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**ALMATY
UNIVERSITY OF
POWER
ENGINEERING AND
TELECOMMUNICATIONS**

Department
of Electrical Engineering

THEORY OF ELECTRICAL CIRCUITS 1

Methodological guidelines and assignments for performing laboratory works for students majoring in specialties: 5B071900 – Radio engineering, electronics and telecommunications; 5B070400 – Computing and software; 5B070300 – Information systems; 5B074600 – Space techniques and technology; 5B060200 – Informatics;
5B071600 – Instrumentation

Almaty 2018

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Methodological guidelines and assignments for making laboratory works contain 10 laboratory works on the following sections: direct current circuits, single-phase sinusoidal current circuits, resonances in electrical circuits, amplitude-frequency and phase-frequency characteristics of electrical circuits, nonlinear DC circuits, non-sinusoidal circuits and two-port circuits.

Each laboratory work includes the purpose of the laboratory work, preparation, order of performance, analysis and design of experimental results, as well as conclusions to the work performed.

Methodological guidelines and assignments are intended for students of all forms of education.

52 illustrations, 33 tables, 10 items of references.

Reviewer: B. I. Tuzelbayev, PhD

Printed according to the plan of publications of non-commercial JSC “Almaty university of power engineering and telecommunications” for 2018.

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2018

Introduction

The laboratory study is of great importance for the quality of training and formation of students' creative thinking and engineering skills.

Methodological guidelines and assignments for performing laboratory works are an integral part of a set of methodological literature on the disciplines: "Theory of electrical circuits" for the 5B071900 - Radio engineering, electronics and telecommunications specialty; "Theory of electrical circuits. Linear and nonlinear circuits" and "Theory of electrical circuits. Calculation methods of linear and nonlinear electrical circuits" for the 5B070400 - Computing and software specialty; "Fundamentals of the theory of circuits" and "Theory of electrical circuits" for the 5B070300 - Information systems specialty; "Theory of electrical circuits" and "Theoretical fundamentals of electrical engineering" for the 5B074600 - Space techniques and technology specialty; "Fundamentals of electrical circuits" and "Theory of electrical circuits" for the 5B060200 - Informatics specialty; "Fundamentals of the theory of linear circuits" and "Theory of linear electrical circuits" for the 5B071600 - Instrumentation specialty.

To improve the quality of training specialists, forming students' creative thinking and engineering skills, laboratory studies are of great importance.

Laboratory works are the set of experimental and theoretical assignments in the study of DC linear electric circuits, single-phase and three-phase sinusoidal current circuits. All laboratory work is carried out by frontal method after the material of a given topic is presented at the lecture.

The practical implementation of the laboratory studies is made at the laboratory workbenches UILS at the department of electrical engineering. The workbench UILS is located on the table and it is a metal box, in which active and passive units, as well as a patchbay to assemble electrical circuits are mounted. The workbench also includes 30 external components (resistors, capacitors and inductors) and a set of connecting wires with plugs.

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

The DC voltage unit comprises:

- adjustable DC stabilized voltage source with regulation range from 0.25 to 24 V;
- unregulated DC voltage source with output voltage of about 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 unit is a functional generator with adjustable frequency and value of voltage of sinusoidal, rectangular and triangular shapes.

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

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

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

The light indicators (LEDs, light indicators), controllers (knobs switches, toggle switches, and buttons) as well as measurement devices are located on the front panel of the units.

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

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

To switch the toggle switch POWER in ON position it is necessary to turn on the power supply units and the NETWORK indicator lights up.

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

The frequency is adjusted 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 $\pm 2\%$.

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

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

Requirements for the registration of report on laboratory work

The students gets the assignment for the current laboratory work in advance at the previous lesson, one or two weeks earlier.

Each student should prepares a report himself in order to carry out a laboratory work, having acquainted with the purpose of work and basic theoretical principles used in the experiment.

Before the implementation of experimental part, the student is interviewed about the preparation for a laboratory work, prepared report for carrying out the work by the instructor and is given the permission to make the work.

Having finished the experimental part, the report should be completed: the student should compare theory and experiment carried out, then draw necessary graphs, give an analysis of the results and make a conclusions.

Each student should defends the report on laboratory work by himself during the current or following laboratory class, or consultations.

The report should contain a title page and the following sections:

- purpose of the work;
- basic theoretical principles and answers to questions while preparing for the laboratory work;
- brief information about the experiment;
- the scheme of analyzed electric circuit;
- formulas, and results of theoretical calculations for specific modes of the electric circuit;
- results of the study: tables, graphs, diagrams, numerical values of circuit parameters, electric currents and voltages, etc.
- conclusions of the work made.

See the template of title page on the next page.

Reports should be performed only on one side of white sheet or of lined paper with size of A4 (210x297 mm). The text should be written neatly. When writing the text the student is allowed to use only generally accepted abbreviations or designations, decrypted at the first mention.

The student is allowed to carry out the next laboratory work if he has made and defended the previous one.

Sample of the title page

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ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS

Department of Electrical Engineering

REPORT on laboratory work № ____

on “_____” 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__

1 Laboratory work № 1. Study of unbranched DC linear electric circuit

Purpose of the laboratory work is obtaining the skills of an experimental study of DC linear electric circuits using Ohm's and Kirchhoff's laws and a superposition theorem.

1.1 Preparation for the laboratory work

1.1.1 Repeat section "Linear electric DC circuit" of TEC1 course.

1.1.2 Answer the following questions in written form:

- 1) Give a formulation of Ohm's and Kirchhoff's laws.
- 2) What are the features of the application of Kirchhoff's laws in the analysis of circuits with current sources?
- 3) What energy source is called the voltage source (EMF) and what is called the current source? Draw the symbols of the ideal voltage and current sources and the equivalent circuit of real sources.
- 4) How to determine EMF of voltage source experimentally?
- 5) How to measure the value and sign of the potential of any point of the circuit using a voltmeter with respect to a point, the potential of which is assumed to be zero?
- 6) What is the potential diagram of the circuit, how to obtain it experimentally?

1.2 Assignments to be performed at the laboratory work

1.2.1 Assemble the electric circuit as shown in figure 1.1. Pre-measure the resistance of the resistors and write down these values into table 1.1.

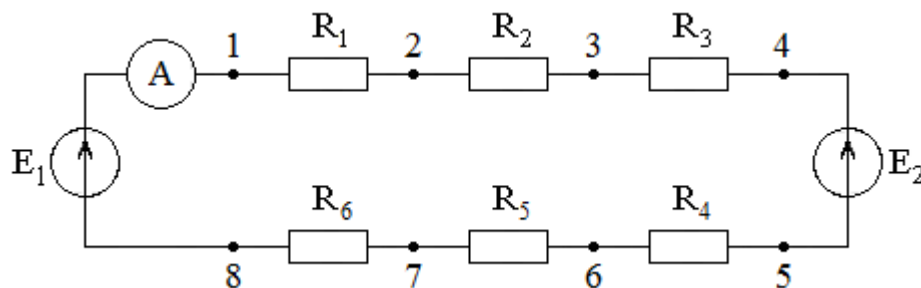


Figure 1.1

1.2.2 Set the EMF of sources $E_1 = 20\text{V}$ and E_2 about $10\dots 15\text{V}$, measure the current and voltages across all resistors of the circuit. Write down the measurement results into table 1.1.

1.2.3 Measure the potentials of all points of the circuit with respect to a point, the potential of which is assumed to be zero, e.g. $\varphi_7 = 0$. Write down the measurement results into table 1.2.

1.2.4 Assemble the electric circuit as shown in figure 1.2.

1.2.5 To test the principle of superposition it is necessary to measure the currents in the branches of the circuit when there is only one of the two sources in the circuit:

- in the circuit in figure 1.3, E_1 is turned on and E_2 is turned off;
- in the circuit in figure 1.3, E_1 is turned off and E_2 is turned on.

It is necessary to replace the excluded voltage sources by jumpers.

Also, measure the currents when both sources are connected to the circuit as shown in figure 1.2. The results of measurements write down into table 1.3.

Table 1.1

Current $I =$	mA; EMFs: $E_1 =$	V, $E_2 =$	V			
Resistors	R_1	R_2	R_3	R_4	R_5	R_6
Voltage U , V						
Resistance R , Ω , experiment						
Conductance G , S, experiment						
Resistance R , Ω , pre-measured						

Table 1.2

Potentials of points	φ_1 , V	φ_2 , V	φ_3 , V	φ_4 , V	φ_5 , V	φ_6 , V	φ_7 , V
Theoretical calculation							
Experimental measurements							

Table 1.3

Kind of study	EMF values	I_1 , mA	I_2 , mA	I_3 , mA
Theoretical calculation	$E_1 =$; $E_2 = 0$			
	$E_1 = 0$; $E_2 =$			
	$E_1 =$; $E_2 =$			
Experimental measurements	$E_1 =$; $E_2 = 0$			
	$E_1 = 0$; $E_2 =$			
	$E_1 =$; $E_2 =$			

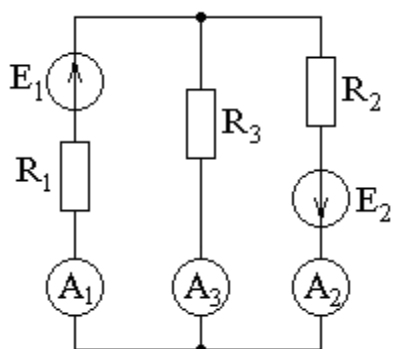


Figure 1.2

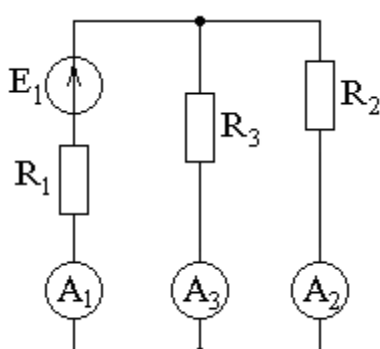


Figure 1.3

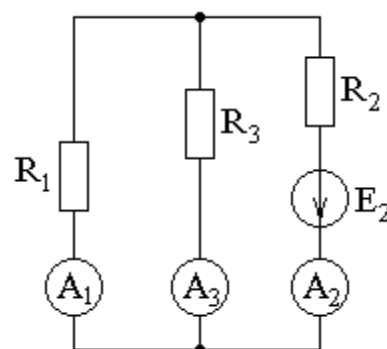


Figure 1.4

1.3 Processing experimental results

1.3.1 Calculate the value of resistances and their conductance, also calculate the current by Ohm's law and the potentials of all points by using the results of experiments for the circuit in figure 1.1.

1.3.2 Plot the potential diagram by using theoretical and experimental data and determine therefrom the current in the circuit for the same circuit. Compare the values of current with ones calculated in the preceding paragraph.

1.3.3 Make a theoretical calculation of currents and compare them with the values measured during the experiment for circuits in figures 1.3 and 1.4.

1.3.4 Make a theoretical calculation of currents by using superposition theorem for the circuit in figure 1.2 and compare them with the values calculated by the experimental data.

1.3.5 Check the compliance of the Kirchhoff laws for all circuits.

1.4 Methodological guidelines

1.4.1 The potential diagram represents the dependences of potential changing along the circuit, starting from one a point, the potential of which is assumed to be zero. Put the value of circuit sections resistance on the horizontal axis, and on the vertical one – the potentials of the respective circuit resistance points in order to cover the loop. The current is determined from potential diagram by the formula:

$$I = \frac{m_{\varphi}}{m_R} \cdot \operatorname{tg} \alpha ,$$

where m_{φ} , m_R are the scales of the potential and resistance, respectively; $\operatorname{tg} \alpha$ is a tangent of the slope angle to the horizontal axis of the corresponding section of polyline of the potential diagram.

The calculation of currents by means of the superposition theorem is performed as follows: the current in any branch is calculated as the algebraic sum of partial currents generated therein by each source separately. When calculating partial currents generated by one source, other sources in the circuit are replaced by their internal resistances, i.e. the voltage source E is replaced by a jumper and the current source J is replaced by an open circuit.

1.5 Revision questions

1. Give a definition of elements of electrical DC circuits.
2. Write down an expression of Ohm's Law for a branch of circuit with EMF.
3. Give the formulation of the Kirchhoff's Current Law (KCL).
4. Give the formulation of the Kirchhoff's Voltage Law (KVL).
5. Formulate the rules to connect an ammeter and voltmeter to DC circuits.
6. How to determine the value of EMF voltage source experimentally?
7. Procedure of drawing a potential diagram for unbranched electrical circuit.
8. Calculation procedure of currents by means of the superposition theorem.

2 Laboratory work № 2. Study of a branched DC linear electric circuit

Purpose of the laboratory work is to obtain the skills of experimental study of branched linear DC circuits using the mesh current analysis, nodal analysis and Thevenin's or Norton's theorem.

2.1 Preparation for the laboratory work

2.1.1 Repeat section "Linear electric DC circuit" of TEC1 course.

2.1.2 Answer the following questions in written form:

- 1) What is the essence of Thevenin's and Norton's theorems?
- 2) How to calculate the equivalent input resistance R_{th} (Thevenin's resistance).
- 3) What is the essence of the maximum power transfer theorem?
- 4) Give the formulas for calculating the value of the equivalent resistance for the series, parallel and hybrid connections of resistances, as well as the formulas to calculate the delta-star and star-delta transformations.

2.2 Procedure of carrying out the work

2.2.1 Draw the scheme of a studied electrical circuit according to the variant of assignment (table 2.1 and figures 2.1...2.6). Specify the positive directions of the currents in the circuit branches.

Assemble the circuit by using resistors and voltage sources. When assembling it should to provide for jacks for connecting measuring instruments.

Ammeter and voltmeter should be connected in accordance with the specified current directions.

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 , V	20	20	15	12	18	10
E_2 , V	15	10	20	20	10	20
Calculate the current by using Thevenin's theorem	I_1	I_2	I_3	I_4	I_5	I_6

2.2.2 Measure the currents in all branches of the circuit, also measure the EMF of voltage sources and voltage drops across all resistors.

Write down the measurement results into table 2.2.

Table 2.2

I_1 , mA	I_2 , mA	I_3 , mA	I_4 , mA	I_5 , mA	I_6 , mA	U_{R1} , V	U_{R2} , V	U_{R3} , V	U_{R4} , V	U_{R5} , V	U_{R6} , V

2.2.3 To determine the current in any branch by using Thevenin's theorem it is necessary to measure open circuit voltage U_{oc} across the branch, when it is open circuit, and short-circuit current I_{sc} in this branch, while it is short-circuit. Write down the measurement results into table 2.3.

