THE MINISTRY OF EDUCATION OF THE REPUBLIC BELARUS

EDUCATIONAL INSTITUTION
"BREST STATE TECHNICAL UNIVERSITY"

Department of automation of technological processes and production

THEORY OF ELECTRICAL CIRCUITS

Laboratory practical
"The study of linear circuits on computer models"

for the students of specialties
1-53 01 02 *"Automated systems processing information "*

Brest 2016

УДК 621.3.01: 004.9

Laboratory work is performed by using a program "Начала электроники" and the package «Electronics Workbench» on computer models.

Carrying out laboratory work on the course "Theory of electrical circuits" with the study of processes on computer models has a number of advantages compared with traditional measurements on electrical circuits.

First, the computer environment for the modern student - "native element" so you can focus on learning concepts and laws.

Secondly, a set of elements for constructing circuits is limited only libraries packets.

Third, save the results, conducting calculations in mathematical packages and formation of reports on laboratory work much simpler, are conducted by modern methods and save time.

Fourth, the students get skills of construction and study of models of electric circuits in packages that have independent significance as a design system.

Fifth, the implementation of the work is not tied to the laboratory equipment that provides opportunities for individual work of students of different forms of education.

Compiled: Yarashevich A.V., Ph.D., associate professor

Reviewer: chief Power Engineer of the Brest branch of "Beltelecom" Petrukovich V.V.

Contents

1. General Methodical instructions

The course of laboratory work of 32 hours for studying the concepts and methods of the theory of electrical circuits. Each work is designed for 4 hours.
Work is being performed by brigades of 2 people.

Descriptions of laboratory work are constructed in such a way that the training of the packaging is in the process of building and research models. This allows you to gradually increase the amount of skills in working programs.
The essence of the work is in four movements:

- Studying of theory related studies on laboratory work, preparation of input data of parameters of circuit elements for a given variant and, if necessary, preparing tables for recording results. After preparing the teacher can conduct a survey and take the a decision on the admission students to perform work.
- Building models on a computer, research and preservation of the results on removable data medium.
- Perform the calculation characteristics of the studied chains theoretical methods and compared with the simulation results.
- Analysis of results and design of the report.

The report on the implementation of the work shall be presented by each student teacher during the next lesson. In the absence of the report without valid reasons a student is not allowed to perform the following work.

The report is performed on A4 sheets and stapled necessarily. The first list is the title, and should contain:

- The name of the University;
- The name of the department;
- The theme of the laboratory work;
- Job number in the text: "Report on the implementation of the laboratory work № ... of TEC";
- Name and group of students;
- The name of the teacher;
- The date of performance.

A report on the work of the following sections:

- Work theme;
- target;
- initial data;
- The results of the computer;
- Theoretical calculations and building;
- Conclusions on the objectives of the study.

2. Literature

1. Fundamentals of circuit theory / GV Zeveke, [et al.] - 5th ed. - M .: Energy, 1989.
2. Fundamentals of electrical circuits. Linear chain /P.N.Mathanov - M .: Higher School, 1981.

Computer programs.

3. Electronics Workbench 4.0, Interactive Image Technologies Ltd., 1996.
4. Mathcad 5.0, MathSoft Inc., 1994.
5. Начала электроники.

3. Methodical instructions for laboratory work

3.1 Laboratory work № 1

Characteristics of the elements and the structure of the circuit

***Objective*:** To build an experimental current - voltage characteristics (CVC) of the voltage source and a resistor, and an analysis of the structure of the branched circuit.

The task for the work:

1) According to the scheme in Figure 1.1 to construct a model of the circuit in the "Start electronics" and remove the CVC voltage source when you change the resistor *R2 from 50 ohms to* ∞ (6 points). Plot the voltage ***U0*** on the current ***I*** (CVC). Values of the parameters of the circuit elements:
U0 = 1,5 V; r 0 = 40 ohms*; *R1 = 100 ohms; R2 from 50 ohms to 1kohm and* ∞*(the gap branch).

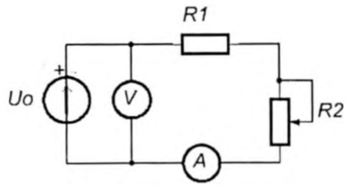


Fig.1.1

2) According to the scheme in Figure 1.2 to construct a model of the circuit in the "Start electronics" and remove the CVC resistor (6 points), fixing the potentiometer at about the middle of the scale and changing the voltage source *U0 from 1.5 V to 12 V* (6 points) . Plot the voltage ***Ur2*** the current ***I*** (CVC) and determine the schedule of resistance ***R2*** through the angle of the line to the horizontal axis of the current. Values of the parameters of the circuit elements:
U0 from 1.5 to 12 V; r 0 = 40 ohms; R1 = 100 ohms.

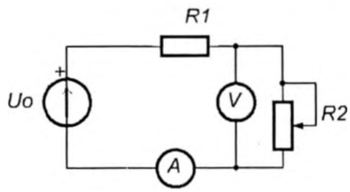


Fig.1.2

3) For the circuit in Figure 1.3 indicate branch currents, voltage, passive circuit elements, determine the number of nodes n, the number of branches m and the number of independent loops p. Build a model of the circuit in the "Start electronics" and measure all the specified voltages and currents.

Values of the parameters of the circuit elements:
all ***Ri* = *Nk ohms; Uo* = *5 V***; N - number of brigade

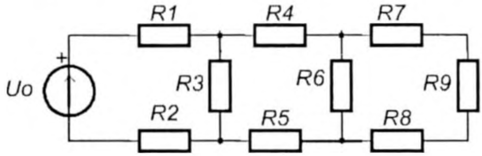


Fig.1.3

Theoretical information
The electrical circuit and its components

The electric circuit comprises a *source* of electric energy, the *receivers* of electric energy *measurement* devices, *connecting* lines and wires.

The electrical circuit is a collection of *sources, consumers* (or, respectively, the active and passive elements) and *converters* of electric energy.

A *source of electrical* energy is called an electrical circuit element that transforms a non-electric energy form into electricity. For example: electrochemical cells and batteries convert chemical energy, thermocouples - thermal, electromechanical generators - mechanical.

Consumer of electricity is called an element of an electrical circuit that converts electrical energy into non-electrical. For example: the bulb - in light and heat, heaters - in the heat, the electric motor - in mechanical.

Electrical energy converter is a device that changes the *size and shape* of the electrical energy. For example: transformers, inverters - convert direct current into alternating, rectifiers - AC to DC devices for frequency conversion.

In order to perform the calculation, you need every electrical device to introduce its *equivalent circuit*. The equivalent circuit of the circuit consists of a set of *idealized elements*, which reflect the individual properties of physically existing devices. Idealized resistor (resistance R) allows for conversion of electromagnetic energy into heat. Idealized capacitor (capacitance C) and the inductance (inductance L) characterized by an ability to accumulate energy, respectively, electric and magnetic fields.

Combinations of sources and consumers of connecting wires forming an electric circuit at each site which may operate an *electrical voltage* and *electrical current* flow. These voltages and currents may be constant or variable over time and dependent on the properties of circuit elements. This section will be considered constant currents and voltages.

Voltage ***U*** on the *circuit* elements is indicated in the diagram (see Fig. 1.4.) Signs "+" and "-", which can be interpreted only by the simultaneous consideration because the sign "+" indicates the point with a relatively high potential

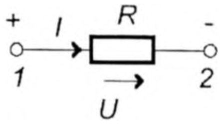


Fig.1.4

$$U_{12} = \varphi_1 - \varphi_2$$
$$[U] = V \qquad (1.1)$$

*Current **I*** in the circuit elements indicated by *an arrow* in the diagram (see Fig. 1.4.). And indicates the direction of the orderly movement of positive electric charges, if the current I expressed as a positive number.

$$I = \frac{q}{t} [I] = A \qquad (1.2)$$

The relationship between the current and voltage on the circuit element called a *current-voltage* characteristic (CVC) of the element, which is usually depicted graphically. Fig. 1.5. CVC displays different types of consumers.

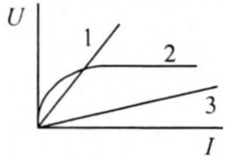


Fig.1.5

Straight CVC (1) and (3) correspond to *linear* elements and curved CVC (2) - *a non-linear* elements. We study in this manual only *linear* chains, for which the ratio or the deviation from a constant low. In this case, when the I-V characteristic represented by a line close to the line, believe that the consumer obeys ***Ohm's law***, according to which the voltage and current are proportional to each other.

This proportionality factor k is called the *electric resistance element R,* which is measured in ohms (ohms).

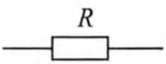


Fig.1.6

As a consumer in the theory of electrical circuits DC resistor acts characterized by resistance (R), for which Ohm's law is valid:

$$\frac{U}{I} = R \text{ or } U = I \cdot R, \; I = \frac{U}{R} \qquad (1.3)$$

The resistor on the circuit diagrams shown in Fig. 1.6.
Reciprocal of resistance is called *conductance* measured in *siemens* (D).
Ohm's law can be represented by conduction:

$$\frac{I}{U} = G \qquad U = \frac{I}{G} \qquad I = U \cdot G \qquad (1.4)$$

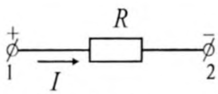


Fig.1.7

In the passive elements of the current *flowing* from the points with relatively high potential to the points having a relatively lower potential. Therefore, in Fig. 1.7. *arrow* directed from the current "+" to "-", which corresponds to Ohm's law in the form of:

$$U_{12} = \varphi_1 - \varphi_2 = I \cdot R \tag{1.5}$$

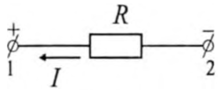


Fig.1.8

For the notation in Fig. 1.8., Ohm's law must be written in the following form:

$$U_{12} = -I \cdot R.$$

Energy sources are modeled by using a *voltage source* (E) and a *current source* (J). CVC sources of energy - it is the characteristics, usually with a pull-down character, because in most cases with increased current voltage source decreases.

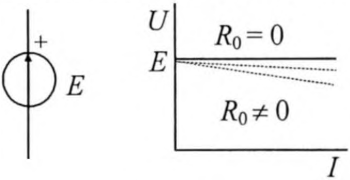


Fig.1.9

The idealized voltage source - a circuit element whose voltage does *not depend* on the current and a predetermined constant. It corresponds to Fig. 1.9. CVC *solid*. In fact, we are dealing with the real sources of tension. They differ from the ideal sources. Their voltage with *increasing* current consumption is *reduced*. CVC real voltage source is shown in Fig. 1.9. the *dotted* line. The *slope* of the line is equal to the internal resistance of the voltage source R0. Any real source of load resistance R >> R0 can be reduced to an idealized as follows (Figure 1.10.)

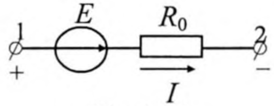


Fig.1.10

$$U_{12} = I \cdot R_0 - E$$
$$E_{реальн} = E - I \cdot R_0 \tag{1.6}$$

Properties of the real voltage source is determined by two parameters - the generated emf E and internal resistance R0.

Idealized current source - it is circuit element, the current is *independent* of voltage and a predetermined constant. It corresponds to the continuous current-voltage characteristics in Fig. 1.11.

