1 Get the readings for the construction of the current-voltage characteristics of the three non-linear elements (as directed by the teacher) according to the scheme in figure 6.1, by changing the voltage between 0 and 20 V. Fill in the table 6.1 for each nonlinear element.

6.2.2 Assemble the circuit with combined connection of three nonlinear elements as shown in figure 6.2. Changing of the input voltage from 0 to 20 V, measure and record the readings in table 6.2.

6.2.3 Assemble circuit with two sources of EMF. Measure the EMF of source, the voltages across each element, the voltage between two nodes and the currents in each branch of the circuit. Write down the measurement results to the table 6.3.

Table 6.1

U, V	0	5	10	15	20
I, mA					

Table 6.2

U, V	0	5	10	15	20
U_1, V					
U_2, V					
I_1, mA					
I_2, mA					
I_3, mA					

Table 6.3

E_1, V	E_3, V	U, V	I_1, mA	I_2, mA	I_3, mA

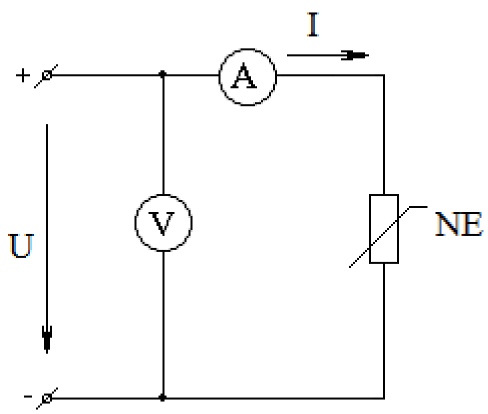


Figure 6.1

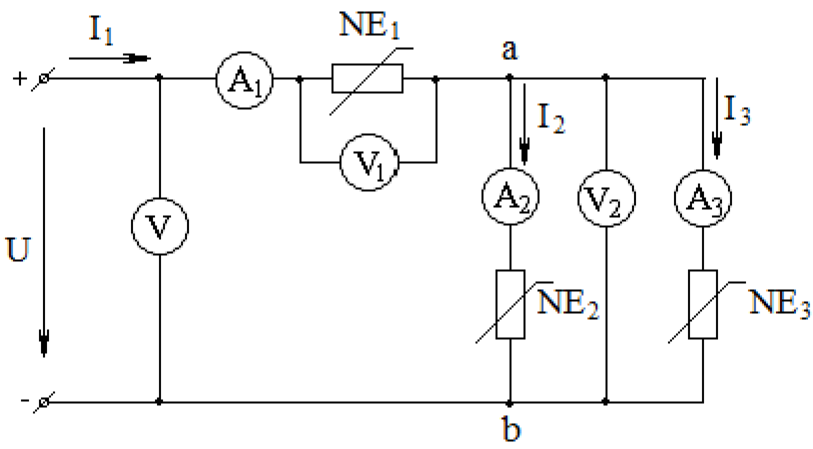


Figure 6.2

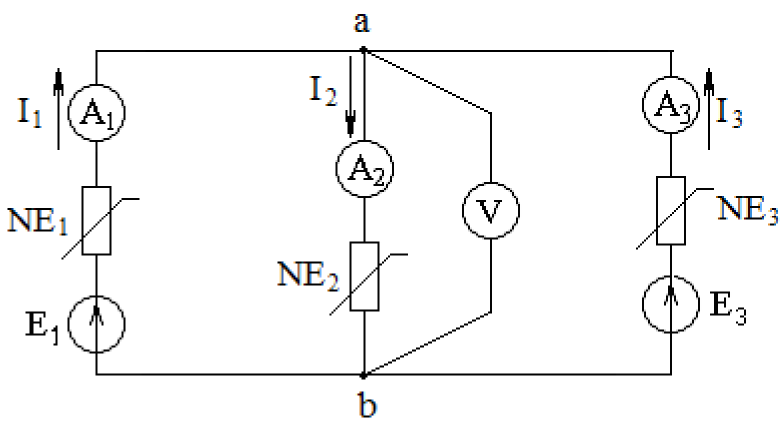


Figure 6.3

6.3 Processing the results of experiments

6.3.1 Draw current-voltage characteristics of three nonlinear elements.

Make the graphical calculation of currents and voltages for the circuit in figure 6.2 and compare the theoretical calculated values with those obtained in the experiment.

Make the graphical calculation of currents and voltages for the circuit in figure 6.3 by applying two nodes method and compare the theoretical calculated values with those obtained in the experiment.

Make conclusions based on the results of the work done.

6.4 Methodological guidelines

The procedure for calculating the electrical circuit in the case of combined connection of non-linear elements (figure 6.2):

− first replace the two parallel-connected non-linear element NE_2 and NE_3 by one equivalent, i.e. plot the current-voltage characteristic of equivalent nonlinear element NE_{eq} by taking several values of the voltage U_{ab} and adding up corresponding values of the currents I_2 and I_3;

– then the resulting equivalent NE_{eq} nonlinear element and the remaining non-linear element NE_1 is considered as a circuit with a series connection of two non-linear elements.

References

Main references

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 references

4 Бессонов Л. А. Теоретические основы электротехники. – М.: Гардарики, 2006. – 701 с.

5 Шебес М. Р., Каблукова М. В. Задачник по теории линейных электрических цепей. – М.: Высшая школа, 1990. – 544 с.

6 Денисенко В. И., Зуслина Е. Х. ТОЭ. Учебное пособие. – Алматы: АИЭС, 2000. – 83 с.