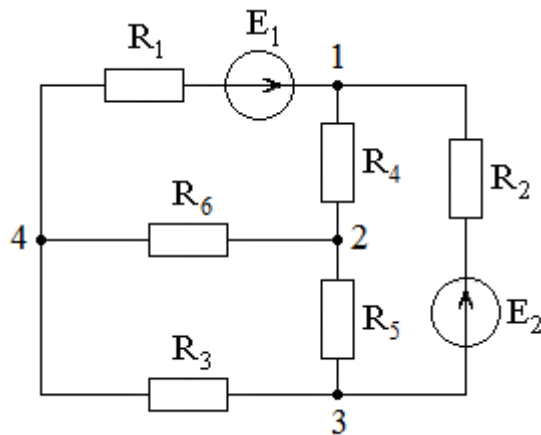


Figure 2.1

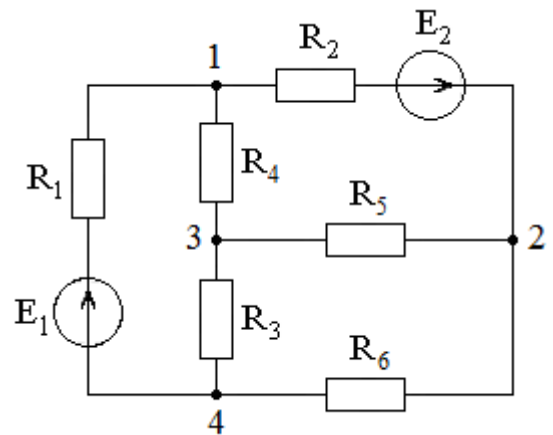


Figure 2.2

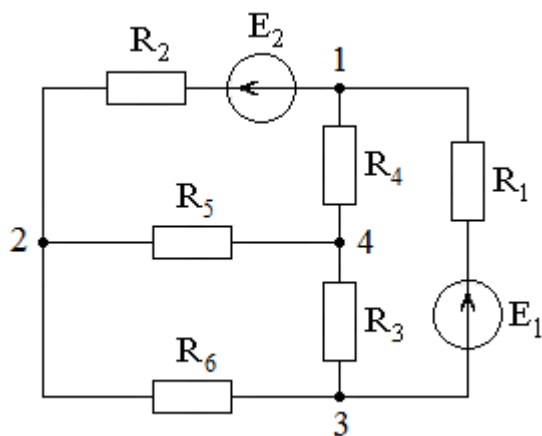


Figure 2.3

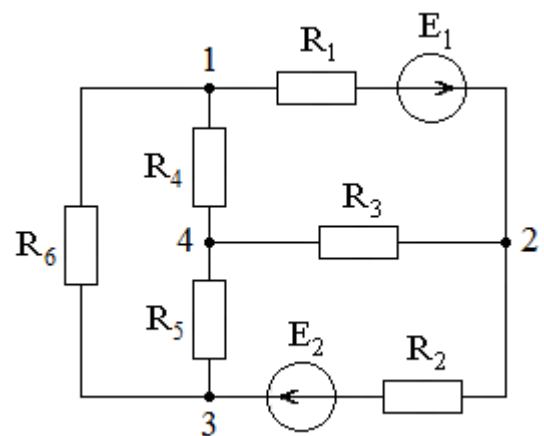


Figure 2.4

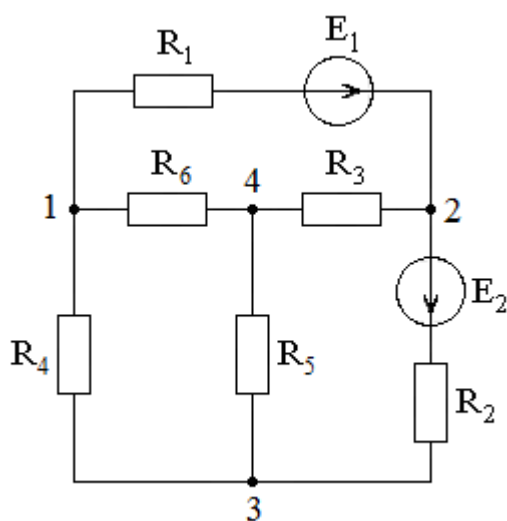


Figure 2.5

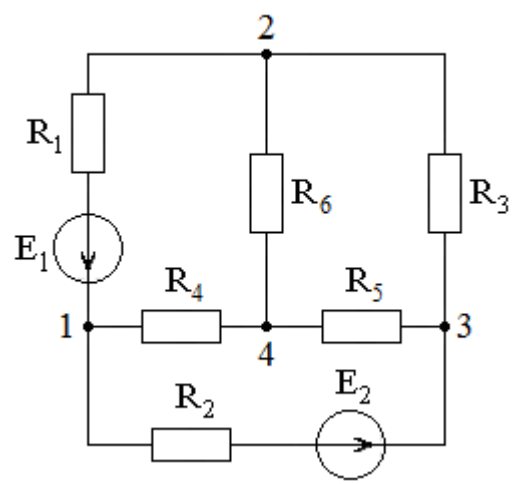


Figure 2.6

Table 2.3

Kind of study	U_{oc} , V	I_{sc} , A	R_{th} , Ω	E_{th} , V	I , A
Theoretical calculation					
Experimental study					

2.3 Processing experimental results

2.3.1 Calculate the currents in all branches of the circuit by using any calculation method of the linear DC electric circuits.

2.3.2 Compare the current value in a specified branch, obtained experimentally with that obtained by theoretical calculation by using Thevenin's theorem (table 2.3). The coincidence accuracy is determined by the formula:

$$\delta = \frac{|I_{theory} - I_{experiment}|}{I_{theory}} \cdot 100\% .$$

2.3.3 Make conclusions about the work done.

2.4 Methodological guidelines

According to Thevenin's theorem, the current in any branch of the linear electric circuit is determined by the formula:

$$I = \frac{U_{oc}}{R_{th} + R} = \frac{E_{th}}{R_{th} + R} ,$$

where U_{oc} is an open circuit voltage across specified branch;

$E_{th} = U_{oc}$ is a Thevenin's *EMF*;

R_{th} is a Thevenin's resistance;

R is a resistance of the specified branch.

Thevenin's resistance R_{th} is equal to the input resistance of the passive circuit with respect to terminals of the opened branch. The passive circuit is obtained from the initial scheme by replacing all sources of *EMF* by jumpers.

Thevenin's resistance R_{th} can also be calculated by the formula:

$$R_{th} = \frac{U_{oc}}{I_{sc}} = \frac{m_U}{m_I} \cdot \operatorname{tg} \alpha ,$$

where: α is the angle slope of current-voltage characteristic to the current axis.

2.5 Revision questions

1. Calculation methods of DC linear branched electric circuits.
2. Maximum power transfer theorem.
3. Thevenin's theorem. An application of Thevenin's theorem.
4. Formulas for calculating the equivalent resistance at series and parallel connections of resistances.
5. Calculation of an equivalent resistance at combine connection of resistances.
6. Calculation of equivalent resistances at delta-star transformation.

3 Laboratory work № 3. Study of an unbranched linear electric circuit of single-phase sinusoidal current

Purpose of the laboratory work is to obtain the skills of an experimental study of unbranched and branched linear electric circuits of single-phase sinusoidal current.

3.1 Preparation for the laboratory work

3.1.1 Study the sections of TEC1 course relating to the circuits of single-phase sinusoidal current.

3.1.2 Proceed the following:

1) Write Ohm's law in a complex form and for the r.m.s. (root means square) values for linear electric R , L , C circuit in figure 3.3.

2) Make up the equations in the complex form using Kirchhoff's laws for circuits in figures 3.1...3.3.

3) How to write the expression for the instantaneous values of the current (voltage) from its complex value?

4) What is called the effective value of electrical quantities such as current, voltage or EMF?

5) For the circuit in figure 3.1, in accordance with the parameters of your variant (table 3.1) find the following:

- calculate the capacitive reactance X_C , impedance \underline{Z} , argument φ , $\cos\varphi$, write down the results into table 3.2;

- calculate the complex r.m.s values of current and voltages across each elements, write down the effective (r.m.s) values into table 3.2;

- calculate the active, reactive and apparent power; write down the results into table 3.2;

- based on the results of the calculation, construct a phasor diagram of current and voltages;

- construct triangles of impedance and power for the circuit.

6) For the circuit in figure 3.2, in accordance with the parameters of your variant (table 3.1) find the following:

- calculate the inductive reactance X_L , impedance \underline{Z} , argument φ , $\cos\varphi$, write down the results into table 3.3;

- calculate the complex r.m.s values of current and voltages across each elements, write down the effective (r.m.s) values into table 3.3;

- calculate the active, reactive and apparent power; write down the results into table 3.3;

- based on the results of the calculation, construct a phasor diagram of current and voltages;

- construct triangles of impedance and power for the circuit.

7) For the circuit in figure 3.3, in accordance with the parameters of your variant (table 3.1) find the following:

- calculate the impedance \underline{Z} , argument φ , $\cos\varphi$, write down the results into table 3.4;
- calculate the complex r.m.s values of current and voltages across each elements, the effective (r.m.s) values write down into table 3.4;
- calculate the active, reactive and apparent power; write the results into table 3.4;
- based on the results of the calculation, construct a phasor diagram of current and voltages;
- construct triangles of impedance and power for the circuit.

3.2 Procedure of carrying out the work

3.2.1 Assemble the electric circuit according to the scheme in figure 3.1; set the parameters of the circuit in accordance with the given variant (table 3.1). Measure the current, voltages across each elements, active power and power factor ($\cos\varphi$).

Write down the measurement results into table 3.2.

Table 3.1

Variant	1	2	3	4	5	6
R, Ω	300	200	150	100	150	200
$C, \mu\text{F}$	4	5	3	6	7	3
L, mH	50	40	30	10	45	35
f, Hz	300	450	400	500	300	350
U, V	3	3	3	3	3	3

Figure 3.1

Table 3.2

Kind of study	U, V	f, Hz	R, Ω	$C, \mu\text{F}$	X_C, Ω	z, Ω	U_R, V	U_C, V	I, mA	$\cos\varphi$	P, W	Q, var	S, VA
Theory													
Experiment													

3.2.2 Assemble the electric circuit according to the scheme in figure 3.2; set the parameters of the circuit in accordance with the given variant (table 3.1). Measure the current, voltages across each elements, active power and power factor ($\cos\varphi$).

Write down the measurement results into table 3.3.

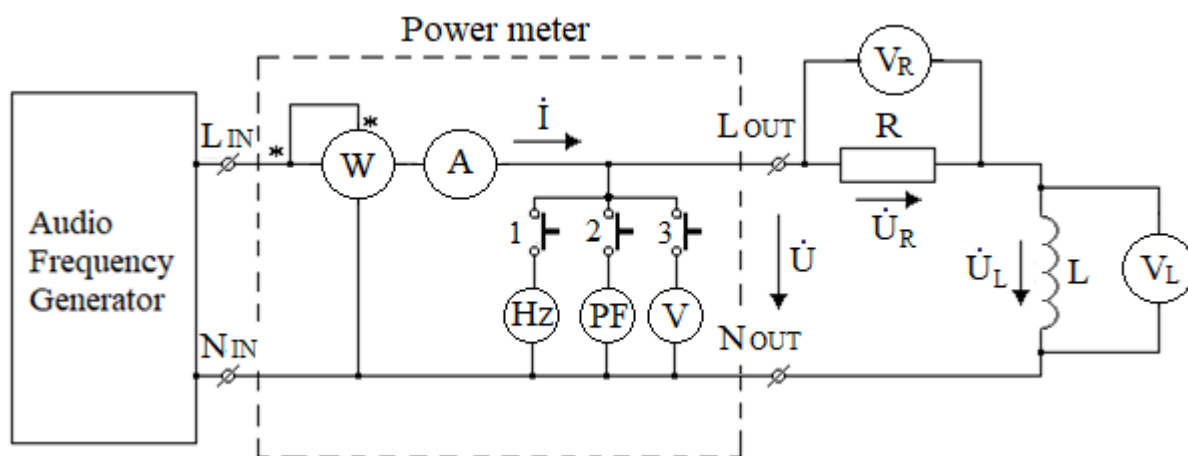


Figure 3.2

Table 3.3

Kind of study	U, V	f, Hz	R, Ω	L, mH	X_L, Ω	z, Ω	U_R, V	U_L, V	I, mA	$\cos\phi$	P, W	Q, var	S, VA
Theory													
Experiment													

3.2.3 Assemble the electric circuit according to the scheme in figure 3.3; set the parameters of the circuit in accordance with the given variant (table 3.1). Measure the current, voltages across each elements, active power and power factor ($\cos\phi$).

Write down the measurement results into table 3.4.

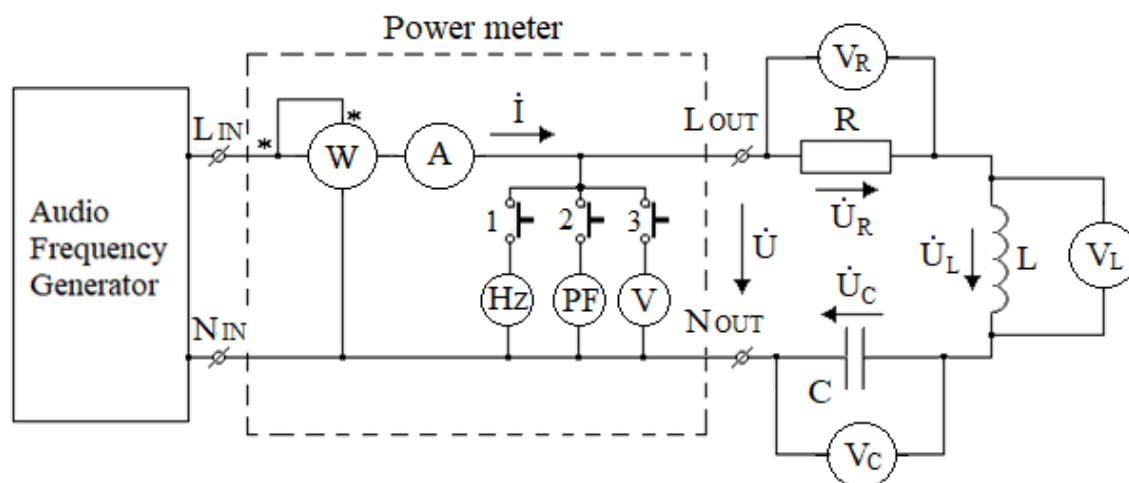


Figure 3.3

Table 3.4

Kind of study	U, V	R, Ω	X_L, Ω	X_C, Ω	X, Ω	z, Ω	U_R, V	U_L, V	U_C, V	I, mA	$\cos\phi$	P, W	Q, var	S, VA
Theory														
Experiment														

3.3 Processing experimental results

3.3.1 For circuits in figures 3.1 ... 3.3, based on the results of experiments, plot the phasor diagrams of current and voltages using a suitable scale.

3.3.2 Verify the fulfillment of Ohm's law and Kirchhoff's voltage law based on the experimental data for the schemes in figures 3.1...3.3. Determine the values of the total impedance.

3.3.3 Based on the results of the experiments, calculate the Q reactive and S apparent power of circuit. Check the relationship between P , Q and S power. Draw the triangles of impedance and power using a suitable scale.

3.4 Methodological guidelines

When constructing the phasor diagrams of current and voltages, for example for the RL -circuit in figure 3.2, the voltage phasor across the active resistance U_R coincides in phase with the current phasor I , and the voltage phasor across the inductor U_L leads on the current phasor I by an 90° . The input voltage leads on the current phasor by an angle φ (figure 3.4, a). The triangles of impedance and power are shown in figures 3.4b and c, respectively.

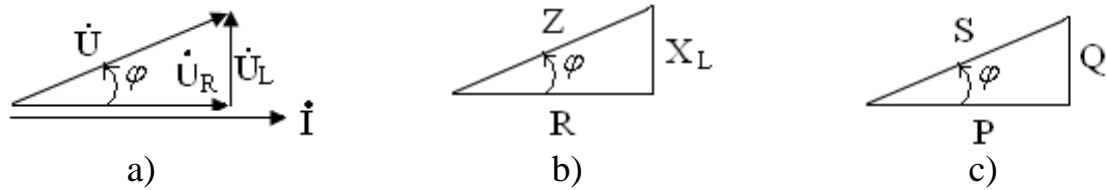


Figure 3.4

The effective value of the input voltage is determined from the experimental data by the formula:

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

The complex total impedance of RL -circuit is calculated by the formula:

$$\underline{Z} = R + j2\pi fL = R + j\omega L = R + jX_L.$$

Modulus of impedance:

$$z = \sqrt{R^2 + X_L^2}.$$

Based on the experimental data, the impedance, resistance and reactance are calculated by the formulas, respectively:

$$z = \frac{U}{I}, \quad R = \frac{U_R}{I}, \quad X_L = \frac{U_L}{I} \quad \text{or} \quad X_C = \frac{U_C}{I}.$$

The active, reactive and apparent power of P , Q and S can be calculated by the formulas: $P = UI \cdot \cos\varphi$, $Q = UI \cdot \sin\varphi$, $S = UI$; or $P = I^2 R$, $Q = I^2 \cdot (X_L - X_C)$, $S = I^2 \underline{Z}$.

Similarly, calculations are performed for the remaining circuits.

The universal power meter used in the circuit allows you to measure the active power, voltage, current, frequency and power factor. The connection diagram of the power meter is shown in figures 3.1, 3.2 and 3.3. The terminals “L IN” and “N IN” – are connected to the power supply and terminals “L OUT” and “N OUT” to the load. Switching on the unit is made by pressing the *Power* button.

The measurement results are displayed on the instrument display. The measurements of power are on the left, next to which there are indicators of units of measurement (mW, W, kW). The measurement readings of current are at the right bottom, next to which there are indicators of units (mA, A). There is a window with the readings of the measurement results of one of three values is top right: voltage (V, kV); frequency (Hz) or power factor (PF). To select the measured value on the control panel, press the corresponding button: “V”, “Hz” or “PF”.

Notes:

1) In the normal operation mode of the instrument, the “RUN” indicator flashes, otherwise it constantly lights or does not light.