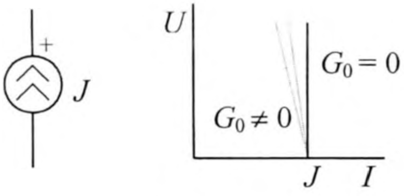


Fig.1.11

In the real source of current with *increasing* voltage generated current *decreases*. CVC real voltage source is shown in Fig. 1.11. the dotted line. The slope of the line is equal to the internal conduction current source G0. Any real current source can be reduced to an idealized as follows (see Fig. 1.12.)

$$J_p = J - U_{12} \cdot G_0, \tag{1.7}$$

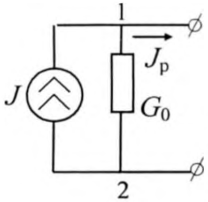


Fig.1.12

Properties of the current source is determined by two parameters: a given current J and internal conductance G0. Less than G0, the closer the actual characteristics of the current source to the idealized.

The structural and topological *properties* of the circuit are those of its *features* that are not related to the characteristics of its constituent active and passive elements. These include the following concepts: the *branch node path.*

Branch circuit portion is called, whose elements are connected in series to each other and are streamlined by the same current.

Node electrical circuit called a junction of several branches. Node connects at least three branches and a branch point.

The branches are connected *in series* are considered, if they are streamlined by the same current. The branches are considered connected in *parallel* when they are connected to the same pair of nodes. When connecting elements common parameter for them is the current in parallel - the voltage between nodes.

Contour of electrical circuit is a collection of successive branches. The sites in which these branches are connected, are branch points. While traversing closed contour start and end points coincide.

Chain in which there is no branching, called *single-loop*, in the presence of branches - *multi-loop*. Multiloop chain characterized by the number of independent loops. The set of independent loops is *determined* by the fact that each of the following *loops*, ranging from elementary, characterized by at least one new branch. The number of independent paths can be determined by Euler's formula:

$$p=n - m + 1, \tag{1.8}$$

where n - the number of branches,

m - number of nodes, $n > m$ always.

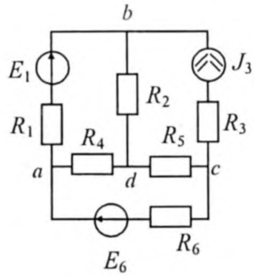


Fig.1.13

In the the circuit in Fig. 1.13. four nodes: a, b, c, d; six branches: ab, bd, bc, ad, dc, ac. Thus, the number of independent loops by Euler's formula is determined as follows:

$$p = 6 - 4 + 1 = 3.$$

This may include the following contours: abcd, dbc, adc or abd, dbca, adc and others.

Contents of the report

Report on laboratory work performed by each student on the basis of experimental data obtained in the performance of work and theoretical calculations and constructions. Report carried out on double pages from a notebook into a cell. Frontpage title. The title page contains the name of the university, the department name, phone number and the subject of the laboratory work, the name of the student and the teacher. In the report includes the following sections:

- The theme of the work;
- The purpose of the work;
- The content of the work.

Contents of the paper includes the name of the experience, the scheme of electric circuits, the data for the experiments, the results of measurements constructed characteristics, design parameters and conclusions for each experience;

- The conclusions of the work as a whole.

3.2 Laboratory work № 2
Equivalent transformations of resistive circuits

Objective: To conduct an experimental test of equivalent transformations of circuits at series - parallel connections and three-pole delta connection and a star.

The task for the work:

1) According to the scheme in Figure 2-1 to build a model of the circuit in the "Start electronics", to measure the input impedance of the circuit with respect to the poles of a) - b) – $\boldsymbol{R_{in}}$ and currents of all branches.

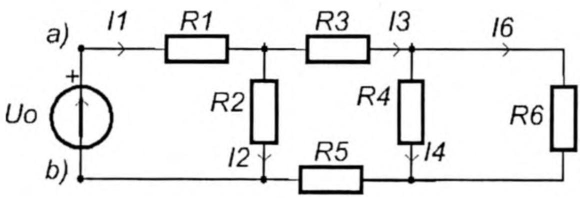


Fig.2.1

Calculate the equivalent resistance of the circuit with respect to the poles of a) - b) – R_{eq} and currents of all branches of the method of proportional values. Compare the results of measurements and calculations. Values of the parameters of the circuit elements all ***Ri = N kohms; Uo = 5 V;*** N - number of brigade **.**

2)According to the scheme in Figure 2.2 to construct a model circuit in the "Start electronics", to measure the input impedance of the circuit with respect to the poles of a) - d) R_{in} , branch currents ***I a, I b, I c*** and voltage ***U a, U b, U c*** with respect to a common point d).

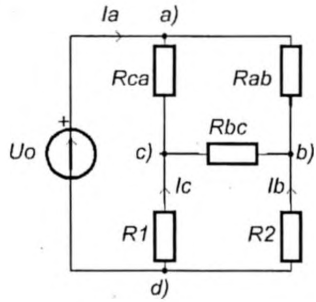


Fig.2.2

Values of the parameters of the circuit elements all ***R = N kohms; Uo = 5 V***; N - number of brigade.

Pay attention to the fact that the input impedance of the circuit can not find equivalent transformations consistently - parallel connections, as ***R ab, R bc, R ca***-pole circuit connected in a) - b) - c) delta.

1) For poles a) - b) - c) calculate the equivalent resistance of the star ***R a, R b, R c***. According to the scheme in Figure 2.3 to construct a model circuit in the "Start electronics", to measure the input impedance of the circuit with respect to the poles of a) - d) ***Rin*** , branch currents ***I a, I b, I c*** and voltage ***U a, U b, U c*** with respect to a common point d). Values of the parameters of the circuit elements: ***R1, R2 = N kohms;***

Uo = 5 V; N - number of brigade.

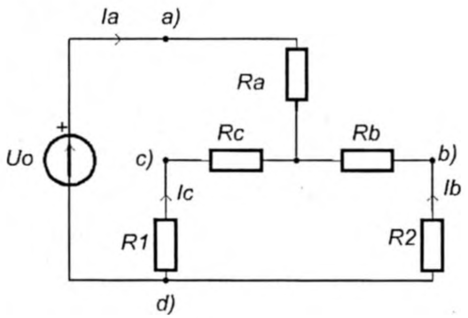


Fig.2.3

Compare measured at 2 and 3 of the voltages and currents, and to draw a conclusion about the equivalence of the chains and the possibility of calculating the circuit in Figure 2.3 equivalent transformations series - parallel connections.

Theoretical information

Equivalent transformation of the passive electrical circuit is to replace it with a different passive circuit at which remain constant currents and voltages rest of the circuit is not subjected to transformation. Among the simplest transformations include the replacement of series and parallel connected consumers equivalent to the consumer.

In series operation the the equivalent resistance is the sum of the resistances (figure 2.4).

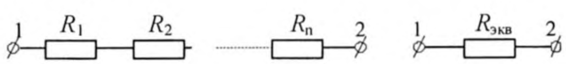


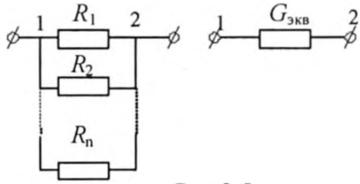
Рис. 2.4

$$R_{экв} = \sum_{i=1}^{n} R_i \quad или \quad \frac{1}{G_{экв}} = \sum_{i=1}^{n} \frac{1}{G_i}$$

When two series-connected consumers:

$$R_{экв} = R_1 + R_2 \quad или \quad \frac{1}{G_{экв}} = \frac{1}{G_1} + \frac{1}{G_2} \quad \Rightarrow \quad G_{экв} = \frac{G_1 \cdot G_2}{G_1 + G_2}.$$

When connected in parallel, the equivalent conductance is the sum of the conductivities of all consumers (see Fig. 2.5).



$$G_{экв} = \sum_{i=1}^{n} G_i \quad или \quad \frac{1}{R_{экв}} = \sum_{i=1}^{n} \frac{1}{R_i}.$$

Рис.2.5

When two parallel-connected consumers:

$$G_{экв} = G_1 + G_2 \quad или \quad \frac{1}{R_{экв}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R_{экв} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

Determination of the equivalent resistance in the mixed compound is made by consumers progressive simplification (folding) of the original circuit.

Example

1. parallel connection of R1 and R2:

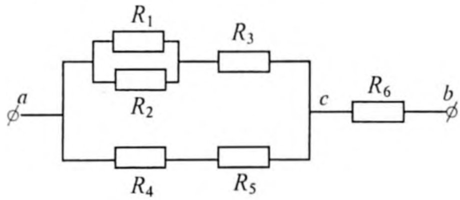


Fig.2.6

$$R_{12} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

2. Series R12 and R3:

$$R_{123} = R_{12} + R_3$$

3. Sequential compound R4 and R5

$$R_{45} = R_4 + R_5$$

4. Parallel connection of R123 and R45:

$$R_{ac} = \frac{R_{123} \cdot R_{45}}{R_{123} + R_{45}}$$

5. Series connection RAC and R6:

$$R_{ab} = R_{ac} + R_{6.}$$

equivalent resistance

$$R_{ab} = \frac{\left(\frac{R_1 \cdot R_2}{R_1 + R_2} + R_3\right) \cdot \left(R_4 + R_5\right)}{\frac{R_1 \cdot R_2}{R_1 + R_2} + R_4 + R_5} + R_6$$

More complex transformations are consumers connected star or delta. These reforms should be made in cases where the circuit can not be isolated in parallel or series connection of consumers

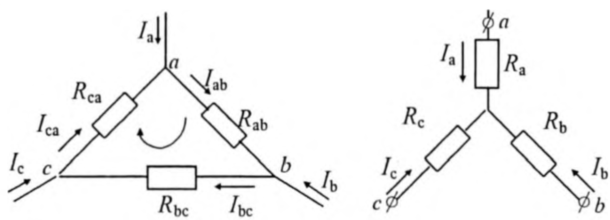


Fig.2.7

The nodes of a, b, c, and delta and a star in Fig. 2.7. connected to the rest of the circuit. Converting a triangle in a star must be such that the same values of the potential points of a triangle and stars flowing to those points, the currents are the same. Then all the external circuit "will not notice" produced replacement.

$$Rb = \frac{Rab \cdot Rbc}{Rab + Rbc + Rca} \quad Ra = \frac{Rab \cdot Rca}{Rab + Rbc + Rca}$$

$$Rc = \frac{Rbc \cdot Rca}{Rab + Rbc + Rca}$$

Resistance of the beam star equal to the product resistances adjacent sides of the triangle divided by the sum of the resistances of its three sides.

Inverse transformation formula can be derived independently

$$Gab = \frac{Ga \cdot Gb}{Ga + Gb + Gc}, Gbc = \frac{Gb \cdot Gc}{Ga + Gb + Gc}, Gca = \frac{Gc \cdot Ga}{Ga + Gb + Gc}$$

or through the resistance:

$$Rab = Ra + Rb + \frac{Ra \cdot Rb}{Rc}, Rbc = Rb + Rc + \frac{Rb \cdot Rc}{Ra}$$

$$Rca = Rc + Ra + \frac{Rc \cdot Ra}{Rb}$$

Resistance side of the triangle is equal to the sum of the resistances of adjacent points of the star and the fruit thereof, divided by the resistance of the third ray.