2) In the normal operation mode of the device, the conversion factor for the voltage transformer and current transformer must be equal to one. If the conversion factor is different from one, the “RATIO” indicator lights (in this case it is necessary to contact the teacher to set the conversion factor to 1).

3.5 Revision questions

1. Write an expression of current I using Ohm’s law in a complex form for the linear electric R , L , and C circuit as in figure 3.1.

2. Draw a phasor diagram of current and voltages across the circuit elements connected in series with a resistor, capacitor and coil of inductance in the circuit of single-phase sinusoidal current.

3. Draw a phasor diagram of voltage and currents flowing through all circuit elements connected in parallel with a resistor, capacitor and coil of inductance in the circuit of single-phase sinusoidal current.

4. Write equations using Kirchhoff’s laws in the complex form for the three analyzed circuits.

5. Write expressions for the calculation of active and reactive power in single-phase sinusoidal current circuits.

6. Write an expression for the calculation of apparent power in single-phase sinusoidal current circuits.

4 Laboratory work № 4. Study of a branched linear electric circuit of single-phase sinusoidal current

Purpose of the laboratory work is the experimental verification of the Ohm's and Kirchhoff's laws for branched sinusoidal current circuits, construction of phasor and topographical diagrams.

4.1 Preparation for the laboratory work

Study the sections of TEC1 course relating to the circuits of single-phase sinusoidal current.

4.1.1 For the circuit in figure 4.1, in accordance with the parameters of your variant (table 4.1) proceed the following:

- calculate the complex r.m.s values of currents in each branch and voltages across each element of the circuit. Write down the effective (r.m.s.) values into table 4.2;

- calculate the argument φ , $\cos\varphi$, active, reactive and apparent power; write down the results into table 4.2;

- based on the results of the calculation, construct a phasor diagram of currents and voltages.

4.1.2 For the circuit in figure 4.2, in accordance with the parameters of your variant (table 4.1) proceed the following:

- calculate the complex r.m.s values of the currents in each element of the circuit. Write down the effective (r.m.s.) values into table 4.3;

- calculate the argument φ , $\cos\varphi$, active, reactive and apparent power; write down the results into table 4.3;

- based on the results of the calculation, construct a phasor diagram of currents and voltage using a suitable scale.

4.2 Procedure of carrying out the work

4.2.1 Assemble the electric circuit according to the scheme in figure 4.1; set the parameters of the circuit in accordance with the given variant (table 4.1).

4.2.2 Measure the currents in each branch, voltages across each elements, active power and power factor ($\cos\varphi$). Write down the measurement results into table 4.2.

Table 4.1

Variant	1	2	3	4	5	6
R_1, Ω	200	100	300	150	300	150
R_2, Ω	300	150	200	100	150	300
$C, \mu\text{F}$	4	6	5	3	7	3
L, mH	50	10	40	30	45	35
f, Hz	300	500	450	400	300	350
U, V	3	3	3	3	3	3

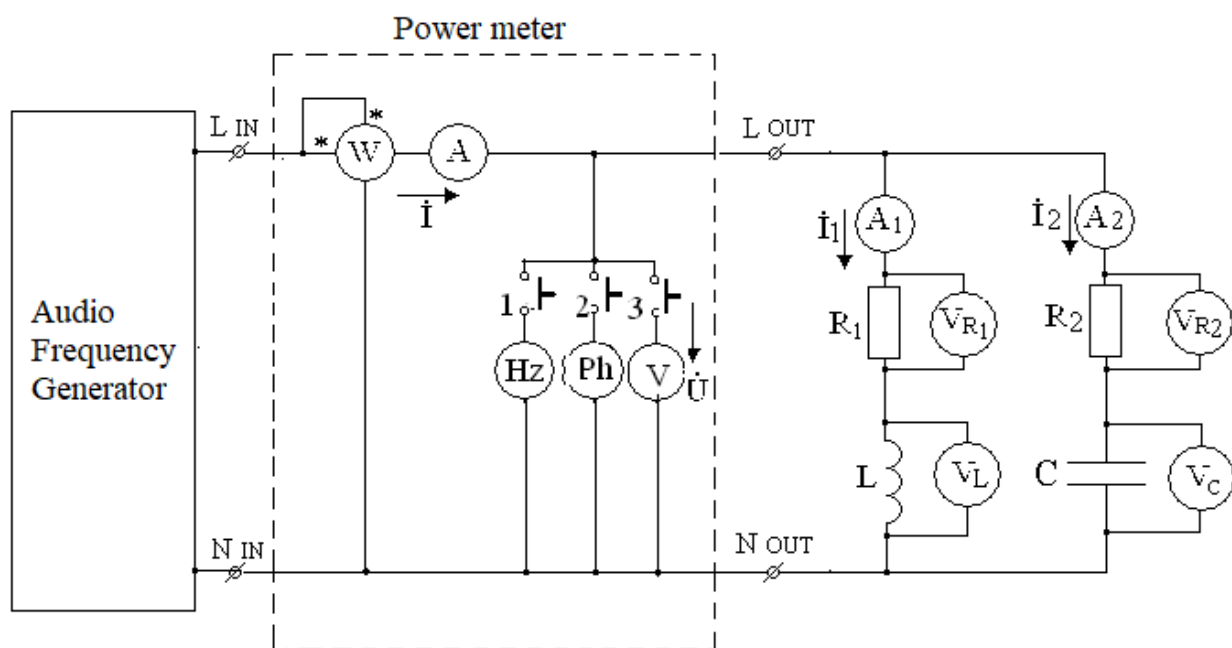


Figure 4.1

Table 4.2

Kind of study	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
Theory												
Experiment												

4.2.3 Assemble the electric circuit according to the scheme in figure 4.2; set the parameters of the circuit in accordance with the given variant (table 4.1).

4.2.4 Measure the currents in each branch, the input voltage of circuit, active power and power factor ($\cos\varphi$). Write down the measurement results into table 4.3.

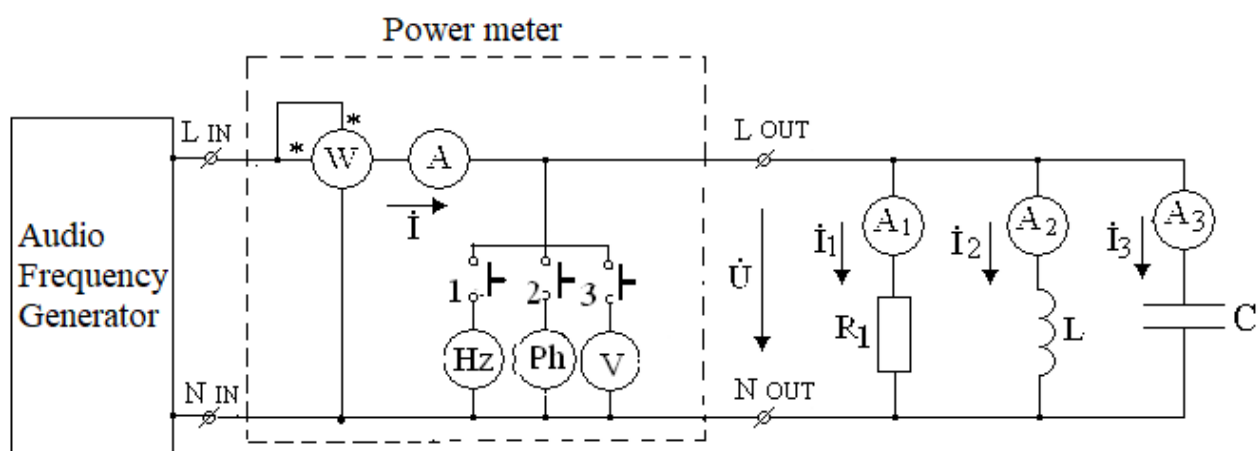


Figure 4.2

Table 4.3

Kind of study	U , V	I , mA	I_1 , mA	I_2 , mA	I_3 , mA	$\cos\varphi$	P , W	Q , var	S , VA
Theory									
Experiment									

4.3 Processing experimental results

4.3.1 According to the experimental data of table 4.2, construct the phasor diagram of currents and voltages for the scheme in figure 4.1.

4.3.2 For the scheme in figure 4.1 check the implementation of the Kirchhoff's voltage and current laws using a phasor diagram. Calculate the reactive Q and the apparent S power of the circuit. Write down the results into table 4.2. Check the relationships connecting P , Q and S power. Construct a triangle of power.

4.3.3 According to the data of table 4.3 construct the phasor diagram of voltage and currents for the circuit in figure 4.2.

4.3.4 For the circuit in figure 4.2 check the implementation of the Kirchhoff's current law (KCL) using phasor diagram.

4.3.5 Calculate the reactive Q and apparent S power of the circuit. Write down the results into table 4.3. Check the relationships connecting P , Q and S power. Construct a triangle of power.

4.4 Methodological guidelines

For the circuit in figure 4.1, the Kirchhoff's current and voltage laws can be verified using a phasor diagram of currents and voltages and the Kirchhoff's voltage law can be verified also by formulas:

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

The phasor diagram for scheme in figure 4.2 is shown in figure 4.3.

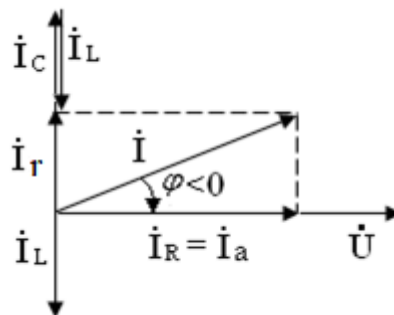


Figure 4.3

The Kirchhoff's current law for scheme in figure 4.2 can be verified by the formula:

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

4.5 Revision questions

1. Write the expression of current I using Ohm's law in a complex form for the linear electric R , L , and C circuit as in figure 4.1.
2. Draw a phasor diagram of current and voltages across the circuit elements connected in series with a resistor, capacitor and coil of inductance in the circuit of single-phase sinusoidal current.
3. Draw a phasor diagram of voltage and currents flowing through all circuit elements connected in parallel with a resistor, capacitor and coil of inductance in the circuit of single-phase sinusoidal current.
4. Write equations using Kirchhoff's laws in the complex form for the three analyzed circuits.
5. Write expressions for the calculation of active and reactive power in single-phase sinusoidal current circuits.
6. Write an expression for the calculation of apparent power in single-phase sinusoidal current circuits.

5 Laboratory work № 5. Analysis of voltage resonance phenomenon

Purpose of the laboratory work is an experimental study of resonance properties of a series oscillatory LC -circuit.

5.1 Preparation for the laboratory work

5.1.1 Repeat section "Phenomenon of the resonance in electric circuits. Resonance of voltages" of TEC1 course.

5.1.2 Answer the following questions in written form:

- 1) What phenomenon in electric circuit is called the resonance?
- 2) What connections of an inductor and a capacitor can cause voltage and current resonance? Draw the circuit diagrams.
- 3) What condition in the electrical circuit brings about a resonance phenomenon? Describe the condition of resonance.
- 4) How to calculate resonant angular frequency ω_0 and linear frequency f_0 ?
- 5) What value is called the characteristic impedance of the circuit?
- 6) Write formulas to calculate the impedance and current of the circuit under voltage resonance.

7) How to calculate the voltage across inductance and capacitance under voltage resonance?

8) How to determine the quality-factor Q of the serial oscillating circuit? How many times does the voltage across inductance and capacitance exceed the input voltage in resonance mode, if the Q -factor is equal to 2.5 or 5.0?

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 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 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 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?

16) According to the variant of assignment (table 5.1) calculate the resonant frequencies ω_0 and f_0 , the characteristic impedance of the circuit ρ and total active resistances of circuit $R_{\Sigma 1}$ and $R_{\Sigma 2}$ for two quality factors $Q_1 = 2.5$ and $Q_2 = 5.0$.

Table 5.1

Variant	L , mH	C , μF
1	20	0,03
2	15	0,05
3	30	0,01
4	20	0,02
5	15	0,04
6	30	0,02

5.2 Procedure of carrying out the work

5.2.1 Assemble a serial oscillating circuit as shown in figure 5.1. Set the input voltage about 3...4V. It is convenient to use blocks of variable resistance, inductance and capacitance, respectively, or external elements as a resistor, inductor and capacitor. Set the parameters according to your variant of assignment (table 5.1). Write the parameters set by circuit elements and the value of resistance of the coil inductance R_{coil} . The value of additional resistance R_{add1} is determined by the formu-

1a $R_{add1} = R_{\Sigma1} - R_{coil}$, where R_{Σ} is total loop active resistance calculated for the quality factor $Q_1 = 2.5$ and R_{coil} is active resistance of coil inductance.

5.2.2 By changing the frequency of input voltage, measure and write down the values of frequency characteristics $I(f)$, $U_{coil}(f)$ and $U_C(f)$ for circuit with a quality-factor $Q_1 = 2.5$ into table 5.2. During the experiment, the r.m.s value of input voltage is kept unchanged.

5.2.3 Set the value of additional resistor $R_{add2} = R_{\Sigma2} - R_{coil}$ 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 into table 5.2.

5.2.4 Set the frequency of the source equal to resonant f_0 and input voltage about 3V ... 4V, the value of additional resistor R_{add2} corresponding to the quality-factor $Q_2 = 5.0$. By changing the capacitance, measure and write down the values of the dependencies $U_C(C)$ and $I(C)$ into table 5.3.

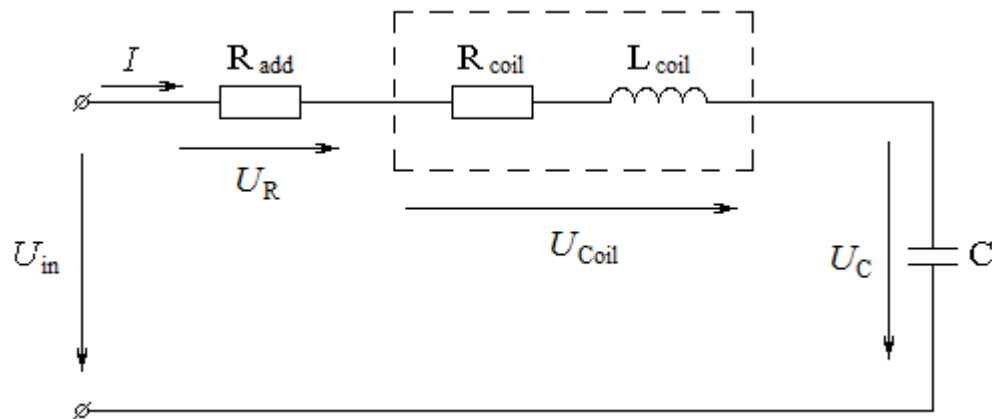


Figure 5.1 – Scheme of serial oscillating LC-circuit

Table 5.2

f, Hz	Quality-factor					
	$Q = 2.5$					$Q = 5.0$
	I, mA	U_C, V	U_{coil}, V	U_L, V	$\varphi_{in}, \text{degrees}$	I, mA
1						
...						
9						

Table 5.3

$C, \mu\text{F}$	I, mA	U_C, V

5.3 Processing experimental results

5.3.1 According to measurement results, written down into table 5.2, plot resonant curve $I(f)$ and frequency characteristics of $U_L(f)$ and $U_C(f)$. Voltage U_L calculated by the formula is

$$U_L = \sqrt{U_{coil}^2 - (R_{coil} \cdot I)^2}.$$

Compare experimental curves with the theoretical ones and make conclusions.

5.3.2 Calculate the dependencies $I/I_0 = F(f/f_0)$ for the quality-factors $Q_1 = 2,5$ and $Q_2 = 5,0$ according to table 5.2. Plot graphs of resonant curves $I/I_0 = F(f/f_0)$ for the two quality-factors. Determine the cut-off frequencies f_1 and f_2 for two values of the quality-factor of 2.5 and 5 according to the resonant curve $I/I_0 = F(f/f_0)$, make conclusions about the width of the oscillating circuit bandwidth.

5.3.3 By the experimental data (table 5.2) determine the resonant frequency f_0 , corresponding to the maximum value of current in the circuit at fixed input voltage.

5.3.4 Calculate and plot the angle φ_{in} of the frequency:

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

where $R_{\Sigma} = R_{coil} + R_{add}$.

Compare the resulting curve with theoretical one, make conclusions.

5.3.5 Calculate the apparent and active power at resonant mode using the experimental data, make conclusions.

5.3.6 Using the experimental data (table 5.2) determine the quality factor of the circuit:

$$Q = \frac{U_{L0}}{U} = \frac{U_{C0}}{U}.$$

Compare that value with the pre-calculated one.

5.3.7 Using the experimental data (table 5.3) plot graphs of dependencies $U_C(C)$ and $I(C)$.

5.4 Revision questions

1. What conditions bring about the phenomenon of resonance in an electrical circuit? Describe the resonance condition.
2. Phenomenon of voltage resonance.
3. Phenomenon of current resonance.
4. Calculation of resonant frequency of the oscillating circuit.
5. Characteristic impedance of the oscillating circuit.
6. Phasor diagram of current and voltages for the electric circuit connected in series with R , L and C under the resonance mode.
7. Phasor diagrams of current and voltages for the electric circuit connected in series with R , L , and C at frequencies below and above the resonant frequency.
8. Bandwidth of serial oscillating circuit.

6 Laboratory work № 6. Analysis of current resonance phenomenon

Purpose of the laboratory work is an experimental study of resonance properties of a parallel oscillatory LC -circuit.

6.1 Preparation for the laboratory work

6.1.1 Repeat section “Phenomenon of resonance in electric circuits. Resonance of currents” of TEC1 course.

6.1.2 Answer the following questions in written form:

1) What electrical circuits cause the resonance of currents?
2) What is the condition for resonance of currents in the electrical circuit?
3) Calculate the nominal characteristic resistance ρ , resonant frequency f_0 and quality factor Q for parallel oscillation circuits (figure 6.1 and figure 6.2), according to the given variant (table 6.1).

4) Plot frequency characteristics of the parallel oscillatory circuit (figure 6.1): $b_L(\omega)$; $b_C(\omega)$; $b(\omega) = b_L(\omega) - b_C(\omega)$.

5) Plot frequency characteristics $I(f)$, $I_L(f)$, $I_C(f)$, $z_{in}(f)$, $\varphi_{Zin}(f)$ for the parallel oscillatory circuit (figure 6.1).

6) Construct a phasor diagram of the currents for a parallel oscillatory circuit under resonant mode (figure 6.1).

7) Calculate the input impedance and current at the input of a parallel oscillating circuit with losses (figure 6.2) under resonant mode.

8) Construct a phasor diagram of the currents of a parallel oscillatory circuit with losses (figure 6.2) under resonant mode.

9) What values of resistances R_1 and R_2 cause the resonance of currents in a parallel oscillatory circuit with losses?

6.2 Procedure of carrying out the work

6.2.1 Assemble the circuit as shown in figure 6.1. Set the voltage at the input of the circuit and parameters of elements according to the variant of the assignment (table 6.1).

Table 6.1

Variant	U , V	L , mH	C , μF	R , Ω	R_1 , Ω	R_2 , Ω
1	3	20	0.08	50	100	200
2	3	16	0.04	60	200	150
3	3	15	0.05	80	150	100
4	3	10	0.05	40	50	250
5	3	12	0.03	30	100	300
6	3	7	0.02	50	100	150

6.2.2 By changing the frequency of input voltage from $0.1f_0$ to $2f_0$, measure and write down the values of frequency characteristics $I(f)$, $I_L(f)$ and $I_C(f)$ into table 6.2. During the experiment, the r.m.s value of input voltage is kept unchanged.

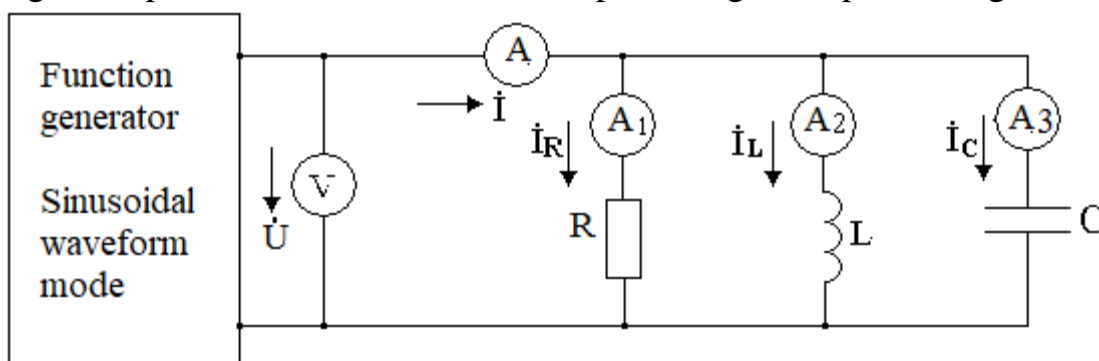


Figure 6.1 – Scheme of parallel oscillating LC -circuit

Table 6.2

f , Hz	U , V	I , mA	I_L , mA	I_C , mA	z_{in} , Ω	φ_{in} , degrees
1						
...						
9						

6.2.3 Assemble the circuit as shown in figure 6.2. Set the input voltage and parameters of elements according to the variant of the assignment (table 6.1).

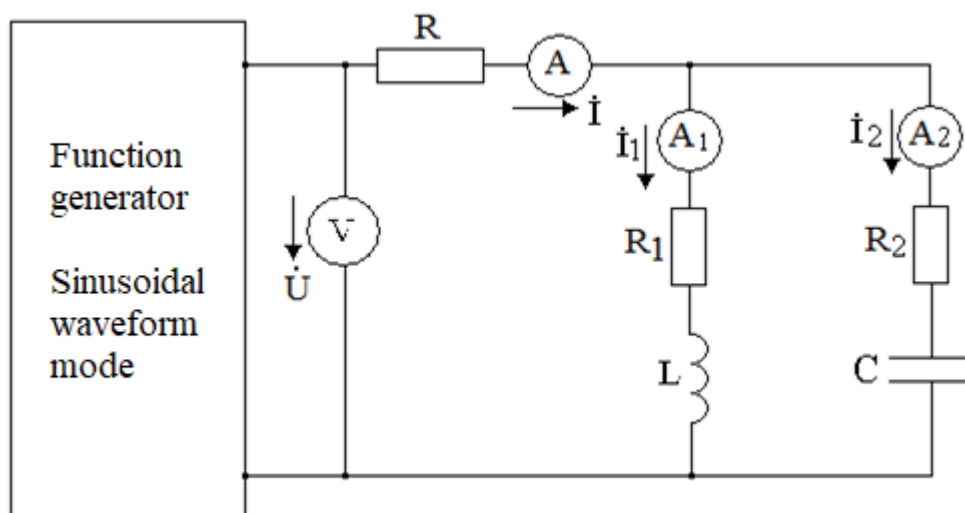


Figure 6.2 – Scheme of parallel oscillating circuit with resistances

6.2.4 By changing the frequency of input voltage from $0.1f_0$ to $2f_0$, measure and write down the values of frequency characteristics $I(f)$, $I_1(f)$ and $I_2(f)$ into table 6.3. During the experiment, the r.m.s value of input voltage is kept unchanged.

Table 6.3

f, Hz	U, V	I, mA	I_1, mA	I_2, mA	z_{in}, Ω
1					
...					
9					

6.3 Processing experimental results

6.3.1 Based on the experimental data (table 6.2), determine the resonant frequency f_0 . Calculate the frequency characteristics of the input impedance $z_{in}(f)$ and $\varphi_{Zin}(f)$. Plot the curves of frequency characteristics $I(f)$, $I_L(f)$, $I_C(f)$, $z_{in}(f)$, $\varphi_{Zin}(f)$ and compare them with theoretical ones.

6.3.2 Based on the experimental data (table 6.3), determine the resonant frequency and compare it with the precalculated value. Construct the curves of the frequency dependences $I(f)$, $I_1(f)$, $I_2(f)$. Calculate and plot the curve of frequency characteristic of the input impedance of the circuit $z_{in}(f)$.

6.3.3 Determine the bandwidth and quality factor of the parallel oscillatory circuits. Determine the equivalent resonant resistance R_{0eq} for parallel oscillatory circuits in figures 6.1 and 6.2.

6.3.4 Construct phasor diagrams at resonant mode for electrical circuits in figures 6.1 and 6.2 using experimental data (tables 6.2 and 6.3).

6.3.5 Calculate the active power consumed by the circuits at resonance.

6.4 Methodological guidelines

Resonant frequency of a parallel oscillatory circuit without and with losses is shown in figures 6.1 and 6.2, respectively:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ and } f_0 = \frac{1}{2\pi\sqrt{LC}} \frac{\sqrt{\rho^2 - R_1^2}}{\sqrt{\rho^2 - R_2^2}}.$$

The nominal characteristic resistance of the circuit is calculated by the formula:

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

The equivalent resonance resistance R_{0eq} of a parallel circuit with losses is calculated by the formula:

$$R_{0eq} = \frac{\rho^2 + R_1 R_2}{R_1 + R_2}.$$

The current of the parallel oscillatory circuit with losses at resonance is calculated by the formula:

$$I_0 = U / R_{0eq}.$$

Q -factor of a parallel oscillatory circuit with losses is: $Q = \rho / (R_1 + R_2)$.

7 Laboratory work № 7. Study of input and transfer frequency characteristics of an electrical circuit using computer simulation

Purpose of the laboratory work is to study the input and transfer frequency characteristics of electrical circuits with one reactive element.

7.1 Preparation for the laboratory work

7.1.1 Repeat the section “Input and transfer frequency characteristics of electrical circuits” of TEC1 course.

7.1.2 Answer the questions in written form and do the following assignments:

1) What is called the input frequency response of an electrical circuit, its frequency response and phase response?

2) What is called the transfer frequency response of an electrical circuit, its frequency response and phase response?

3) What is called the boundary frequency? Calculate the boundary frequencies for R_1L -circuit and R_2C -circuit according to the given variant (table 7.1).

4) Write formulas for amplitude-frequency characteristic and phase response of input characteristics for RL and RC circuits: $z_{in}(\omega)$ and $\varphi_{Zin}(\omega)$.

5) Plot graphs of amplitude frequency response and phase frequency response of input characteristics for RL and RC circuits.

6) Write formulas for frequency response and phase response of complex voltage transfer functions for RL and RC circuits: $H_u(\omega)$, $\varphi_{Hu}(\omega)$.

7) Plot graphs of frequency response and phase response of voltage transfer functions for RL and RC circuits.

8) What are the values of frequency response and phase response of transfer functions with respect to the voltage at boundary frequency?

7.2 Procedure of carrying out the work

7.2.1 Assemble R_1L circuit diagram (figure 7.1). Set the values of parameters L , R_1 and U according to the variant of the assignment (table 7.1). By varying the frequency of the input voltage from $0.1 \cdot f_b$ to $2 \cdot f_b$, measure the current in the circuit, the voltage across the inductor and the time shift in phase $T_2 - T_1$ between the voltage $u_{in}(t)$ and current $i(t)$ at the input of the circuit. Write down the results into table 7.2.

Table 7.1 – Variants of the circuit's parameters

Variant	U , V	R_1 , Ω	L , mH	C , μF	R_2 , Ω	C , μF
1	3	1000	60	0.08	150	0.25
2	3	750	80	0.04	100	0.30
3	3	480	50	0.05	200	0.20
4	3	750	40	0.05	120	0.30
5	3	680	25	0.02	250	0.20

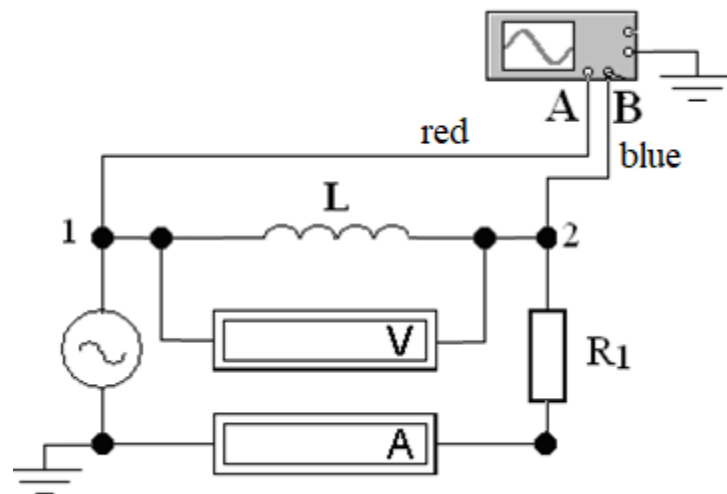


Figure 7.1

Table 7.2 – Measured results of frequency characteristics of R_1L -circuit

$U_{in} = \quad ; f_b = \quad ; R_1 = \quad ; L = \quad .$				
f, Hz	I, mA	U_L, V	$T_2 - T_1, \text{ms}$	$\varphi_{Zin}, \text{degrees}$
f_1				
...				
f_{12}				

Table 7.3 – Calculation of frequency responses of R_1L -circuit

f, Hz	Input characteristic		Transfer characteristic	
	z_{in}, Ω	$\varphi_{Zin}, \text{degrees}$	H_{UL}	$\varphi_{Hu}, \text{degrees}$
f_1				
...				
f_{12}				

7.2.2 Assemble R_2C -circuit diagram (figure 7.2). Set the values of parameters C, R_2 and U according to the variant of the assignment (table 7.1).

7.2.3 By changing the frequency of input voltage from $0.1f_b$ to $2f_b$, measure the current in the circuit, the voltage across the capacitor and time shift in phase $T_2 - T_1$ between the voltage $u_{in}(t)$ and current $i(t)$ at the input of the circuit. Write down the results into table 7.4.

Table 7.4 – Measured results of frequency characteristics of R_2C -circuit

$U_{in} = \quad ; f_b = \quad ; R_2 = \quad ; C = \quad .$				
f, Hz	I, mA	U_C, V	$T_2 - T_1, \text{ms}$	$\varphi_{Zin}, \text{degrees}$
f_1				
...				
f_{12}				

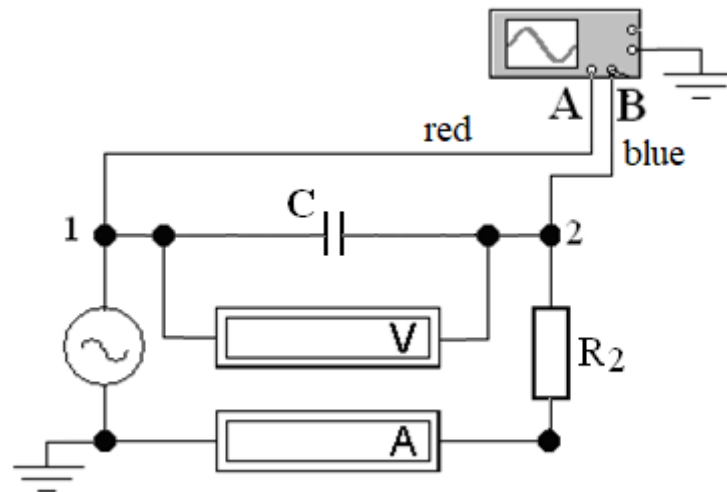


Figure 7.2

Table 7.5 – Calculation of frequency responses of R_2C -circuit

f, Hz	Input characteristic		Transfer characteristic	
	z_{in}, Ω	$\varphi_{Zin}, \text{degrees}$	H_{UC}	$\varphi_{Hu}, \text{degrees}$
f_1				
...				
f_{12}				

7.3 Processing experimental results

7.3.1 From the experimental data of table 7.2, calculate the values of module $z_{in} = U/I$ and argument $\varphi_{Zin} = 360^\circ(T_2 - T_1) \cdot f$ of input impedance of RL circuit. The results of calculations write down into table 7.3. Plot the frequency response curves $z_{in}(f)$ and $\varphi_{Zin}(f)$ of the input characteristic of RL circuit and compare them with theoretical ones. From the graphs, determine the boundary frequency for RL circuit.

7.3.2 Based on the experimental data of table 7.2, calculate the values of amplitude-frequency characteristic $H_{uL} = U_L/U$ and phase-frequency characteristic $\varphi_{HuL} = 90^\circ - \varphi_{Zin}$ of the voltage transfer characteristic for RL circuit. Write down the results into table 7.3. Plot graphs of amplitude-frequency response of $H_{uL}(f)$ and phase-shift frequency response of $\varphi_{HuL}(f)$ of the voltage transfer function for RL circuit and compare them with theoretical ones.