Method of proportional values

The essence of this method is as follows. In the branch farthest from the source (R6) are given a certain value of current or voltage. For convenience usually 1A or 1B. Then, moving to the beginning of the chain alternately define currents and voltages of all the branches up to the branch containing the source. So determine the voltage Vin and current Iin. Which must have a source to cause in all branches of the currents and voltages of the calculated values. If the emf (E) or Set the current (J) with these values do not match, you will need to change in proportion to the calculated values of currents and voltages branches by multiplying them by the ratio of $\frac{E}{U_{вх}}$ или $\frac{J}{J_{вх}}$.

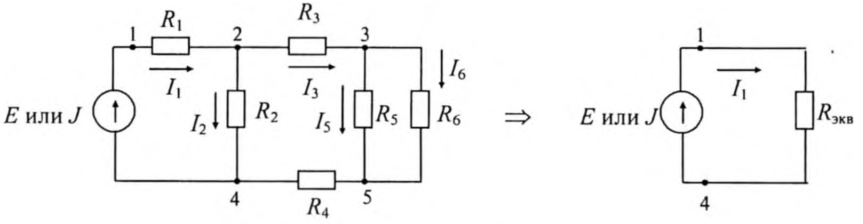


Fig. 2.8.

For the circuit in Fig. 2.1. let I6 = 1. Then

$$U_{35} = I_6 \cdot R_6 \quad I_5 = \frac{U_{35}}{R_5}.$$

I3 can be determined by Kirchhoff's law 1

$$I_3 = I_5 + I_6.$$

U24 determined according to Kirchhoff's law 2

$$U_{24} = I_3 \cdot (R_3 + R_4) + U_{35}.$$

According to Ohm's law:

$$I_2 = \frac{U_{24}}{R_2},$$

1 Kirchhoff's law:

$$I = I_2 + I_3.$$

$$U_{вх} = U_{24} + I_1 \cdot R_1.$$

Conversion factor is defined as follows:

$$k = \frac{E}{U_{вх}}.$$

All calculated values of current and voltage is necessary to multiply by a factor of k.

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- The theme of the work;
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- The conclusions of the work as a whole.

3.3 Laboratory work № 3

Method of superposition and the principle of reversibility of linear chains

Objective: To perform a pilot-tested method of superposition and the principle of reversibility of resistive circuit.

The task for the work:

1) Check the method of superposition.

According to the scheme in Figure 3.1 collect chain in the "Beginning of electronics." The parameters of the circuit elements***: Ua = 5V, Ub = 10 V, Ra = N kOhm, Rb = 2N Kohm, Rc = 3N Kohm,*** where N - number of brigades.

The circuit comprises two voltage source and can not be calculated using the equivalent transformations.

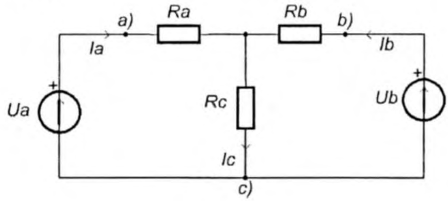


Fig.3.1

Measure the current value ***Ic*** of the actions of the two sources of ***Ua*** and ***Ub.*** In the scheme of Figure 3.2 assemble circuit and measure the current value of I_c^a Source ***Ua.***

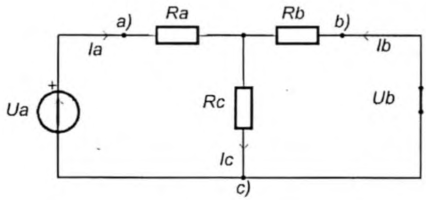


Рис.3.2

Calculate the value of current I_c^a and compare with the measurements.
In the scheme of Figure 3.3 assemble circuit and measure the current value of I_c^b Source ***Ub.***

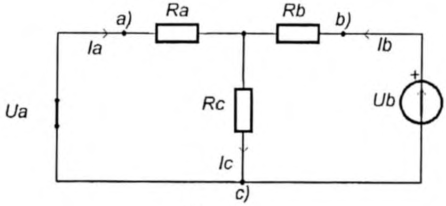


Fig.3.3

Calculate the value of current I_c^b and compare with the measurements

Verify the theorem overlay.

$$I_c = I_c^a + I_c^b$$

2) Verify the principle of reversibility.

According to the scheme in Figure 3.4 collect chain in the "Beginning of electronics." The parameters of the circuit elements: ***Uo = 5V, Ra = N kOhm, Rb = 2N Kohm, Rc = 3N Kohm***, where N - number of brigades.

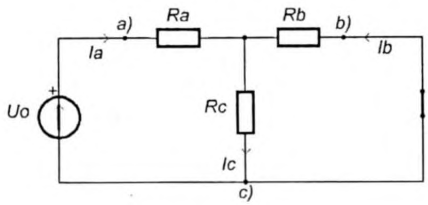


Fig.3.4

Measure the current value ***Ib***. Move the source voltage ***Uo*** in branch ***Rb***, shorting branch with seized voltage source. In the resulting circuit in Figure 3.5 to measure the current ***Ia.***

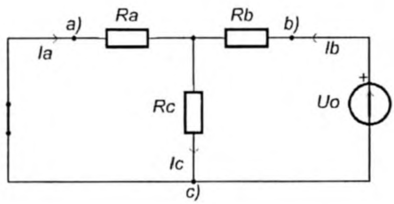


Fig.3.5

Compare the measured currents ***Ib*** and ***Ia***, express a conclusion on the principle of reversibility

Theoretical information:

Theorem overlay.

Method of superposition is as follows: the current or voltage of an arbitrary branch circuit DC is defined as the algebraic sum of the currents or voltages caused by each source individually.

Using this method, the problem of calculating the branched circuit with n sources is reduced to a joint decision n chains with a single source.

The algorithm for calculating the linear electric circuit by superposition:

1 Optionally set the direction of the currents in the branches of the circuit.

2 Initial circuit comprising n sources, convert to n subcircuits, each of which contains only one source. Other sources are eliminated as follows: voltage sources are short-circuited, the branches with current sources are dropped.

3 Determine the currents of each of the sub-schemes by any of the known methods. In most cases, the calculation is based on Ohm's law, using the method of equivalent transformations of passive networks.

4 The total current any branch of the original circuit is defined as the algebraic sum of the currents subsidiary subcircuits.

The principle of reversibility

If the source voltage branch lines a) causes a current Ib the branches b), after the transfer source in the in branch b) it causes in branch a) an equal by value current Ia.

Contents of the report

Report on laboratory work performed by each student on the basis of experimental data obtained in the performance of work and theoretical calculations and constructions. Report carried out on double pages from a notebook into a cell, the first sheet of the title. The title page contains the name of the university, the name of the department, the theme of the laboratory work, the name of the student and the teacher. In the report includes the following sections:

- The theme of the work;
- The purpose of the work;
- The content of the work.

Contents of the paper includes the name of the experience, the scheme of electric circuits, the values of the elements and the raw data for the experiments, the results of measurements constructed characteristics, calculation of the measured parameters on the models and conclusions for each experience;

- The conclusions of the work as a whole.

3.4 Laboratory work № 4

Amplitude and phase relations for circuit elements harmonic current

Objective: To analyze the amplitude - phase relations for the resistor, capacitor and inductor in steady sinusoidal mode.

The task for the work:

1. Resistor on alternating current.

Collect in the program *Electronics Workbench (EWB)* circuit diagram (Figure 4.1). Circuit parameters: ***Ug = 120, fg = 50 Hz, R = 110 Ohm, r = 0,1 Ohm.***

Double click with the left mouse button, expand the oscilloscope. Click on the Expand button, set extended screen. In the settings scan Time base, scale *5.00 ms / div*, mode *Y / T*. In the synchronization mode, set the *Auto*.

In the Channel A, which is connected to the voltage at the input of the circuit, set the *AC* and scale is *100 V / div*. In the Channel B, which is connected to the voltage of the resistor r = 0.1 ohms, set the *AC* and scale *200m V / div*.

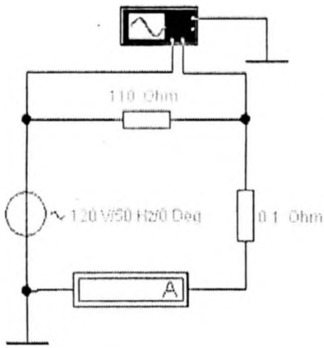


Fig.4.1

Set the ammeter to measure mode on alternating current .

Click on the button in the upper right corner of the program include a mode simulation of processes in the chain. Repeated click stop the process. Ammeter will show acting value of the current. The oscilloscope fix the instantaneous value of the voltage across the resistor *R* (*Channel A*) and the voltage across the resistor ***r***, which coincides in phase a current circuit (*Channel B*). If a sinusoids voltages are small in amplitude, expand their scale of adjustment *Channel A and Channel B.*

Move the *red T1* and *blue T2* pointfinders on the oscilloscope screen to maximum voltage sinusoidal signal in two neighboring oscillations. Oscilloscope mark amplitude voltage values *VA1, VB1* and harmonic signal period *T2 - T1*. Save the circuit diagram for the report to the clipboard by clicking on the ***Edit*** function is then ***Copy as Bitmap*** in the panel of the program and isolating the of the field with the scheme of the circuit ***in a frame***. Open the file of *Word*. Insert the saved from the buffer circuit. Save the analogous field of the oscilloscope.

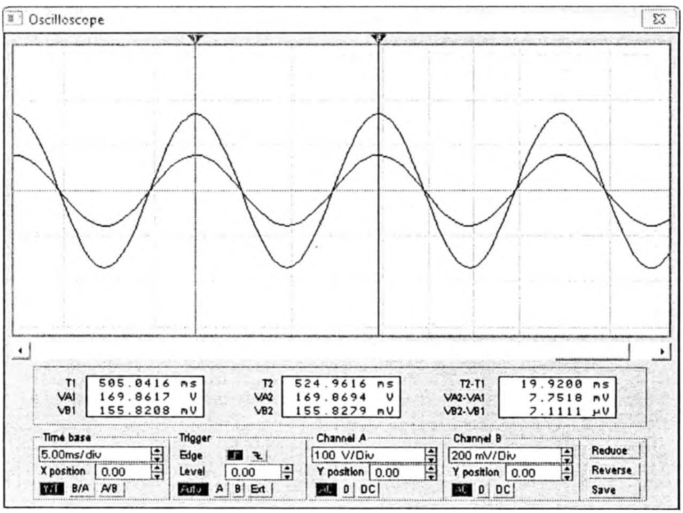


Fig.4.2

2. The capacitor on alternating current.

Collect in the program *Electronics Workbench (EWB)* circuit diagram on Figure 4.3, replacing the previous circuit resistor ***R*** to the capacitor ***C.***

Circuit parameters: ***Ug = 120, fg = 50 Hz, C = 50 μF, r = 0,1 Ohm.***

Run the simulation and chop it. Set the red pointfinder *T1* tu maximum sinusoids channel *A,* that is connected to the ***voltage at the input*** of the circuit. Put the blue pointfinder *T2* to the nearest right maximum channel *B,* which is connected to the ***voltage of the resistor r = 0.1 ohms, is in phase with the current*** chain. Save the circuit diagram and the panel of the oscilloscope for the report.