7.3.3 From the experimental data of table 7.4, calculate the values of module $z_{in} = U/I$ and argument $\varphi_{Zin} = 360^\circ(T_2 - T_1) \cdot f$ of input impedance of RC circuit. The results of calculations write down into table 7.5. Plot the frequency response curves $z_{in}(f)$ and $\varphi_{Zin}(f)$ of input characteristic of RC circuit and compare them with theoretical ones. From the graphs, determine the boundary frequency for RC circuit.

7.3.4 Based on the experimental data of table 7.4, calculate the values of amplitude-frequency characteristic $H_{uC} = U_C/U$ and phase-frequency characteristic $\varphi_{HuC} = -90^\circ - \varphi_{Zin}$ of the voltage transfer characteristic for RC circuit. Write down the results into table 7.5. Plot graphs of amplitude-frequency response of $H_{uC}(f)$ and

phase-shift frequency response of $\varphi_{H_{uC}}(f)$ of the voltage transfer function for RC circuit and compare them with theoretical ones.

7.4 Methodological guidelines

7.4.1 Measure the shift of initial phases between the input voltage and current by using an oscilloscope (figure 7.3). To measure the initial phase shift, channel A of the oscilloscope is connected to point 1 (the wire is colored red), and channel B of the oscilloscope is connected to point 2 (the wire is colored blue). By setting cursor 1 to the transition point through zero of the input voltage $u_{in}(t)$, and cursor 2 to the transition point through voltage zero on the resistor that repeats the current curve $i(t)$, the time shift of initial phases between the voltage $u_{in}(t)$ and current $i(t)$ directly on the display $T_2 - T_1$.

7.4.2 The input amplitude-frequency characteristic (AFC) of the circuit is the dependence of input impedance modulus on the frequency $z(f)$. The input phase-frequency characteristic (PFC) of the circuit is the dependence of argument of the input impedance on the frequency $\varphi_{Zin}(f)$.

The boundary frequency f_b is the frequency at which the reactance is equal to the resistive resistance, i.e. in RL -circuits $R = \omega_b L$, and in RC -circuits $R = 1/\omega_b C$.

The modulus and argument of input impedance for RL circuit is determined by the formulas:

$$z_{in}(f) = \sqrt{R_1^2 + (\omega L)^2} = R_1 \sqrt{1 + \left(\frac{2\pi f L}{R_1}\right)^2} = R_1 \sqrt{1 + \left(\frac{f}{f_b}\right)^2} ;$$

$$\varphi_{Zin}(f) = \arctan\left(\frac{\omega L}{R_1}\right) = \arctan\left(\frac{2\pi f L}{R_1}\right) = \arctan\left(\frac{f}{f_b}\right) .$$

The modulus and argument of input impedance for RC circuit is determined by the formulas:

$$z_{in}(f) = \sqrt{R_2^2 + \left(\frac{1}{\omega C}\right)^2} = R_2 \sqrt{1 + \left(\frac{1}{2\pi f R_2 C}\right)^2} = R_2 \sqrt{1 + \left(\frac{f_b}{f}\right)^2} ;$$

$$\varphi_{Zin}(f) = -\arctan\left(\frac{1}{\omega R_2 C}\right) = -\arctan\left(\frac{1}{2\pi f R_2 C}\right) = -\arctan\left(\frac{f_b}{f}\right) .$$

7.4.3 The complex voltage transfer factor $H_u(j\omega)$ is the ratio of complex output voltage \dot{U}_2 to complex input voltage \dot{U}_{in} : $H_u(j\omega) = \dot{U}_2 / \dot{U}_{in}$.

For RL circuit, the complex voltage transfer factor is determined by the formula:

$$H_{uL}(j\omega) = \frac{\dot{U}_2}{\dot{U}_{in}} = \frac{\dot{I} \cdot j\omega L}{\dot{I} \cdot (R_1 + j\omega L)} = \frac{j\omega L}{R_1 + j\omega L}.$$

The modulus and the argument of complex voltage transfer factor for RL circuit is calculated by the formulas:

$$H_{uL}(\omega) = \frac{\omega L}{\sqrt{R_1^2 + (\omega L)^2}}, \quad \varphi_{HuL}(\omega) = 90^\circ - \arctan\left(\frac{\omega L}{R_1}\right).$$

For RC circuit, the complex voltage transfer factor is determined by the formula:

$$H_{uC}(j\omega) = \frac{\dot{U}_2}{\dot{U}_{in}} = \frac{\dot{I} \cdot 1/j\omega C}{\dot{I} \cdot (R_2 + 1/j\omega C)} = \frac{1}{1 + j\omega R_2 C}.$$

The modulus and the argument of complex voltage transfer factor for RC circuit is calculated by the formulas:

$$H_{uC}(\omega) = \frac{1}{\sqrt{1 + (\omega R_2 C)^2}}, \quad \varphi_{HuC}(\omega) = -\arctan(\omega R_2 C) = -90^\circ - \varphi_{Zin}.$$

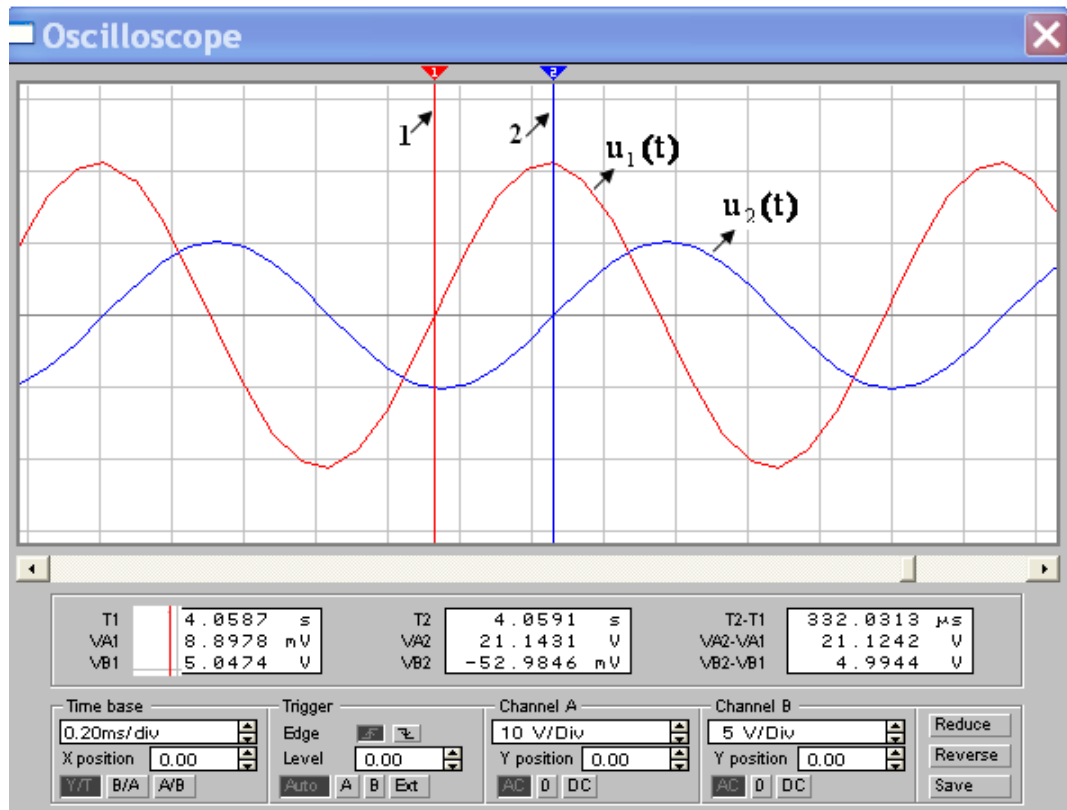


Figure 7.3

8 Laboratory work № 8. Study of passive two-port circuits using computer simulation

Purpose of the laboratory work is to study the various operation modes of passive symmetrical two-port circuits and determine their parameters using computer simulation.

8.1 Preparation for the laboratory work

8.1.1 Repeat the section “Two-port circuits” of TEC1 course.

8.1.2 Answer the questions and do the following assignments in written form:

- 1) Give the definition of a two-port circuit.
- 2) What is called the passive two-port circuit?
- 3) What is called the symmetrical two-port circuit?
- 4) Write transfer equations of two-port circuits by \underline{A} -, \underline{Z} -, \underline{Y} -, \underline{G} - and \underline{H} - parameters.

5) Calculate the complex RMS values of output voltages \dot{U}_2 , input \dot{I}_1 and output \dot{I}_2 currents at idling and short-circuit modes according to given variant of input voltage U_1 and parameters of passive symmetrical two-port circuit (table 8.1). Write down the calculation results into table 8.3 to the “Theory” row.

6) Which restriction equation should be satisfied by \underline{A} -parameters of passive symmetrical and asymmetrical two-port circuits?

7) Write the expressions to determination of \underline{A} -parameters of passive symmetrical two-port circuit. Calculate \underline{A} -parameters of passive symmetrical two-port circuit according to given variant (table 8.1). Write down the results of the calculations into table 8.4 to the “Theoretical calculation” row.

8) How to determined the input impedance of two-port circuit?

9) Calculate input impedances of two-port circuit at the idle (open-circuit) and short-circuit test modes \underline{Z}_{oc} , \underline{Z}_{sc} according to variant given into table 8.1. The results of calculations write down into table 8.5 to the “Theoretical calculation” row.

10) Write the expression of characteristic propagation constant $\underline{\Gamma}_C$ for the symmetrical two-port circuit.

Table 8.1 – Assignment variants for the laboratory work

Variant	Scheme	U_1 , V	f , kHz	R , Ω	L , mH	C , μF
1	8.1	20	1.0	80	10	–
2	8.2	30	1.5	85	–	1.5
3	8.3	25	0.5	65	–	4.0
4	8.4	15	0.8	95	16	–
5	8.5	35	2.0	50	–	2.0
6	8.6	40	2.5	110	6	–
7	8.7	10	2.0	120	8	–
8	8.8	45	1.5	100	–	1.0

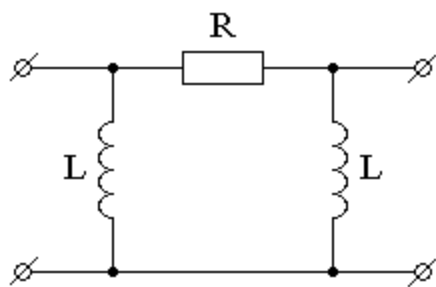


Figure 8.1

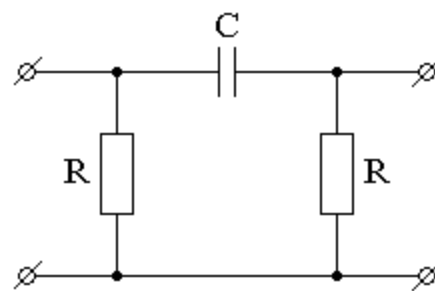


Figure 8.2

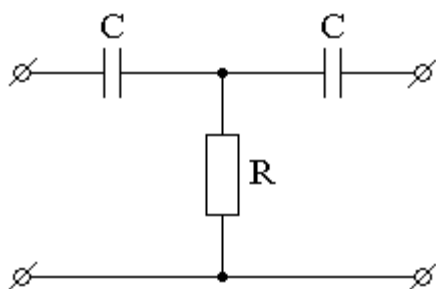


Figure 8.3

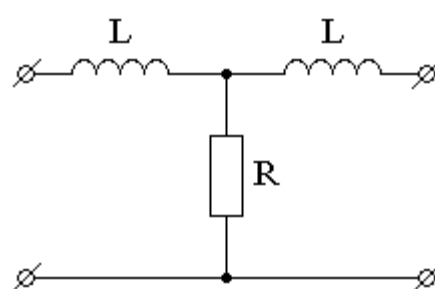


Figure 8.4

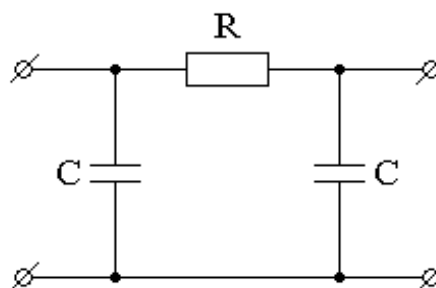


Figure 8.5

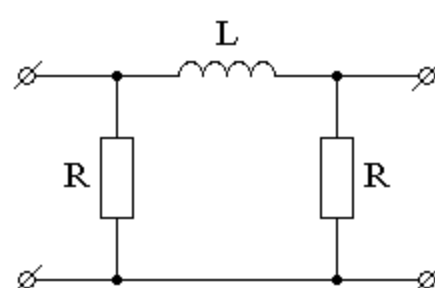


Figure 8.6

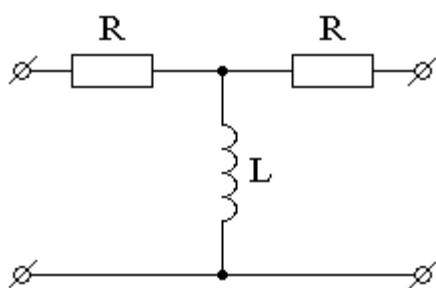


Figure 8.7

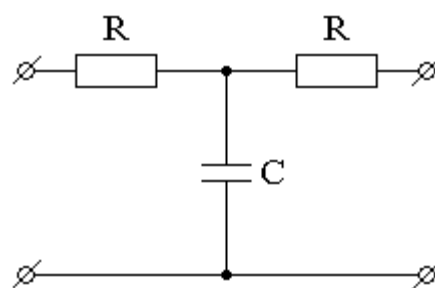


Figure 8.8

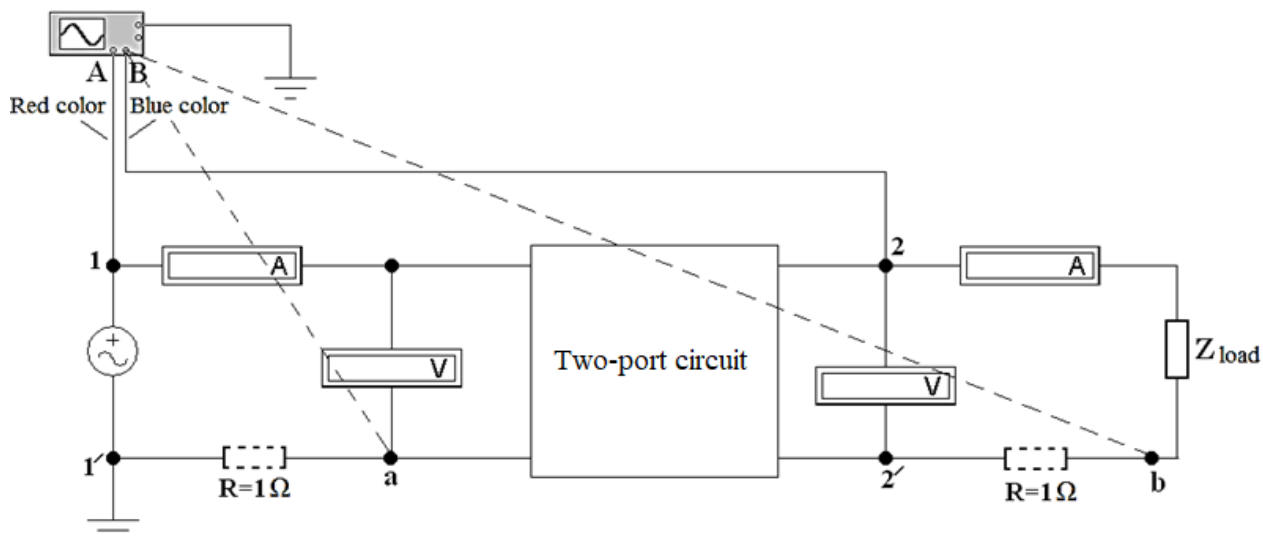


Figure 8.9

8.2 Procedure of carrying out the work

8.2.1 Assemble the electric circuit using the scheme shown in figure 8.9 with specified parameters of two-port circuit according to assignment variant.

8.2.2 Set RMS value of input voltage U_1 and frequency f of generator according to assignment variant.

8.2.3 Measure input U_1 and output U_2 voltages, input current I_1 of the two-port circuit at the idling mode across output points 2-2' ($Z_{load} = \infty$, $I_2 = 0$). In addition, measure the time interval $\Delta t_{u2} = T_2 - T_1$, which corresponds to phase shift angle between the input $u_1(t)$ and output $u_2(t)$ voltages and time interval $\Delta t_{i1} = T_2 - T_1$, which corresponds to phase shift angle between the input voltage $u_1(t)$ and input current $i_1(t)$ of the two-port circuit. Write down the measurement results into table 8.2.

8.2.4 Measure input I_1 and output I_2 currents, input voltage U_1 of the two-port circuit at the short-circuit test mode across output points 2-2' ($Z_{load} = 0$, $U_2 = 0$). In addition, measure time interval $\Delta t_{i1} = T_2 - T_1$, which corresponds to phase shift angle between input voltage $u_1(t)$ and input current $i_1(t)$ and time interval $\Delta t_{i2} = T_2 - T_1$, which corresponds to phase shift angle between input voltage $u_1(t)$ and output current $i_2(t)$ of the two-port circuit. Write down the measurement results into table 8.2.

Table 8.2 – Determination of initial phase angles of currents and voltages

Operation mode	\underline{U}_1 , V	U_2 , V	$T_2 - T_1$, s	ψ_{u2} , deg	I_1 , A	$T_2 - T_1$, s	ψ_{i1} , deg	I_2 , A	$T_2 - T_1$, s	ψ_{i2} , deg
Idling										
Short circuit										

Table 8.3 – Complex RMS values of voltages and currents at various modes

Operation mode	Kind of study	\dot{U}_1, V	\dot{U}_2, V	\dot{I}_1, A	\dot{I}_2, A
Idling	Theory				
	Experiment				
Short circuit	Theory				
	Experiment				

Table 8.4 – \underline{A} -parameters of two-port circuit

Kind of study	\underline{A}_{11}	$\underline{A}_{12}, \Omega$	$\underline{A}_{21}, \text{S}$	\underline{A}_{22}
Theoretical calculation				
Calculation by experimental data				

Table 8.5 – Secondary parameters of two-port circuit

Kind of study	$\underline{Z}_{sc}, \Omega$	$\underline{Z}_{oc}, \Omega$	\underline{Z}_c, Ω	$\underline{\Gamma}_c$
Theoretical calculation				
Calculation by experimental data				

8.3 Processing experimental results

8.3.1 Calculate initial phase angles of output voltage Ψ_{u2} and initial phase angles of input Ψ_{i1} and output currents Ψ_{i2} of the two-port circuit for all studied operation modes by using corresponding measured values of $\Delta t = T_2 - T_1$. Write down the obtained results into table 8.2.

8.3.2 Write down complex RMS values of the voltages \dot{U}_1, \dot{U}_2 and currents \dot{I}_1, \dot{I}_2 for all studied modes into table 8.3 to the “Experiment” row.

8.3.3 Calculate \underline{A} -parameters of passive symmetrical two-port circuit: \underline{A}_{11} , \underline{A}_{12} , \underline{A}_{21} and \underline{A}_{22} by using the experimental data of voltages values \dot{U}_1, \dot{U}_2 and currents values \dot{I}_1, \dot{I}_2 in the idling (open-circuit) and short-circuit tests by following formulas:

$$\underline{A}_{11} = \left(\frac{\dot{U}_1}{\dot{U}_{2oc}} \right)_{I_2=0} ; \quad \underline{A}_{21} = \left(\frac{\dot{I}_{1oc}}{\dot{U}_{2oc}} \right)_{I_2=0} ; \quad \underline{A}_{12} = \left(\frac{\dot{U}_1}{\dot{I}_{2sc}} \right)_{U_2=0} ; \quad \underline{A}_{22} = \left(\frac{\dot{I}_{1sc}}{\dot{I}_{2sc}} \right)_{U_2=0} .$$

Write down the calculation results into table 8.4 to the “Calculation by experimental data” row.

8.3.4 Calculate input impedances of two-port circuit for all studied modes by using the experimental data. Write down the obtain results into table 8.5 to the “Calculation by experimental data” row.

8.3.5. Compare the theoretical data with those obtained during the experiments. Make conclusions on the work done.

8.4 Methodological guidelines for measurement of initial phase angels of sinusoidal time-varying voltages and currents

It is possible to measure initial phase angles of sinusoidal time-varying voltages and currents relatively to initial phase angle of input voltage $u_1(t)$ by means of the oscilloscope (figure 8.10). In order to measure the initial phases of voltages the channel (A) of oscilloscope should be connected to the point (1) (this wire is colored red) and the channel (B) – to the point (2) (this wire paints in blue color). Set the first (red) and the second (blue) survey lines to the same phase point of the input $u_1(t)$ and output $u_2(t)$ voltages, for example in start zero point of sinusoidal time-varying function. Read the corresponding time shift interval $\Delta t_{u2} = T_2 - T_1$ between the voltages $u_2(t)$ and $u_1(t)$ on the third (last) subwindow of the oscilloscope beneath the main screen. Calculate the phase shift angle by the formula:

$$\psi_{u2} - \psi_{u1} = 360^\circ \cdot f \cdot (-\Delta t_{u2}) = -360^\circ \cdot f \cdot (T_2 - T_1).$$

Assume the initial phase angle of the input voltage $u_1(t)$ of zero $\psi_{u1} = 0$, then the above expression determine the value of ψ_{u2} – an initial phase angle of output voltage $u_2(t)$.

To measure initial phases of currents the method of converting the current into the potential is used by connecting into the circuit a resistor with small value of resistance for measuring current by means the oscilloscope.

In order to measure the initial phase angle of input current $i_1(t)$ the resistor R with resistance of 1Ω should be plugged in between points (a) and (1'). Channel (A) of oscilloscope should be connected to point (1) (this wire colored red) and channel (B) – to point (a) (this wire is colored blue). Set the first (red) and the second (blue) survey lines to the same phase point (for example in zero point) of input voltage $u_1(t)$ (red color curve) and input current $i_1(t)$ (blue color curve). Read the corresponding time shift interval $\Delta t_{i1} = T_2 - T_1$ between input current $i_1(t)$ and input voltage $u_1(t)$. Calculate the phase shift angle ψ_{i1} of input current $i_1(t)$ by the above formula.

In order to measure the initial phase angle of output current $i_2(t)$ switch the resistor R with resistance of 1Ω between points (2') and (b). Channel (A) of oscilloscope should be connected to point (1) (this wire is colored red) and the channel (B) – to point (2') (this wire is colored blue). Set the first (red) and the second (blue)

survey lines to the same phase point (for example in zero point) of input voltage $u_1(t)$ (red color curve) and output current $i_2(t)$ (blue color curve). Read the corresponding time shift interval $\Delta t_{i_2} = T_2 - T_1$ between output current $i_2(t)$ and input voltage $u_1(t)$. Calculate the phase shift angle Ψ_{i_2} of output current $i_2(t)$ by the above formula. After all measurements resistor R with resistance of 1Ω should be plugged off.

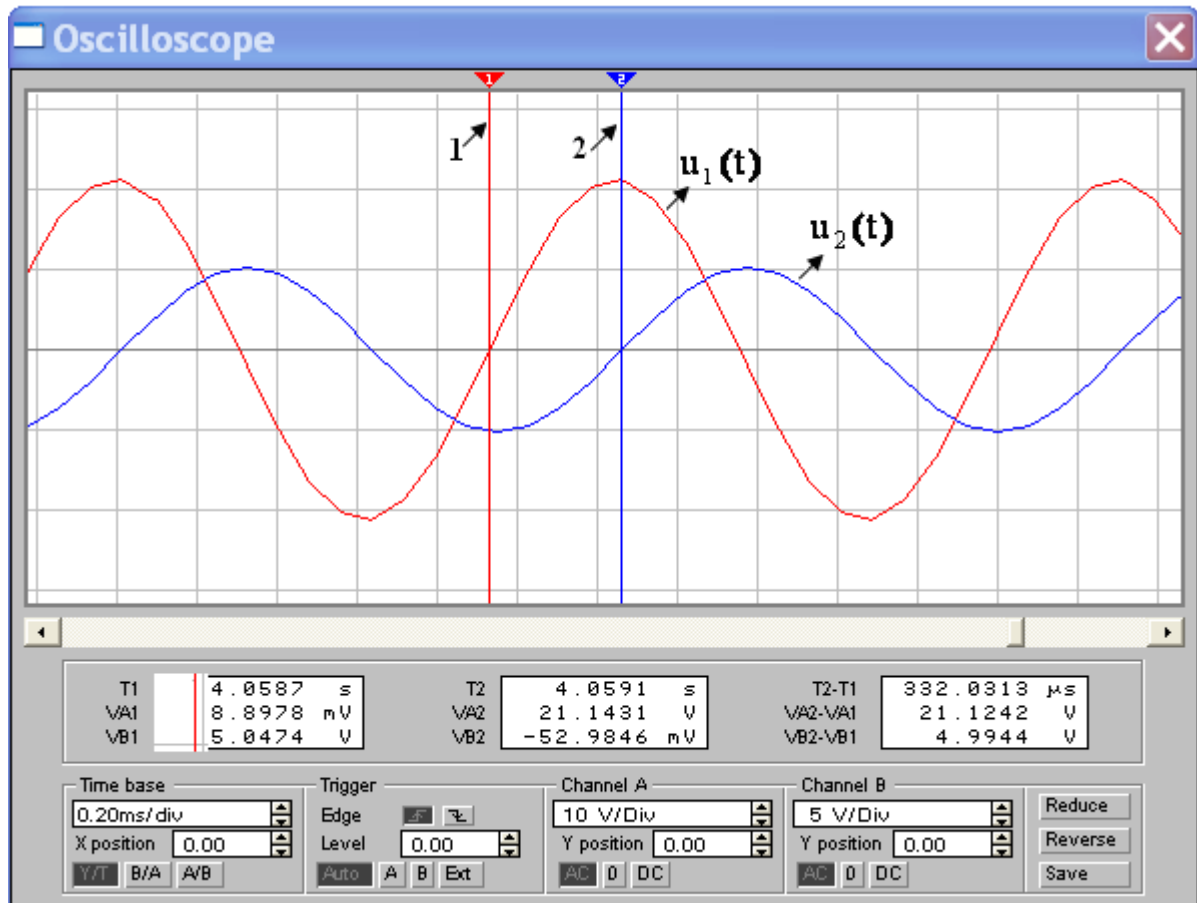


Figure 8.10

8.5 Revision questions

1. Main equations of two-port circuits.
2. Determination of \underline{A} -parameters of two-port circuits.
3. Equivalent schemes of two-port circuits.
4. Characteristic impedance \underline{Z}_C of symmetrical two-port circuits.
5. Propagation constant $\underline{\Gamma}_C$ of symmetrical two-port circuits.
6. Input impedance of symmetrical two-port circuits at idle and short-circuit operation modes.

9 Laboratory work № 9. Study of DC electric circuit with nonlinear resistive elements

Purpose of the laboratory work is to obtain the skills of experimental study of electrical DC circuits with nonlinear elements.

9.1 Preparation for the laboratory work

9.1.1 Repeat section “Nonlinear electric DC circuits” of TEC1 course.

9.1.2 Answer the questions in the written form and do the following assignments:

1) What kind of non-linear elements are called symmetric and asymmetric? Show their current-voltage characteristics.

2) What is the difference between static and differential resistances of nonlinear elements?

3) Draw a scheme for getting the readings required to construct current-voltage characteristics of the nonlinear element. As a power source, you need to use a regulated DC power supply. Connect necessary measuring instruments to the circuit.

4) Give an example of graphical calculation method for electrical circuit with a single source of EMF and 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 graphical calculation method for electrical circuit with a combined connection of three nonlinear resistors.

7) Give an example of graphical calculation method for the electrical circuit with nonlinear elements by applying method of two nodes.

9.2 Procedure of carrying out the work

9.2.1 Take readings to construct current-voltage characteristics of three nonlinear elements (by the teacher’s instructions) according to the scheme in figure 9.1, by changing the voltage between 0 and 20 V. Fill in the Table 9.1 for each nonlinear element.

9.2.2 Assemble the circuit with combined connection of three nonlinear elements as shown in figure 9.2. Changing the input voltage from 0 to 20 V, measure and record the readings into table 9.2.

9.2.3 Assemble circuit with two sources of EMF as shown in figure 9.3. Measure the EMFs of sources, voltages across each element, voltage between two nodes and currents in each branch of the circuit. Write down the measurement results into table 9.3.

Table 9.1

U, V	0	5	10	15	20
I, mA					

Table 9.2

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

Table 9.3

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

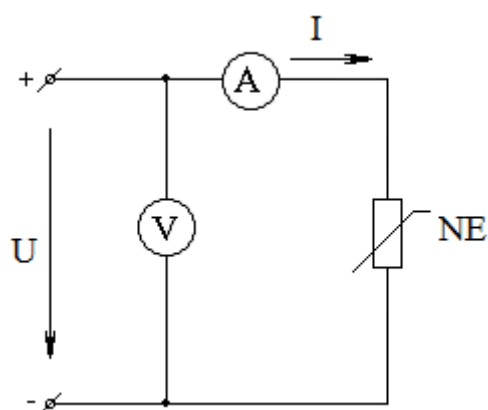


Figure 9.1

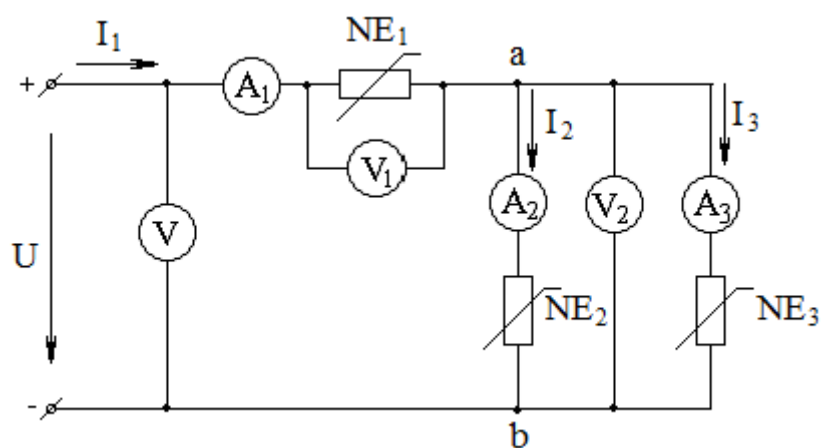


Figure 9.2

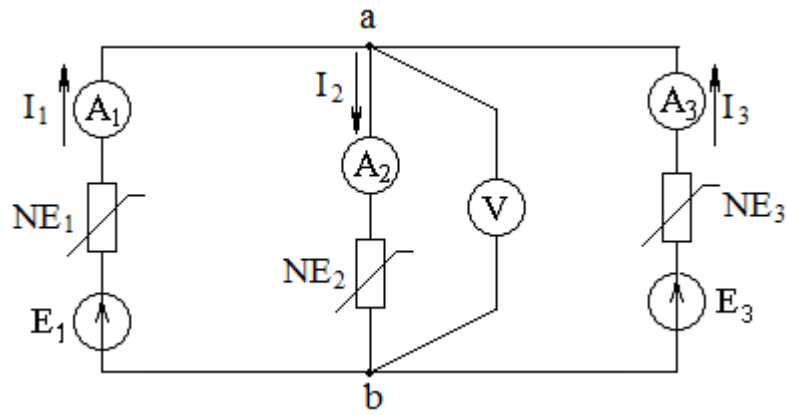


Figure 9.3

9.3 Processing experimental results

9.3.1 Draw current-voltage characteristics of three nonlinear elements.

Make the graphical calculation of currents and voltages for the circuit in figure 9.2 and compare the theoretical calculated values with those obtained during the experiment.

Make the graphical calculation of currents and voltages for the circuit in figure 9.3 by applying two nodes method and compare the theoretical calculated values with those obtained during the experiment.

Make conclusions based on the results of the work done.

9.4 Methodological guidelines

9.4.1 Graphical calculation method of unbranched circuits with nonlinear resistive elements.

DC voltage source $E = U$ is applied to the circuit in figure 9.4 with a series connection of two nonlinear resistors NE_1 and NE_2 , whose current-voltage characteristics (CVCs) $I_1(U_1)$ and $I_2(U_2)$. It is required to determine the current I and voltages U_1 and U_2 across the elements NE_1 and NE_2 .