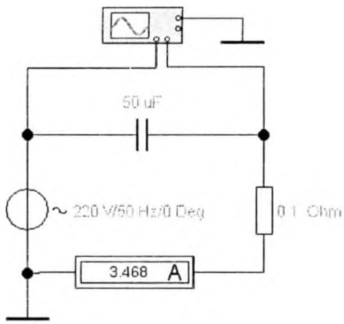


Fig.4.3

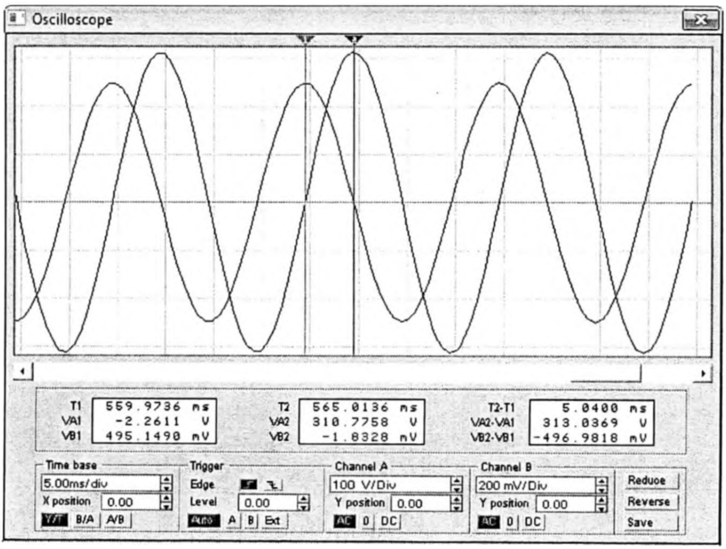


Fig.4.4

3. The inductance on alternating current.

Collect in the program Electronics Workbench (EWB) circuit diagram on Figure 4.5, replacing the previous scheme capacitor *C* on inductance ***L* = *50 mGn*** and set the oscillator frequency ***fg* = *50 Hz***.

Run the simulation and chop it. Set the red pointfinder *T1* tu maximum sinusoids channel *A*, that is connected to the ***voltage at the input*** of the circuit. Put the blue pointfinder *T2* to the nearest right maximum channel *B*, which is connected to the ***voltage of the resistor r = 0.1 ohms, is in phase with the current*** chain. Save the circuit diagram and the panel of the oscilloscope for the report.

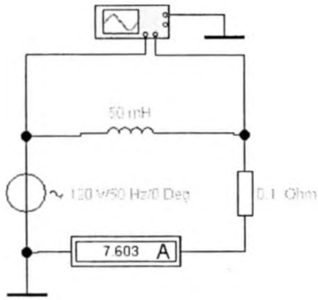


Fig.4.5

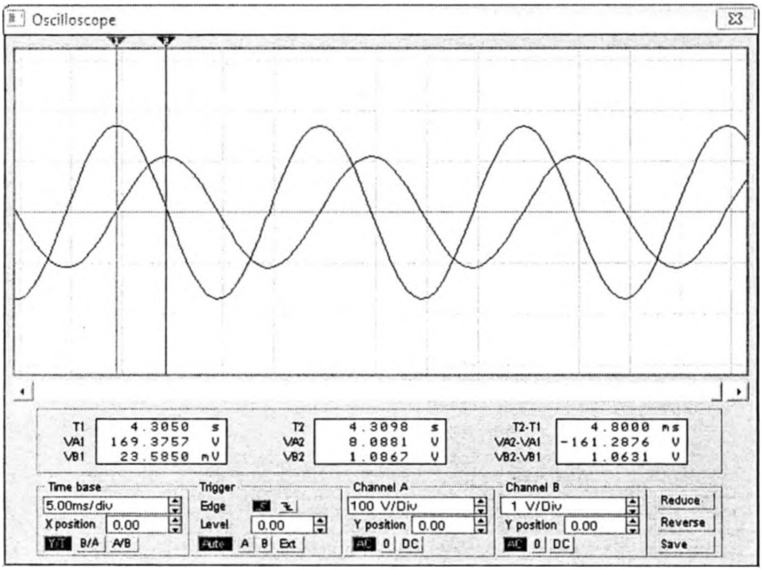


Fig.4.6

Theoretical information:

Alternating current i (t) and the voltage u (t) is called the currents and voltages that vary with time.

Signals instantaneous values which are repeated in a certain fixed period of time, called periodic, but this time interval T - period.

The reciprocal of the period is called the frequency:

$$f = \frac{1}{T} \quad [f] = c^{-1} = \text{Гц}.$$

Angular (circular) frequency:

$$\omega = \frac{2\pi}{T} = 2\pi f \qquad [\omega] = \text{рад/с}.$$

In the electric power industry have been widely applied sinusoidal signals.

$$u(t) = U_m \sin(\omega t + \psi_u), \quad i(t) = I_m \sin(\omega t + \psi_i),$$

где $u(t)$, $i(t)$ - the instantaneous value;

U_m, I_m – The amplitude of the AC signal - maximum modulo its value;

$\omega t + \psi_u$, $\omega t + \psi_i$ – phase harmonic signal - an argument with sinus at each time point;

ψ_u, ψ_i – the initial phase - the argument value at the initial time (t = 0). Phase measured in radians or degrees.

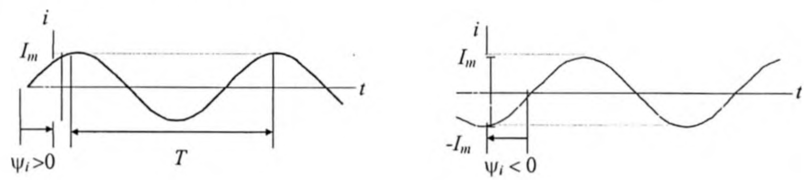


Fig.4.9

Periodic values of currents and voltages are usually characterized by the mean square for the period. These values are called the effective value (RMS - Root Mean Squared) current of voltage and current and is denoted ***I, U***:

Ammeter and voltmeter shows effective value (RMS - Root Mean Squared) the of currents and voltages.

$$I = \frac{I_m}{\sqrt{2}}. \qquad U = \frac{U_m}{\sqrt{2}}.$$

In the analysis of circuits with sinusoidal current use complex rms values, abbreviated as they are called complex values, and the corresponding vectors in the complex plane - vectors of complex values. The connection between the complex amplitude and the complex rms values is set according to the formula:

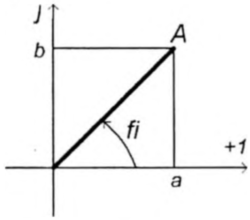
$$\dot{I} = Ie^{j\psi_i} = \frac{I_m}{\sqrt{2}} e^{j\psi_i}; \quad \dot{I}_m = \sqrt{2}\dot{I}.$$

An example of a symbolic representation of a function of time

$i = 10\sin\left(\omega t + \frac{\pi}{3}\right)$. $\qquad \dot{I}_m = 10e^{j\frac{\pi}{3}}$ - complex amplitude;

$\dot{I} = \frac{10}{\sqrt{2}}e^{j\frac{\pi}{3}}$ – complex rms value or complex.

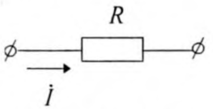
Vector set of complex values of sinusoidal quantities of one frequency shown in the complex plane is called a phasor diagram. Using the vector diagram, the addition and subtraction of complex values can be replaced by addition and subtraction of the corresponding vectors.



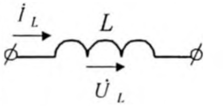
$$\dot{A} = A\angle\varphi = Ae^{j\varphi} = A\cos\varphi + jA\sin\varphi = a + jb,$$

где $a = \mathrm{Re}(\dot{A}) = A\cos\varphi$ и $b = \mathrm{Im}(\dot{A}) = A\sin\varphi$ $\; A = \sqrt{a^2 + b^2}$; $\; \varphi(fi) = \mathrm{arctg}\frac{b}{a}$.

Consider Ohm's law in the symbolic form of circuit elements for harmonic current



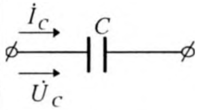
if $u(t) \to \dot{U}$, then $\dot{U} = \dot{I}R$. This is Ohm's law in symbolic form.



$u_L = Li'_L \to$

$\dot{U}_L = j\omega L\dot{I}_L = jX_L\dot{I}_L$.

Ohm's law $\frac{\dot{U}}{\dot{I}} = jX_L$.

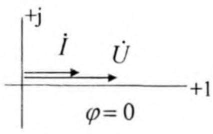


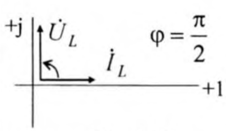
$u_C = \frac{1}{C}\int_{-\infty}^{t} i_C dt \to$

$\dot{U}_C = \frac{1}{j\omega C}\dot{I}_C = -j\frac{1}{\omega C}\dot{I}_C =$

$= -jX_C\dot{I}_C$.

Ohm's law $\frac{\dot{U}}{\dot{I}} = -jX_C$.





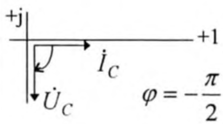


Fig.4.10

Fig. 4.10 shows vector diagrams of voltages and currents for resistance, inductance and capacitance

Contents of the report:

a) The objective of the work;
b) the results of the simulation circuit with a resistor R (circuit diagram, oscillograms of the voltage, rms current in the circuit, the amplitude and the RMS value of the voltage of the generator, the phase voltage and current in the circuit);
- a vector diagram of voltage and current in the circuit;
- Conclusions on the ratio of amplitudes and phases in a circuit with a resistor;

c) The results of the simulation circuit with the capacitor C (circuit diagram, oscillograms voltage, RMS current in the circuit when the generator frequency *fg = 50 Hz*, amplitude voltage and acting values of the generator, the phase voltage and current in the circuit);
- - a vector diagram of voltage and current in the circuit;
- Conclusions on the ratio of amplitudes and phases in a circuit with the capacitor;

d) The results of the simulation circuit with the inductance ***L*** (circuit diagram, oscillograms voltage, RMS current in the circuit when the generator frequency *fg = 50 Hz*, amplitude voltage and acting values of the generator, the phase voltage and current in the circuit);
- a vector diagram of voltage and current in the circuit;
- Conclusions on the ratio of amplitudes and phases in a circuit with the inductance.

3.5 Laboratory work № 5

Amplitude and phase relations for a series RLC circuit

Objective: To analyze the amplitude - phase relations for the series RLC circuit in steady sinusoidal mode.

The task for the work:

Collect in the program Electronics Workbench (EWB) circuit diagram (Figure 5.1).

Circuit parameters: ***Ug = 120 V, fg = 20 Hz, R = 110 ohms, C = 25 µF, L = 2.5 mGn.***

Run the simulation and chop it. Set the red pointfinder *T1* tu maximum sinusoids channel *A*, that is connected to the ***voltage at the input*** of the circuit. Put the blue pointfinder *T2* to the nearest right maximum channel *B*, which is connected to the ***voltage of the resistor r = 110 ohms, is in phase with the current*** chain. Save the circuit diagram and the panel of the oscilloscope for the report.