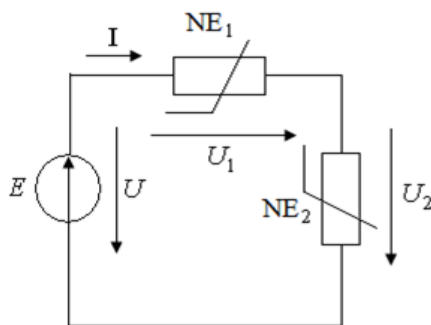


Figure 9.4

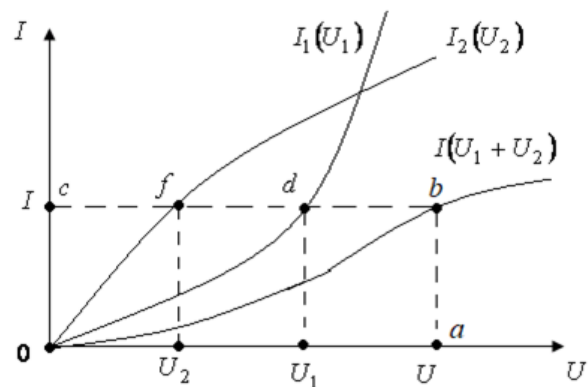


Figure 9.5

Let us write the Kirchhoff's voltage law for a nonlinear circuit in figure 9.4:

$$U = U_1 + U_2 .$$

The current in both elements is the same: $I_1 = I_2 = I$.

We construct the curve $I(U) = I(U_1 + U_2)$ of current-voltage characteristic (CVC). For this purpose, we sum the voltages U_1 and U_2 under similar current values (figure 9.5), plot the abscissa voltage $U = E$ from point a and draw a straight line parallel to y-axis until it intersects with the curve $I(U_1 + U_2)$. The segment ab is equal to the current I in the scale m_i : $I = m_i \cdot ab$. From point b we draw a line bc parallel to the axis of abscissas, as a result we obtain segments cd and cf , equal on scale m_u to voltages U_1 and U_2 : $U_1 = m_u \cdot cd$ and $U_2 = m_u \cdot cf$.

9.4.2 Graphical calculation method of circuits with parallel connection of nonlinear elements. Direct current source J is applied to the circuit in figure 9.6 with a parallel connection of nonlinear resistive elements NE_1 and NE_2 with current-voltage characteristics (CVCs) $I_1(U_1)$ and $I_2(U_2)$ (figure 9.7).

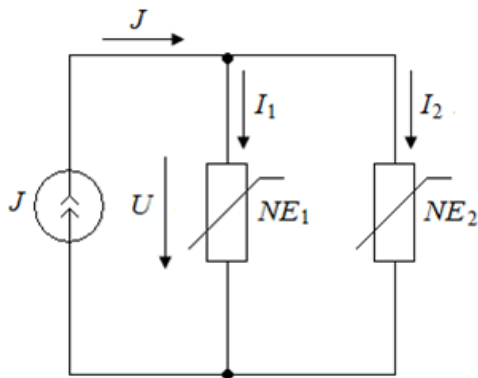


Figure 9.6

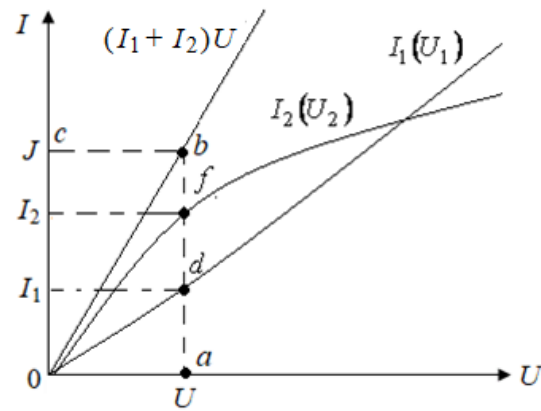


Figure 9.7

When elements are connected in a parallel, $U_1 = U_2 = U$ and according to the Kirchhoff's current law $J = I_1 + I_2$. First we construct the auxiliary characteristic $(I_1 + I_2)U$ by summing the ordinates of the curves $(I_1)U_1$ and $(I_2)U_2$ for similar voltage values $U_1 = U_2 = U$. Next, we plot the value of current of current source J and from point c draw a straight line parallel to the abscissa axis until it intersects with the curve $(I_1 + I_2)U$ at point b . From point b , we drop the perpendicular to the abscissa axis to point a . The segment $0a$ in the scale m_u is equal to the voltage across the elements $U = m_u \cdot 0a$, and the segments ad and af in the scale m_i are equal to the currents: $I_1 = m_i \cdot ad$ and $I_2 = m_i \cdot af$ (figure 9.7).

9.4.3 The procedure for calculating the electrical circuit in the case of combined connection of non-linear elements (figure 9.2).

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 nonlinear elements.

10 Laboratory work № 10. Study of a linear electric circuit of periodic non-sinusoidal current using computer simulation

Purpose of the laboratory work is obtaining the skills of the experimental study of a linear electric circuit of periodic non-sinusoidal current using computer simulation.

10.1 Preparation for the laboratory work

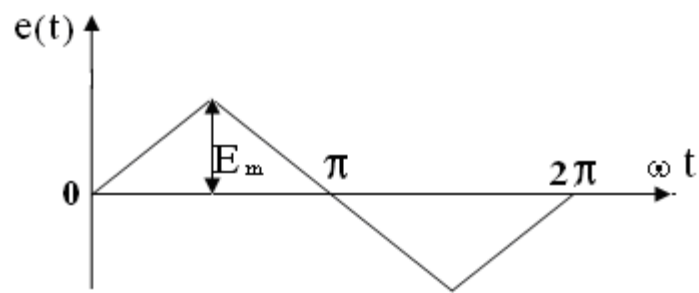
10.1.1 Repeat section “Linear electric circuit of periodic non-sinusoidal current” of TEC1 course.

10.1.2 Answer the questions in the written form and do the following assignments:

- 1) What currents and voltages are called periodic non-sinusoidal?
- 2) Decomposition of periodic non-sinusoidal currents and voltages in a Fourier series.
- 3) Write procedure of calculation of currents in linear electric circuits with periodic non-sinusoidal waveforms.
- 4) Calculate the current at the input of the circuit, according to the variant of assignment (table 10.1).
- 5) How to calculate effective values of periodic nonsinusoidal currents and voltages. Calculate effective values of current and voltage at the input of the circuit, according to the variant of assignment (table 10.1). Write down the results into table 10.2.
- 6) How to calculate the active, reactive and apparent power of periodic non-sinusoidal current. Calculate the active, reactive and apparent power, according to the variant of assignment (table 10.1). Write down the results into table 10.2.
- 7) Plot the curves of given periodic non-sinusoidal applied voltage $e(t)$ and calculated current at the input of the circuit $i_1(t)$.

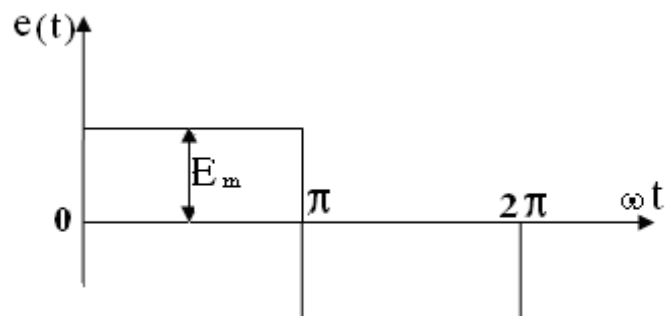
Table 10.1

Variant	1	2	3	4	5	6
Scheme	10.3	10.4	10.5	10.6	10.7	10.8
Curve of $e(t)$	10.1	10.2	10.1	10.2	10.1	10.2
E_m , V	40	50	60	80	30	20
f , kHz	1.0	1.2	1.5	1.3	2.0	0.8
R_1 , Ω	100	150	80	200	50	90
R_2 , Ω	80	100	100	100	60	50
R_3 , Ω	150	80	50	120	90	40
L , mH	3	2	4	2	1	6
C , μF	4	3	2	5	6	1



$$e(t) = \frac{8E_m}{\pi^2} \left(\sin \omega t - \frac{1}{9} \sin 3\omega t + \frac{1}{25} \sin 5\omega t + \dots \right)$$

Figure 10.1



$$e(t) = \frac{4E_m}{\pi} \left(\sin \omega t + \frac{1}{3} \sin 3\omega t + \frac{1}{5} \sin 5\omega t + \dots \right)$$

Figure 10.2

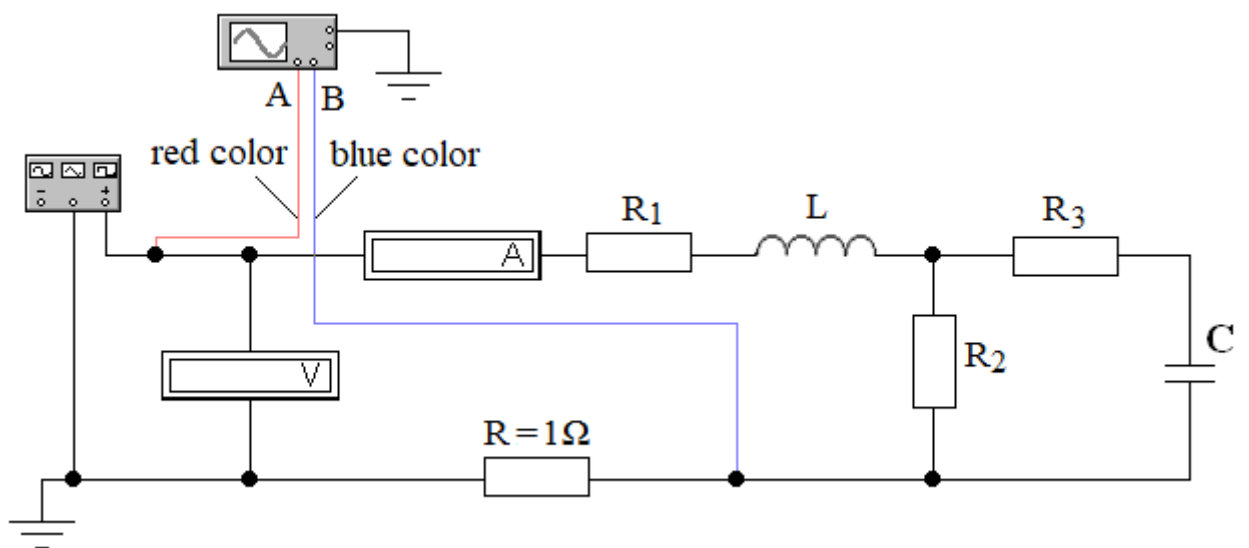


Figure 10.3

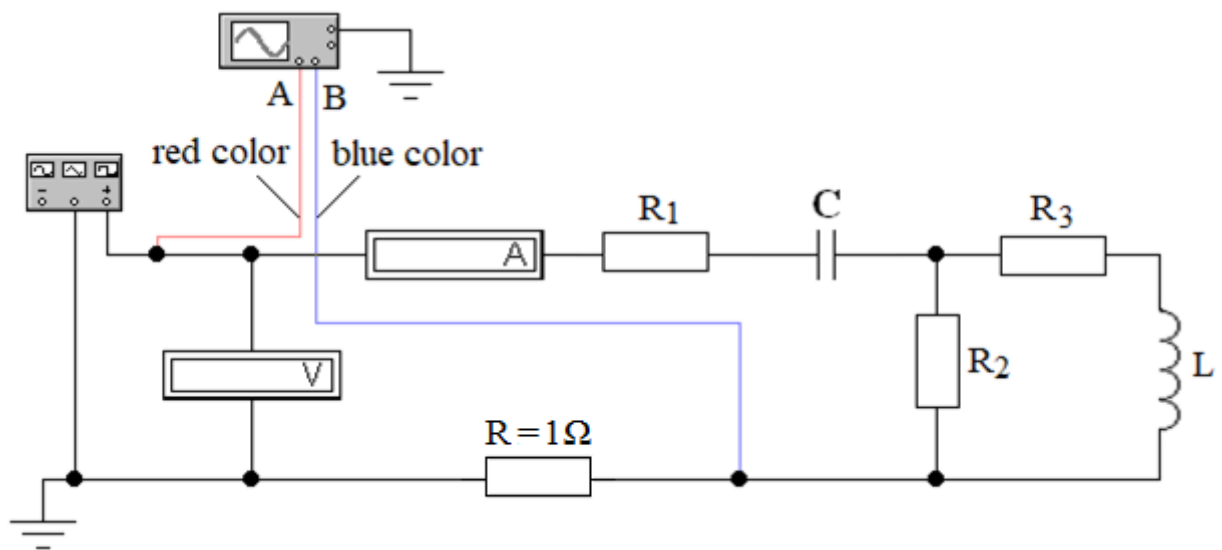


Figure 10.4

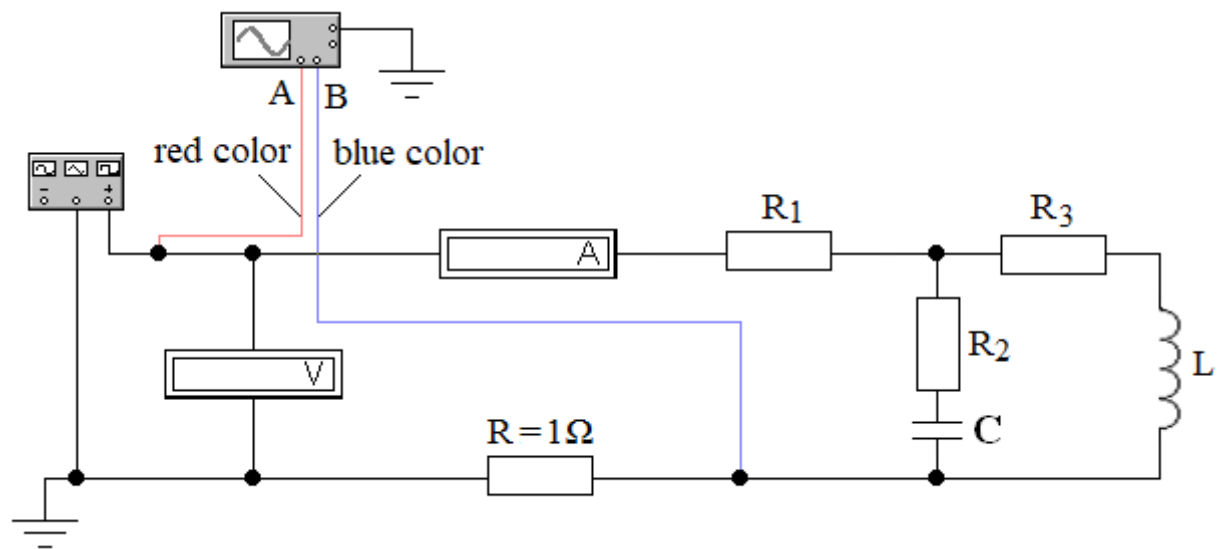


Figure 10.5

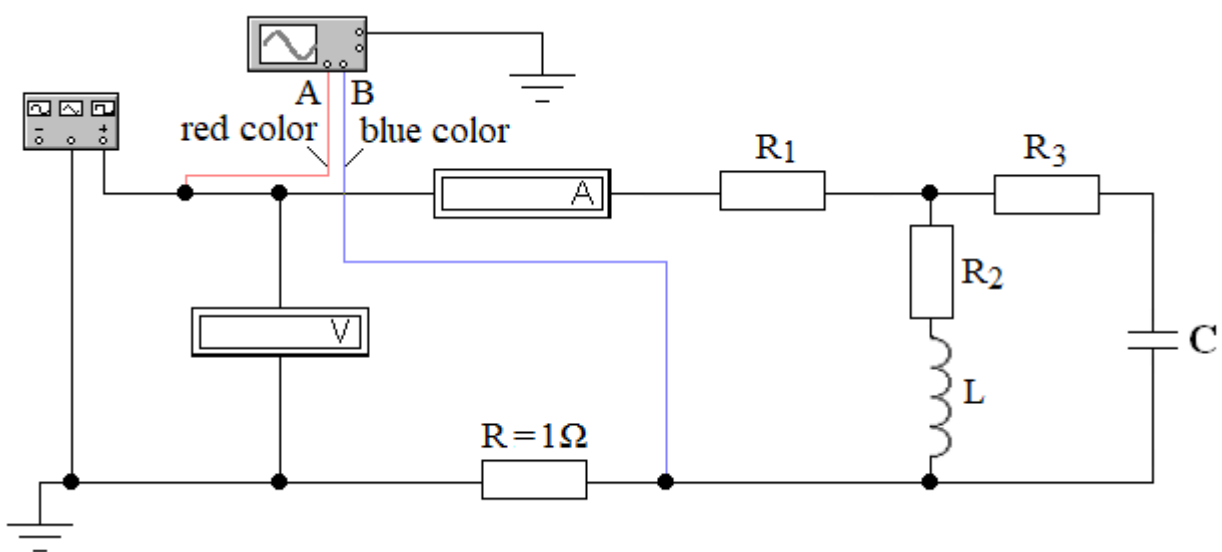


Figure 10.6

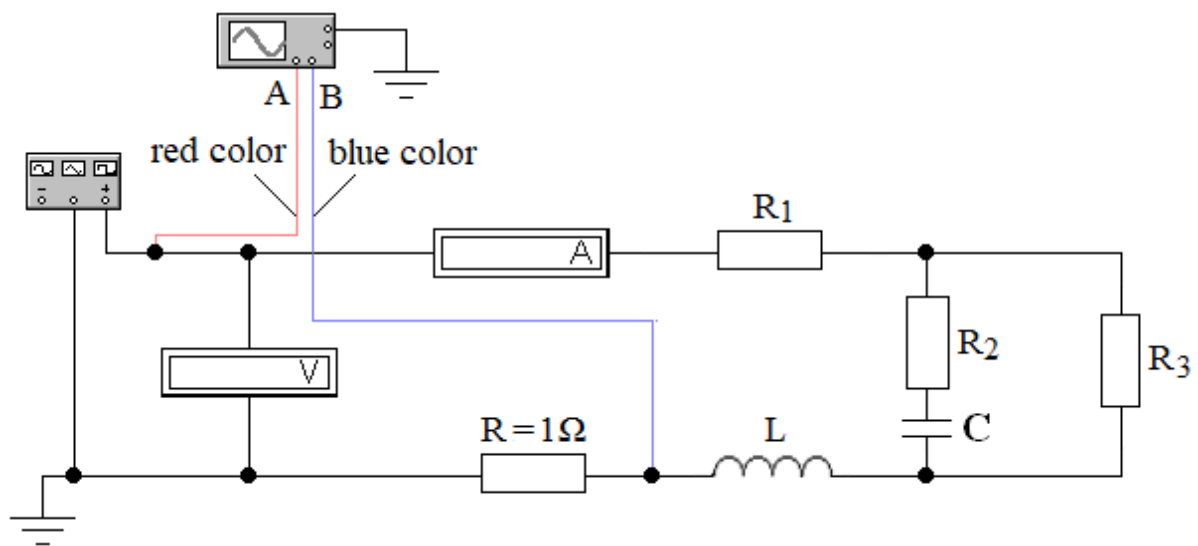


Figure 10.7

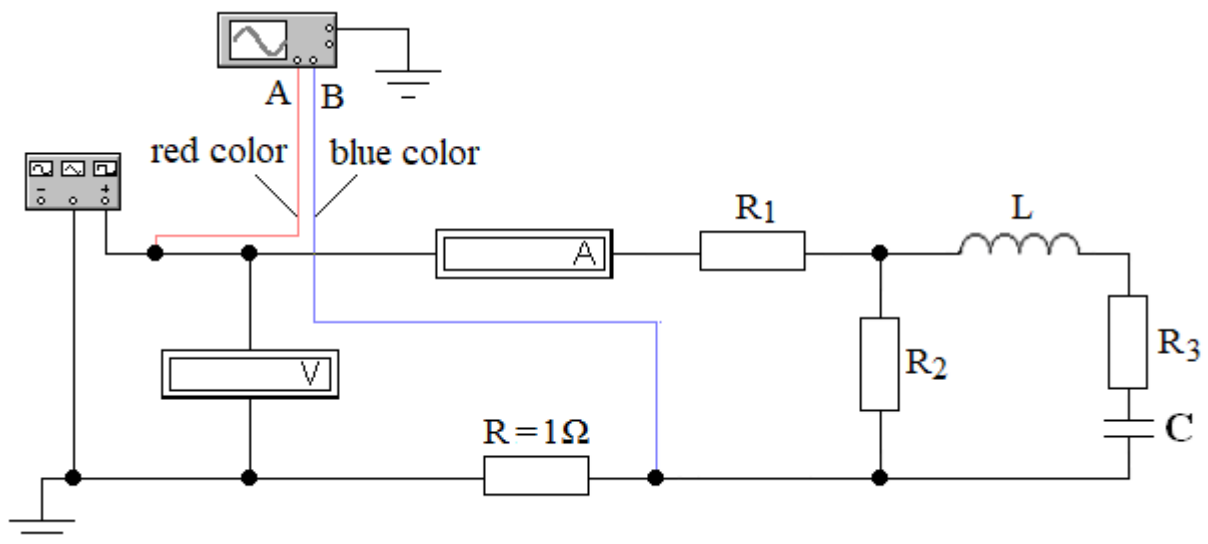


Figure 10.8

10.2 Procedure of carrying out the work

10.2.1 Assemble the circuit according to the assignment variant (table 10.1). Set given values of circuit parameters. Set a given kind of EMF waveform $e(t)$ – on the source, given values of amplitude E_m and frequency f .

10.2.2 Measure effective (r.m.s.) values of voltage and current at the input of the circuit. Write down the values obtained into table 10.2.

10.2.3 Switch on the oscilloscope. The oscilloscope displays input voltage curves $e(t)$ (channel A, red color curve) and the voltage curve across resistor $R = 1\ \Omega$, which repeats the current curve at the input of circuit $i_1(t)$ (channel B, blue color curve). Draw obtained voltage and current curves.

Table 10.2

Kind of study	U , V	I_1 , mA	S , VA	P , W	Q , var
Theoretical calculation					
Experimental study on the computer					
Accuracy δ , %					

10.3 Processing experimental results

10.3.1 From the experimental data of table 10.2, calculate the apparent power S of non-sinusoidal periodic current.

10.3.2 Compare experimental values of voltage, current, and power with values calculated theoretically. Determine, in percent, how many differ the experimental values of voltage, current, and power from those calculated theoretically:

$$\delta_U = \frac{U_{exp.} - U_{theory}}{U_{exp.}}, \% ; \quad \delta_U = \frac{U_{exp.} - U_{theory}}{U_{exp.}}, \% ; \quad \delta_S = \frac{S_{exp.} - S_{theory}}{S_{exp.}}, \%$$

Write down the values obtained into table 10.2. Explain why the experimental values differ from the theoretical ones.

10.3.3 Compare voltage and current curves obtained experimentally with theoretically obtained ones $e(t)$ and $i_1(t)$. Explain the difference between experimental voltage and current curves from those obtained theoretically.

10.4 Methodological guidelines

10.4.1 The calculation of linear electric circuits with periodic non-sinusoidal power supplies includes three stages:

a) decomposition of non-sinusoidal periodic functions of the EMF into a trigonometric Fourier series. For the given EMFs:

$$e(t) = \frac{8E_m}{\pi^2} \left(\sin \omega t - \frac{1}{9} \sin 3\omega t + \frac{1}{25} \sin 5\omega t + \dots \right);$$

$$e(t) = \frac{4E_m}{\pi} \left(\sin \omega t + \frac{1}{3} \sin 3\omega t + \frac{1}{5} \sin 5\omega t + \dots \right).$$

While calculating, we confine ourselves to the first three terms;

b) application of the principle of superposition and calculation of currents and voltages in the circuit for each of the harmonic components separately. When calculating the circuit for each sinusoidal component, one can use a complex method.

The inductive and capacitive reactances for the k -th harmonic are:

$$X_L^{(k)} = k\omega L = k \cdot X_L^{(1)} \quad \text{and} \quad X_C^{(k)} = \frac{1}{k\omega C} = \frac{X_C^{(1)}}{k} ;$$

c) formulation of the final solution considering the results of calculation for each of the harmonic components obtained at the previous stage:

$$i_1(t) = i_1^{(1)}(t) + i_1^{(3)}(t) + i_1^{(5)}(t) ;$$

d) the curves of the instantaneous voltage and current values can be plotted in the Mathcad application. An example of the curves of the instantaneous voltage and current values is shown in figure 10.9. To plot the voltage and current curves in one figure, you must enter a scale factor for the voltage or current values so that the order of these quantities becomes the same.

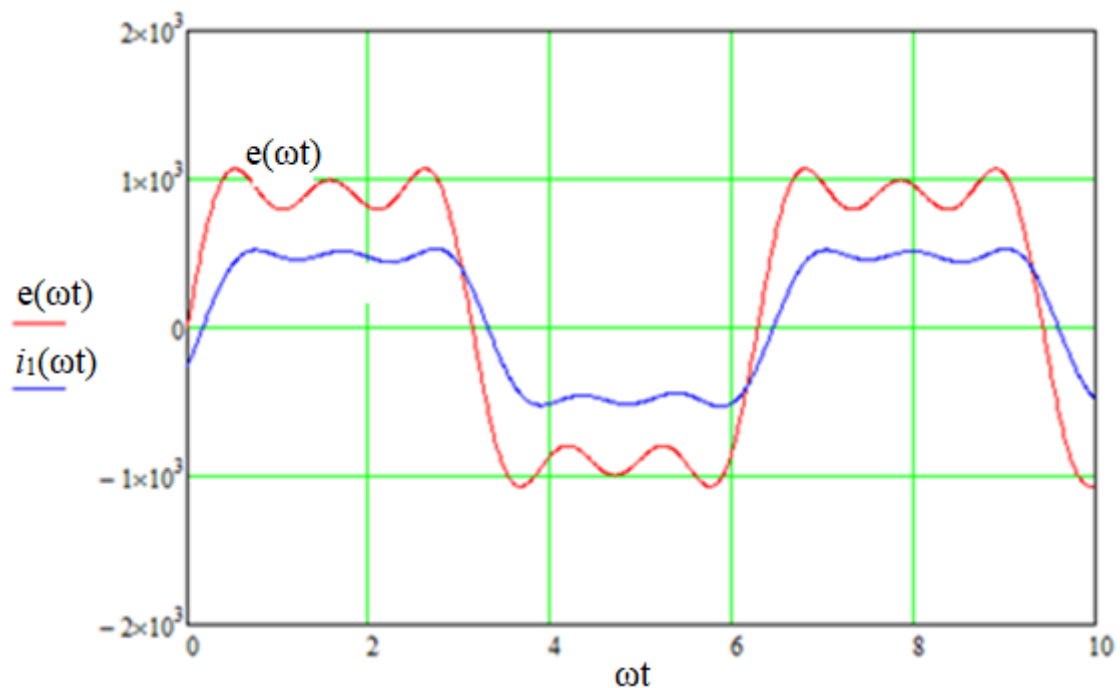


Figure 10.9

10.4.2 The experimental part of the laboratory work is carried out in the Electronics Workbench application.

10.4.3 Setting the specified periodic non-sinusoidal EMF and its parameters is performed by double clicking on the function generator icon, then the dialog window of source properties opens. The specified EMF curve, the maximum (amplitude) value of E_m , and the frequency f are set in this dialog window (figure 10.10).

The parameters of circuit elements are set similarly.

10.4.4 To obtain voltage and current curves on the oscilloscope display, connect its terminals as shown in figures 10.3-10.9. To obtain the curve of input voltage, channel A is connected to the input of studied circuit (this wire is colored red). To obtain the current curve, channel B is connected to resistor $R = 1 \Omega$ (this wire is

colored blue). Figure 10.11 shows voltage and current curves obtained on the oscilloscope screen.

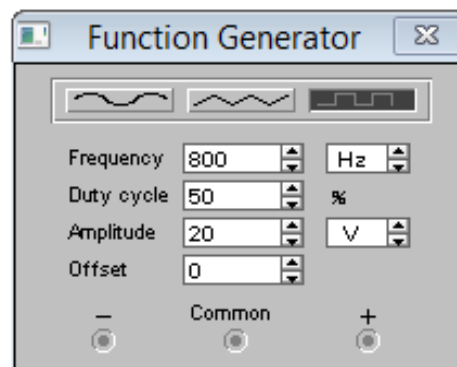


Figure 10.10

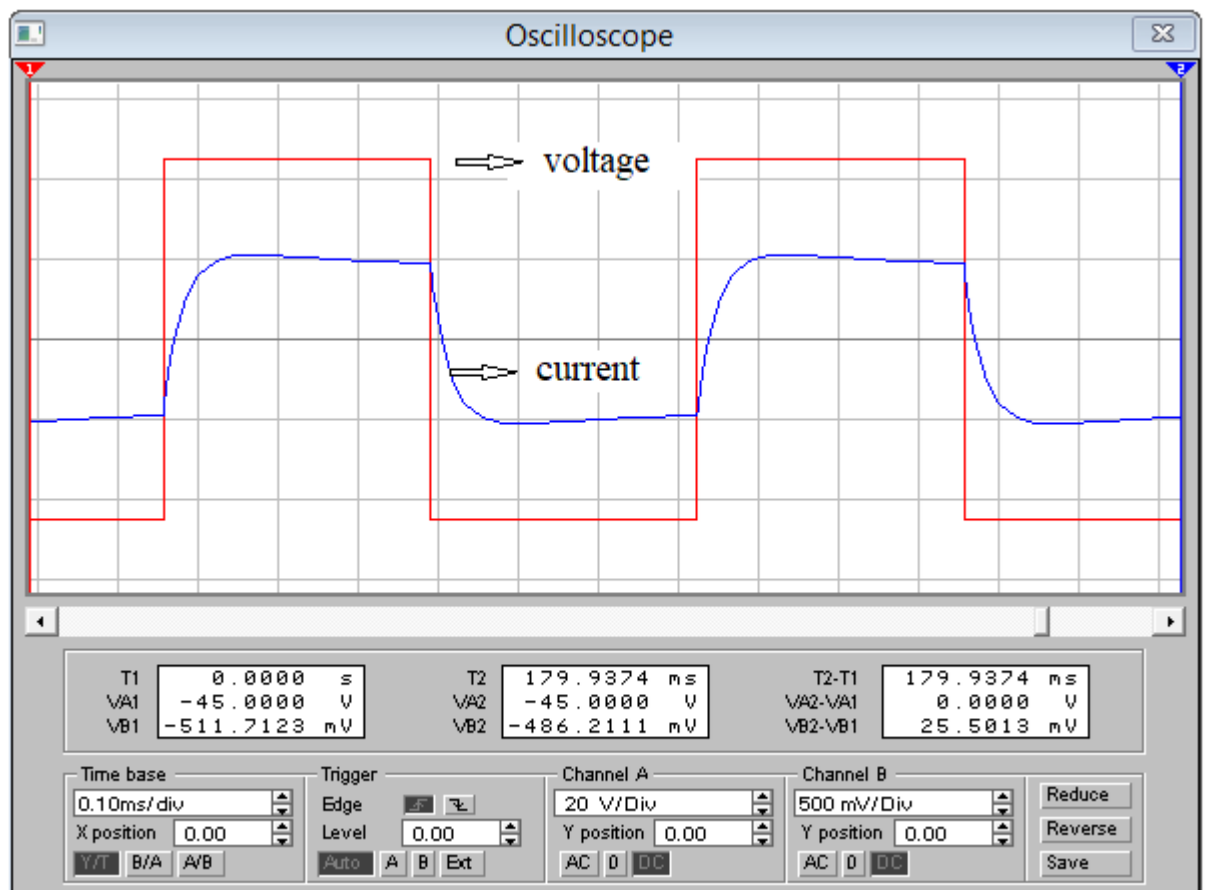


Figure 10.11

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THEORY OF ELECTRICAL CIRCUITS 1

Methodological guidelines and assignments for laboratory works for the following specialties: 5B071900 – Radio engineering, electronics and telecommunications; 5B070400 – Computing and software; 5B070300 – Information systems; 5B074600 – Space techniques and technology; 5B060200 – Informatics; 5B071600 – Instrumentation

Editor S. B. Bukhina
Standard expert N. K. Moldabekova

Signed to publication _____
Printed 50 copies
Volume 3,25 edu.-pub. sheet

Layout size 60×84 1/16
Printout paper № 1
Order ____ Price 1625 tenge

Copying service
noncommercial Joint Stock Company
Almaty university of power engineering and telecommunications
126, Baitursynov Street, Almaty, 050013