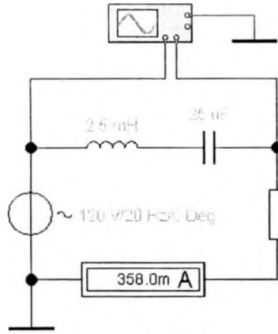


Fig.5.1

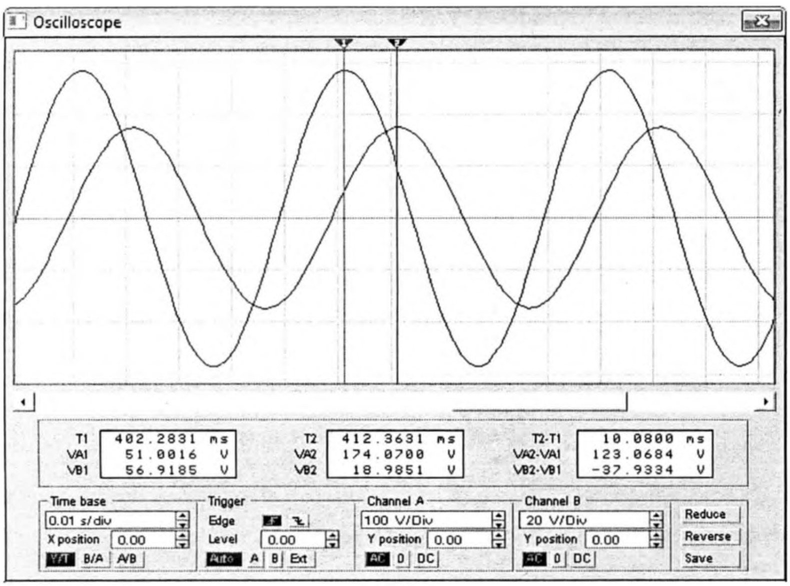


Fig.5.2

Set the oscillator frequency fg = 2000 Hz.

Run the simulation and chop it. Set the red pointfinder *T1* tu maximum sinusoids channel *A*, that is connected to the ***voltage at the input*** of the circuit. Put the blue pointfinder *T2* to the nearest right maximum channel *B*, which is connected to the ***voltage of the resistor r = 110 ohms, is in phase with the current*** chain. Save the circuit diagram and the panel of the oscilloscope for the report.

Theoretical information:
Series connection of R, L, C

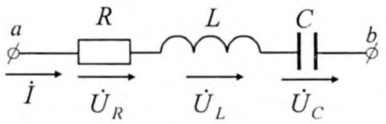


Fig.5.3

2 Kirchhoff's law :

$u_{ab}(t) = u_R + u_L + u_C$.

$u_R \to \dot{U}_R = \dot{I}R; \quad u_L \to \dot{U}_L = \dot{I}\,jX_L;$

$u_C \to \dot{U}_C = -j\dot{I}X_C$.

$$\dot{U}_{ab} = \dot{U}_R + \dot{U}_L + \dot{U}_C = \dot{I}(R + jX_L - jX_C) = \dot{I}(R + j(X_L - X_C)) = \dot{I}\underline{Z},$$

Where $\underline{Z}$ be a complex circuit resistance.

Based on Euler's theorem

$$\dot{U}_{ab} = \dot{I}Ze^{j\varphi} = \dot{I}\sqrt{R^2 + (X_L - X_C)^2}\,e^{j\,\mathrm{arctg}\frac{X_L - X_C}{R}}.$$

Impedance equal to the modulus of complex impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$, argument of complex impedance is the phase difference of voltage and current $\varphi = \psi_u - \psi_i = \mathrm{arctg}\dfrac{X_L - X_C}{R}$.

The complex impedance may be represented as

$$\underline{Z} = Ze^{j\varphi} = Z\cos\varphi + jZ\sin\varphi = R + jX,$$

R - the real part of the impedance is called the active resistance $R = Z\cos\varphi$;

X - the imaginary part of the complex impedance is called reactance, $X = Z\sin\varphi = X_L - X_C$.

Ohm's law in a general form $\dot{I} = \dfrac{\dot{U}}{\underline{Z}}$, where $\underline{Z}$ may be the following: for resistance $\underline{Z} = R$, for inductance $\underline{Z} = jX_L = X_L e^{j90^\circ}$, for capacity $\underline{Z} = -jX_C = X_C e^{-j90^\circ}$.

For the circuit construct a vector diagram of currents and voltages. As for all the common element is the current, the current vector chosen as the initial vector, sending it to the real axis (see Fig. 5.4).

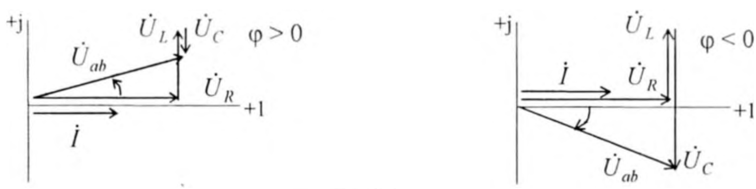


Fig.5.4

There are three modes of operation of this circuit:

$X_L > X_C$ - Inductive mode $\varphi > 0$;

$X_L = X_C$ - the resonance voltages $\varphi = 0$

$X_L < X_C$ - Capacitive mode $\varphi < 0$.

Angle φ (the difference between the initial phases of the voltage and current) is determined by the angle of rotation of the current vector to the vector voltage: if the rotation is determined by the counter-clockwise direction, the $\varphi > 0$ (lagging current), or - $\varphi < 0$ (leading current). Nature of the chain determines a greater reactance.

Contents of the report:

Report on laboratory work should contain

a) The purpose of the work;

b) simulation results RLC circuit (circuit diagram, waveform voltages, the rms value of the current in the circuit at the frequency of generator fg = 20 Hz and at a frequency of fg = 2,000 Hz, peak voltage and current of the generator, the phase difference of voltage and current in the circuit when the generator frequency fg = 20 Hz fg = 2000 Hz);

- Calculation acting and the amplitude values of the current, active, reactive, complex impedance of the circuit and the phase difference between two values of the frequency;
- The vector diagrams of voltages and currents in the circuit;
- Conclusions about the relationship of the amplitudes and phases in an RLC circuit in dependence on the frequency;

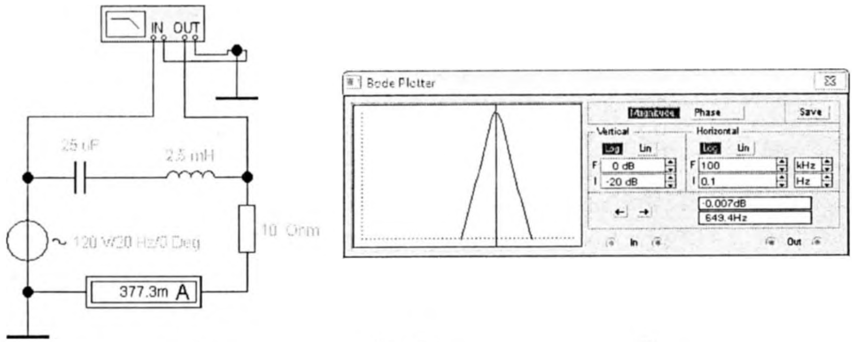
3.6 Laboratory work № 6
Voltage resonance in a series RLC circuit

Objective: To study the parameters of a series RLC circuit at resonance mode voltages and construction of amplitude - frequency characteristics (AFC) of the oscillating circuit.

The task for the work:

1. Construction of the AFC circuit and the resonance frequency.

Collect in the program Electronics Workbench (EWB) circuit diagram (Figure 5.1).
Circuit parameters: ***Ug = 120, fg = 20 Hz, R = 10 ohms, C = 25 μF, L = 2.5 mGn.***



a) Fig.6.1 б)

Double-clicking the left mouse button, expand the Bode Plotter, intended mode *Magnitude* for plotting the relationship voltage ***Ur***, displaying the current circuit ***I***, at the entrance to the voltage ***Ug*** Out on the input ***In***.

Graph describes the AFC circuit. Set on the plotter parameters vertical axis: *Log* to plot on a logarithmic scale, *I = - 20 dB, F = 0 dB;*
horizontal axis:
Log logarithmic scale frequency axis, *I = 0,1 Hz, F = 100 kHz.*

Clicking on the button in the upper right corner of the window, activate simulation of processes in the chain. Clicking again, stop the process, and the ammeter shows value of the current plotter lock loop frequency response.

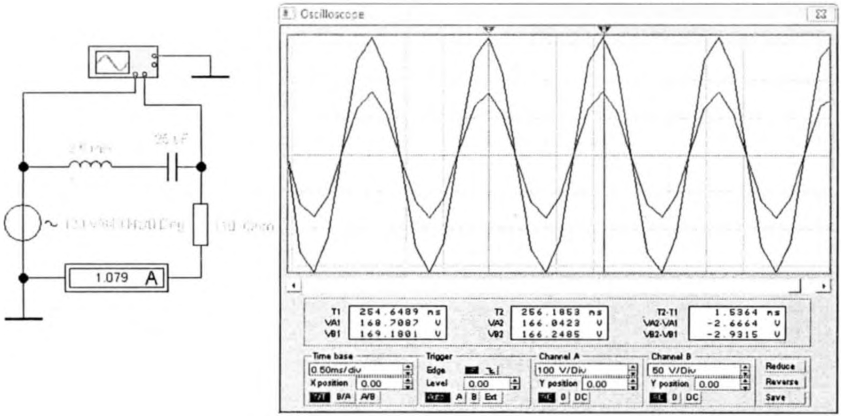
Placing viewfinder on the plotter to the maximum response determine the resonant frequency ***f res***, the mapped coordinate the frequency axis in the lower window of the plotter.

Save the field program for EWB report in *Word* file by clicking on the *Edit* function and then *Copy as Bitmap* in the program panel and the release of the field is similar to Figure 5.1.

Change the value of the resistor at ***R = 110 ohms***. Turn and stop the simulation. Set the cursor to the maximum frequency and field programs to save the report

2. Study of amplitude - phase relationships of the oscillatory circuit.

Collect in the program *Electronics Workbench (EWB)* circuit diagram (Figure 5.2). Circuit parameters: ***Ug = 120, fg = f res, R = 110 ohms, C = 25 µF, L = 2.5 mGn.***



a) Fig.6.2 b)

Start and stop the simulation and save the report to a field similar EWB to Figure 5.2.

Theoretical information:

The voltage resonance is observed in the sequential circuits. Consider the voltage resonance mode to sequentially RLC-circuit.

For the circuit in Fig. 6.3 true

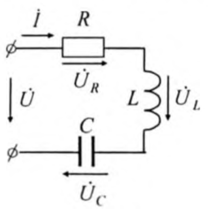


Fig. 6.3

$$\dot{U} = R\dot{I} + j(X_L - X_C)\dot{I} = \dot{U}_R + \dot{U}_L + \dot{U}_C.$$

Change the frequency of the generator or inductance or capacitance parameters so that

$$X = X_L - X_c = 0.$$

Then $\dot{U}_L + \dot{U}_C = jX_L\dot{I} - jX_C\dot{I} = 0,$

input voltage $\dot{U} = R\dot{I} = \dot{U}_R.$

The current and the voltage at the input are in phase. In the circuit - mode resonance:

$$\varphi = \mathrm{arctg}\frac{X}{R} = 0.$$

The frequency at which resonance is observed may be determined from the relationship

$$\omega_0 L = \frac{1}{\omega_0 C} \Rightarrow \omega_0 = \frac{1}{\sqrt{LC}}. \qquad f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \text{Hz}$$

The current in the resonance circuit mode $I_0 = \dfrac{U}{\sqrt{R^2 + (X_L - X_C)^2}} = \dfrac{U}{R}$,

Full power circuit $S = I_0^2 Z = I_0^2 R = P$,

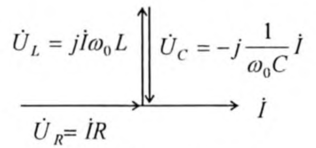


Fig. 6.4

Fig. 6.4 shows a vector diagram that corresponds to the resonance.

At each time point $U_L - U_C = 0$.

Given that $\omega_0 = \dfrac{1}{\sqrt{LC}}$,

$$\omega_0 L = \frac{1}{\omega_0 C} = \frac{1}{\sqrt{LC}} L =$$

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

where $\boldsymbol{\rho}$ - characteristic or resonant circuit impedance, measured in ohms.

The ratio of the voltage across the reactive elements (U_L and U_C) to the voltage at the input mode is called resonance Q of the circuit:

$$Q = \frac{U_L}{U} = \frac{U_C}{U} = \frac{\omega_0 L I_0}{R I_0} = \frac{I_0}{\omega_0 C I_0 R} = \frac{\rho}{R}.$$

The larger $\rho = \sqrt{\dfrac{L}{C}}$ and smaller than the resistance in the circuit, the higher voltage on the reactive elements as compared with the voltage on the input circuit.

Contents of the report:

Report on the implementation of laboratory work must contain

a) The purpose of the work;

b) the results of the construction of the AFC circuit and the resonance frequency of the oscillatory circuit simulation by a plotter (circuit diagram, AFC on the plotter chain with small losses at R = 10 ohms,
the resonant frequency f res of the experiment, the frequency response on the plotter chain with heavy losses at R = 110 ohms);
- Calculation of the resonance frequency f_o on the circuit parameters L and C;
- Conclusions about the nature of the response and selectivity for different circuit R;

c) calculation of the characteristic (wave) resistance ρ and Q of the circuit Q and conclusions about the relationship with the characteristics of the circuit parameters of the contour.

3.7 Laboratory work №7

Study three-phase circuit "star - a star"

Objective: To study the effect of the load conditions of the phases and the neutral conductor on the parameters of three-phase circuits with the phases of the generator and the load on the scheme "star - a star."

The task for the work:

1. ***To investigate the effect of the load on the parameters of the three-phase circuit with the phases of the generator and the load on the scheme "star - a star" without neutral conductor.***

Gather in the program Electronics Workbench (EWB) circuit diagram in Figure 7.1.

Options Chains - Generator Phase A - **220 V, 50 Hz, 240 °**
- Generator phase B - **220V, 50 Hz, 120 °**
- Generator phase C - **220V, 50 Hz, 0 °**
- Load resistance in a symmetric mode

Ra = Rb = Rc = N * 1k, N - number of brigades.

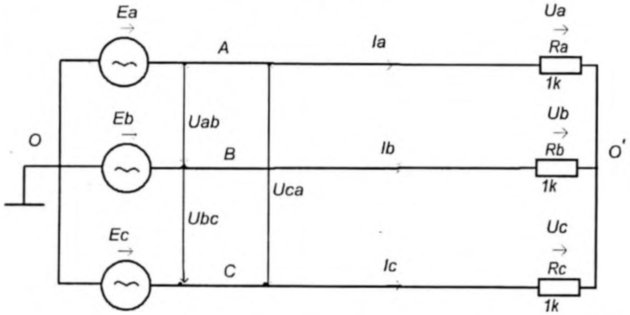


Figure 7.1. Scheme of the 3-phase circuit "star - a star" without neutral conductor

Connect the oscilloscope in accordance with Figure 7.2. Including modeling and fix the waveform is similar to Figure 7.3.

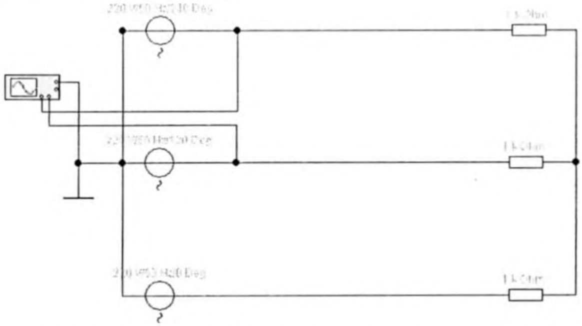


Figure 7.2. Preparation of the waveform voltage phases A and B of the generator

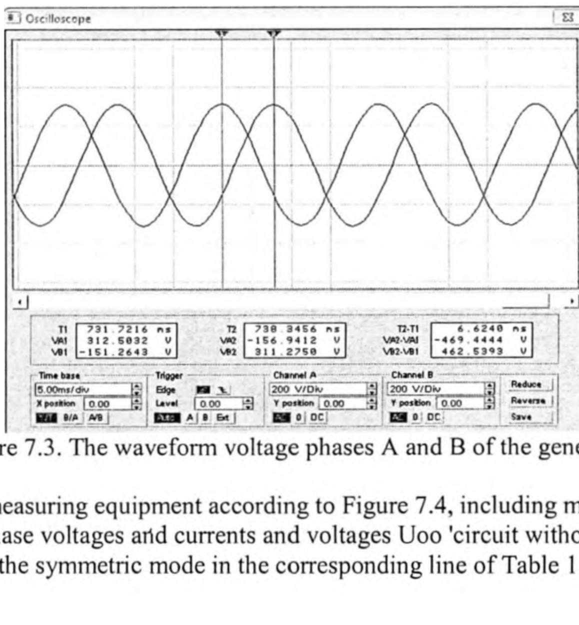


Figure 7.3. The waveform voltage phases A and B of the generator

Connect the measuring equipment according to Figure 7.4, including modeling and fix line and phase voltages and currents and voltages Uoo 'circuit without neutral conductor for the symmetric mode in the corresponding line of Table 1.

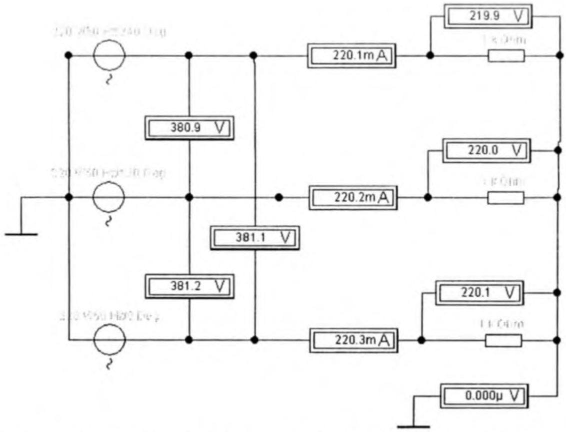


Figure 7.4. Measurement of line and phase voltages and currents and voltages Uoo ' circuit without neutral conductor for the symmetric mode

Table 1. "The Star - Star" without neutral conductor

mode	U_{ab} B	U_{bc} B	U_{ca} B	U_a B	U_b B	U_c B	$U_{OO'}$ B	I_a A	I_b A	I_c A
Symmetrical mode										
Unbalanced mode										
Reactive load phase										
Phase failure										

To establish *an asymmetric mode*, change the *resistance* of the load phase, a certain number of teams, increasing it ***by 2 times***. For teams 1 and 4 - in phase A; for two crews, 5 - in phase B; 3. crews for 6 - in phase C.
Including modeling and lock the readings in Table 1.

In order to establish a regime of *reactive load* replace unbalanced resistor capacitor with capacitance ***C = N * 1 uF***. Including modeling and lock the readings in Table 1. Phase failure mode is set in phase with a condenser, including simulation, parameters are recorded in Table 1.

2. To investigate the effect of the load and neutral wires on the parameters of the three-phase circuit with the phases of the generator and the load on the scheme "star - a star" with neutral conductor.

Gather in the program Electronics Workbench (EWB) to the circuit diagram neutral conductor in Figure 7.5.

Parameters are similar to elements of the circuit without a neutral wire in claim 1 job.

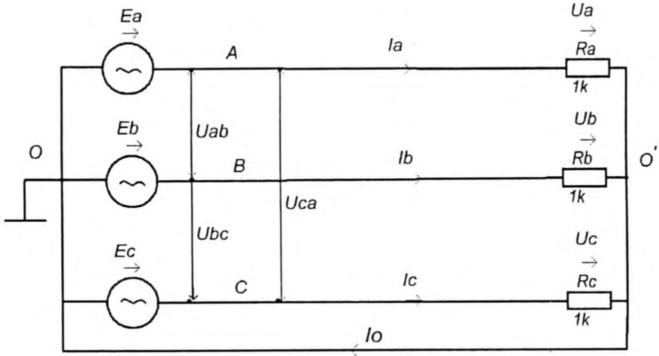


Figure 7. 5. Scheme 3-phase circuit "star - a star" with neutral conductor

Connect the measuring equipment according to Figure 7.6, including modeling, lock the line and phase voltages and currents and the current Io in the chain c neutral wire for the symmetric mode in the corresponding line of Table 2.

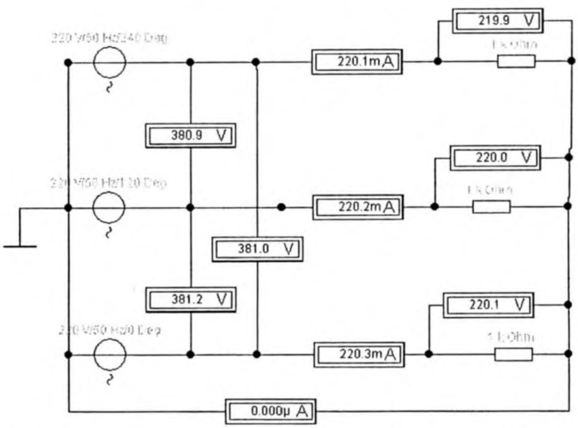


Figure 7. 6. Measurement of line and phase voltages and currents and the neutral wire for the symmetric mode

Table 2. "The Star - a star" with neutral conductor

mode	U_{ab} B	U_{bc} B	U_{ca} B	U_a B	U_b B	U_c B	I_O A	I_a A	I_b A	I_c A
Symmetrical mode										
Unbalanced mode										
Reactive load phase										
Phase failure										

Unbalanced modes, reactive loads and phase failure are established and fixed similarly claim 1 job.

Theoretical information:

Under the three-phase circuit (system) to understand the totality of the three-phase source (generator), load and connecting wires.

Upon rotation of the conductor in a uniform magnetic field therein induced emf

$$e = E_m \sin(\omega t + \alpha).$$

Secure the hard one axle three identical coil (winding) are offset relative to each other in space by (120Deg) and they begin to rotate in a uniform magnetic field at an angular velocity ω (Fig. 7.7).

In this case, the coil A will be induced

$$e_A = E_m \sin(\omega t).$$

Same EMF arise in the coils B and C, respectively, but through 120Deg 240Deg and after the start of the rotation, i.e.

$$e_B = E_m \sin(\omega t - 120^\circ);$$

$$e_C = E_m \sin(\omega t - 240^\circ).$$

The set of two coils, rotating on the same axis with an angular velocity ω, in which the induced electromotive force, equal in magnitude and shifted from each other by an angle 120Deg, referred to as symmetric three-phase generator

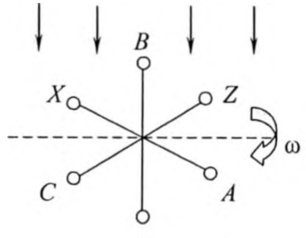


Fig. 7.7

Each coil of the generator - a phase generator. The generator in Fig. 7.7 Phase B «follows» for Phase A, Phase C - for phase B.

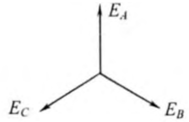


Fig. 7.8

We proceed from the instantaneous values of EMF to their complexes:

$$e_A = E_m \sin(\omega t) \ \rightarrow \ \dot{E}_A,$$

$$e_B = E_m \sin(\omega t - 120^\circ) \ \rightarrow \dot{E}_B = \dot{E}_A e^{-j120^\circ},$$

$$e_C = E_m \sin(\omega t - 240^\circ) \ \rightarrow \dot{E}_C = \dot{E}_A e^{-j240^\circ},$$

Sum Instant EMF corresponds to the sum of these complexes EMF.

$$e_A + e_B + e_C \rightarrow \dot{E}_A + \dot{E}_B + \dot{E}_C = \dot{E}_A = 0.$$

Schedule changes in the instantaneous values of EMF at ψ = 90Deg is shown in Fig. 7.9. In every moment of the algebraic sum of the EMF is zero.

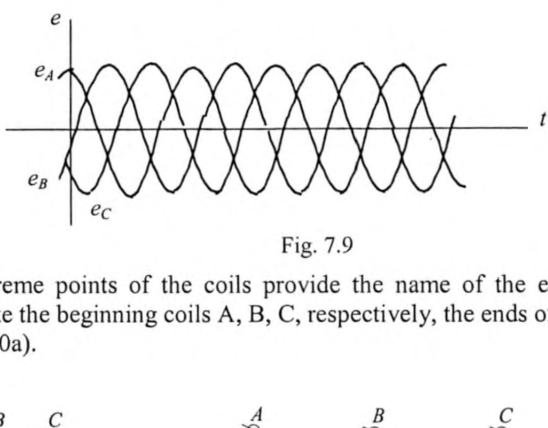


Fig. 7.9

The extreme points of the coils provide the name of the end and the beginning. Designate the beginning coils A, B, C, respectively, the ends of the X, Y, Z (Fig. 7.10a).

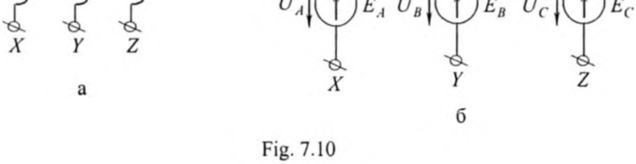


Fig. 7.10

Phase winding three-phase generator can be represented as a source of EMF $\dot{E}_A, \dot{E}_B, \dot{E}_C$ (Fig. 7.10 b).

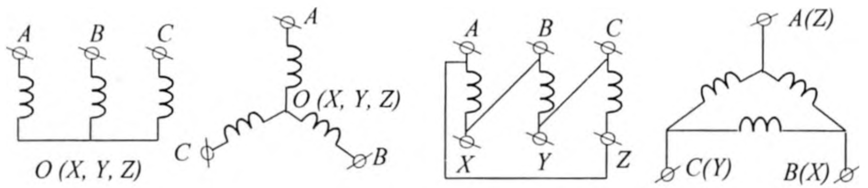


Fig.7.11

Connections in star and triangle, phase and line quantities

In three-phase circuits use two types of connections generator windings - a star, and a triangle (Fig. 7.11).

When connected in a star ends of the phase windings is connected to one node, called a neutral or zero point, and represent, as a rule, by the letter O. When connected to a triangle generator windings are connected so that the top of one another connected to the ends. EMF in the coils in this case are respectively. If the generator is not connected to the load, then it is not windings currents flow because the amount of EMF zero.

The star and triangle are included and load resistance as shown in Fig. 7.12.

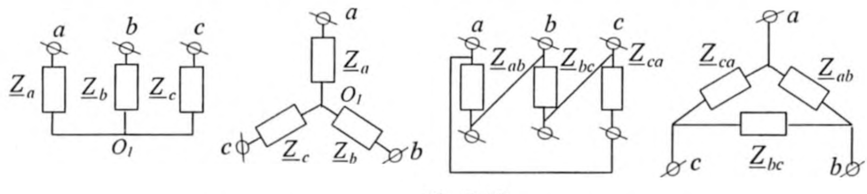


Fig.7.12

Phase resistance $\underline{Z}_a, \underline{Z}_b, \underline{Z}_c, \underline{Z}_{ab}, \underline{Z}_{bc}, \underline{Z}_{ca}$, connected in a triangle or a star, called phases of the load.

The connecting wires between the beginning of the load phase and the beginning of the phase generator called the line conductors. The wire connecting the zero point of the generator and the load is called zero or neutral conductor.

The direction of the currents in the line conductors taken to choose from the generator to the load, and in a zero - the load to the generator.

Figure 7.1:

$\dot{U}_{ab}, \dot{U}_{bc}, \dot{U}_{ca}, \dot{I}a, \dot{I}b, \dot{I}c$ – line voltages and currents.

$\dot{U}a, \dot{U}b, \dot{U}c$ – phase voltages.

Linear voltage (the voltage between the line conductors) - is the difference between the respective phase voltages

$$\dot{U}_{ab} = \dot{U}_a - \dot{U}_b, \quad \dot{U}_{bc} = \dot{U}_b - \dot{U}_c, \quad \dot{U}_{ca} = \dot{U}_c - \dot{U}_a.$$

Thus, the phase voltage at the generator - is the voltage applied to the windings of the generator

$\dot{U}_{AO}, \dot{U}_{BO}, \dot{U}_{CO},$ voltage phase load - it is the voltage across the respective resistances $\dot{U}_{aO_1}, \dot{U}_{bO_1}, \dot{U}_{cO_1}$. Phase currents - the currents flowing in the phases of the generator and the load.

Expression of the phase voltages of a three-phase star - a star without neutral conductor through the line voltage

In the circuit of Figure 7.1 is generally

$\underline{Z}_a \neq \underline{Z}_b \neq \underline{Z}_c$. Currents in the phases defined by the relations

$$\dot{I}_a = \underline{Y}_a \dot{U}_a; \quad \dot{I}_b = \underline{Y}_b \dot{U}_b; \quad \dot{I}_c = \underline{Y}_c \dot{U}_c.$$

According to the first law of Kirchhoff

$$\dot{I}_a + \dot{I}_b + \dot{I}_c = \underline{Y}_a \dot{U}_a + \underline{Y}_b \dot{U}_b + \underline{Y}_c \dot{U}_c = 0.$$

$$\dot{U}_a = \frac{\underline{Y}_b \dot{U}_{ab} - \underline{Y}_c \dot{U}_{ca}}{\underline{Y}_a + \underline{Y}_b + \underline{Y}_c} \qquad \dot{U}_b = \frac{\underline{Y}_c \dot{U}_{bc} - \underline{Y}_a \dot{U}_{ab}}{\underline{Y}_a + \underline{Y}_b + \underline{Y}_c}, \quad \dot{U}_c = \frac{\underline{Y}_a U_{ca} - \underline{Y}_b \dot{U}_{bc}}{\underline{Y}_a + \underline{Y}_b + \underline{Y}_c}$$

Contents of the report:

The report on the implementation of laboratory work should contain

a) the purpose of the work;

b) target and studies circuit without neutral conductor, comprising:

- Circuit diagram in four modes and waveform generator voltage;
- A table of measurement results of voltages and currents in different modes;
- Calculation of the phase voltages using a program for calculating with complex variables;
- Conclusions on the effect of the load conditions on the phase voltages with numerical justification

c) the objectives and results of the research chain with neutral conductor, including:

- circuit diagram in four modes;

- Table of measurements of voltages and currents in different modes,
- Conclusions on the effect of the load conditions on the phase voltages with numerical justification;
- Conclusions on the role of neutral conductor in three-phase circuits.

3.8 Laboratory work №8
Study the four-pole.

Objective: To determine A - four-pole parameters on the basis of experiences of idling and short-circuit the input of fixed frequency and calculate the resistance of T - and U - the equivalent four-pole circuits.

The task for the work:

1. ***The definition of the parameters of the signal at the input and output of emergency in the experience of idling***

Circuit number is selected by the team. To measure the phase difference between voltage and current to enable the input and output four-pole resistors R = 1 ohm, assuming their test circuit elements four-pole.

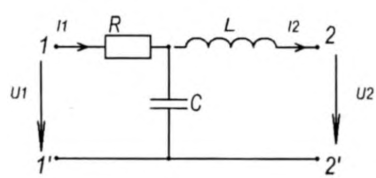


Fig.8.1

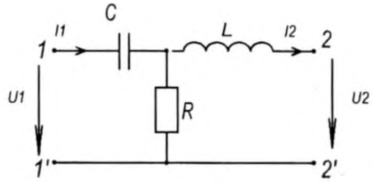


Fig.8.2

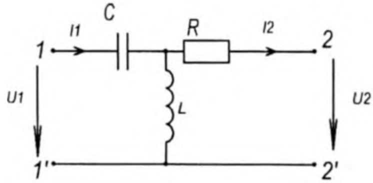


Fig.8.3

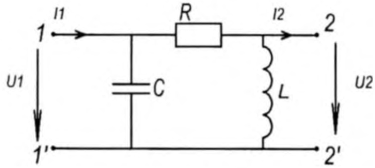


Fig.8.4

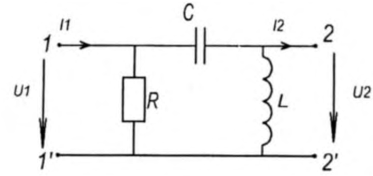


Fig.8.5

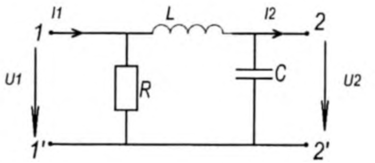


Fig.8.6

Collect program EWB circuit diagram for your version of Figure 1 - 6 analogous to Figure 8.7. Circuit parameters: ***E = 50V, F = 100 Hz, R = 100 ohms, C = 10 μF, L = 100 mGn.*** Set the AC for the ammeter and voltmeter.

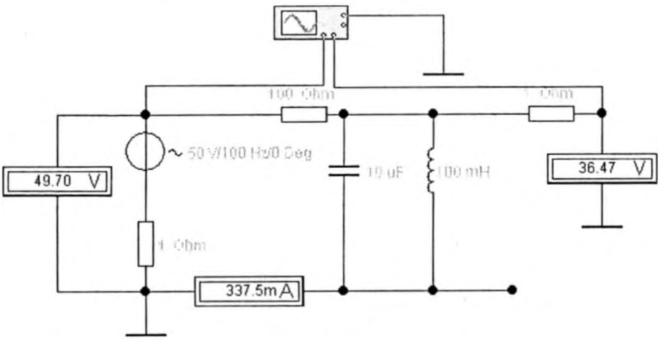


Figure 8.7. The circuit for the experience of idling with measurement ϕ11

Open the panel of the oscilloscope and set the oscilloscope Figure 8.8, run the simulation. Choose sweep out time (Time base) so that the screen housed within longer period of sinusoid signals. Set the cursor 1 at the beginning of the sinusoid channel A sight 2 at the beginning of the sinusoid channel B.

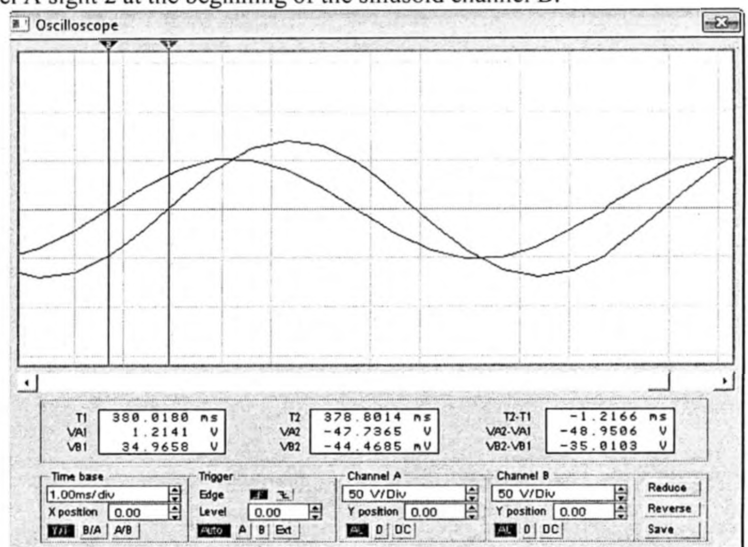


Figure 8.8. The waveform of the input voltage and the output at idling experiment

Oscillogram fixed sine wave voltage at the input and output of four-pole. Save the diagram and waveform.

To measure the phase difference between the input current and voltage at the output of switch channel A of the oscilloscope for an additional resistor at the input, in accordance with Fig.8.9

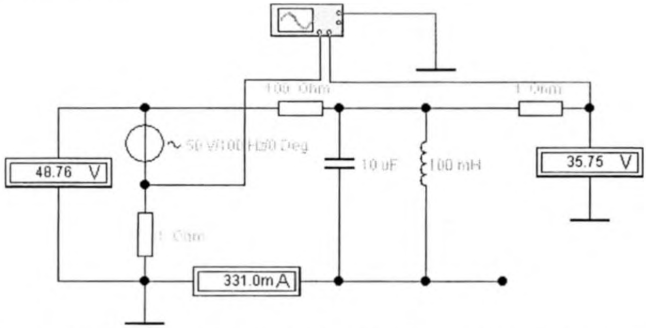


Figure 8.9. Driving experience for idling with measurement $\phi 21$.

Start the simulation and save the scheme and the waveform.

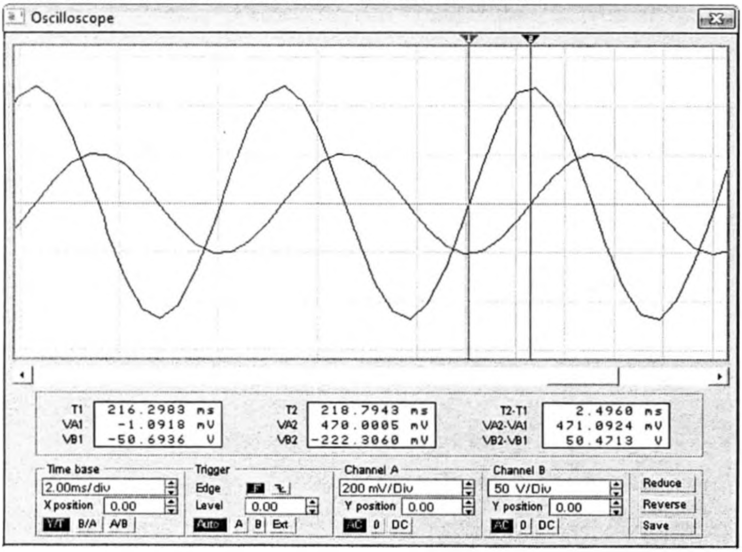


Figure 8.10. The waveform "current" on the input and output voltage experience at idling

2. Defining the parameters of the signal at the input and output of the four-pole in the short-circuit experience

Collect program EWB circuit diagram analogous to Figure 8.11.

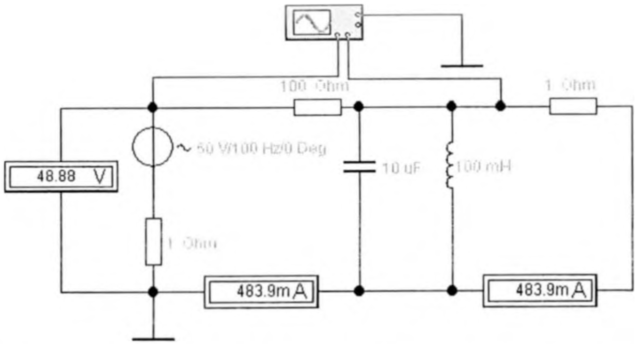


Figure 8.11. Scheme to experience short-circuit with measurement ϕ12

Start the simulation, set up the cursor on the waveform and save the results.

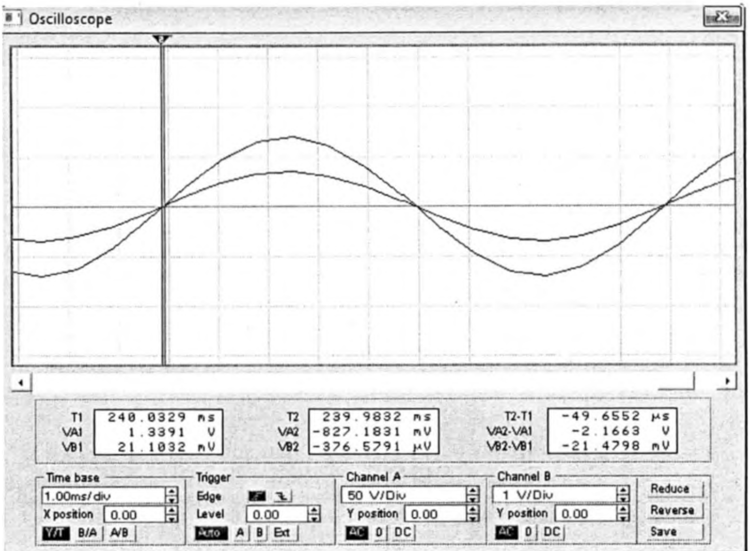


Figure 8.12. The waveform of the input voltage and the "current" output when short-circuit experiment

To measure the phase difference of input current and output current switch channel A of the oscilloscope for an additional resistor at the input, in accordance with Fig.8.13

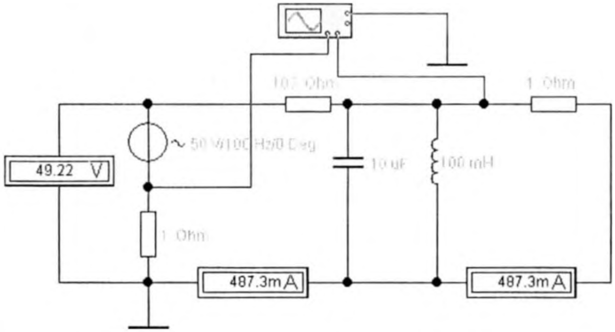


Figure 8.13. Scheme to experience short-circuit with measurement $\phi 22$

Start the simulation, set up the cursor on the waveform and save the results.

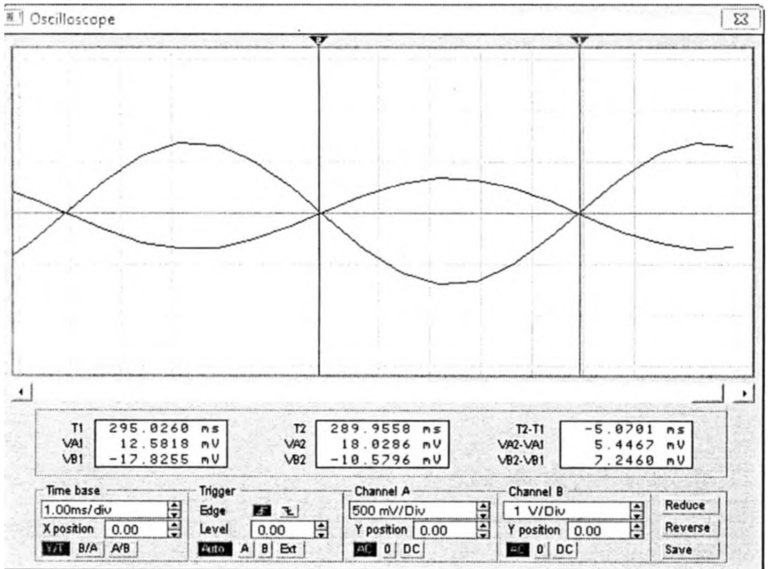


Figure 8.14. The waveform "currents" in the input and output in the short-circuit experiment

Theoretical information:

Quadripole called complex circuit having four outer clamp through which it can communicate with external circuits. Transformer, filter, power line, a bridge circuit can be regarded as quadripole.

The theory of quadripoles they enable communication between the voltages, currents of the two branches connected to the four clamps the complex chain, without examining modes of its parts.

The basic equations quadripoles

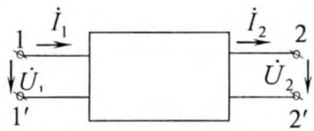


Fig. 8.15

Conditionally accepted to represent quadripoles as shown in Fig. 8.15. This is a "pass" quadripole. It electric energy is transferred from left to right.

One pair of terminals is called primary (input), and the other - secondary (output) and denote the 1-1′ and 2-2′.

Denote the input current $\dot{I}_1$, input voltage -$\dot{U}_1$, current and voltage at the output

-$\dot{I}_2$ and $\dot{U}_2$. Quadripole is a transmission link between the power source and the load. To the conclusion 1-1′, usually joins the power source; conclusions 2-2′ - *load.*

The relationship between the two voltages and two currents that determine the mode on the primary and secondary conclusions can be written in different forms. If we consider two of these parameters are given, then the other two values are related systems of two equations, which are called equations quadrupole.

The most common form of the equations a quadrupole is such, in which the input current and voltage expressed in terms of the output voltage and current.

$$\begin{aligned} \dot{U}_1 &= A_{11}\dot{U}_2 + A_{12}\dot{I}_2, \\ \dot{I}_1 &= A_{21}\dot{U}_2 + A_{22}\dot{I}_2. \end{aligned} \tag{8.1}$$

Equation (8.1) is called the equation of A-quadrupole parameters.

To determine $\dot{U}_1$ and $\dot{I}_1$ sufficient to know only three of the four factor, ie among the A parameters , only three independents.

Definition of A-parameters with idling and short-circuit
Idling (XX) and short circuit (SC) quadrupole match circuit in Fig. 8.16.

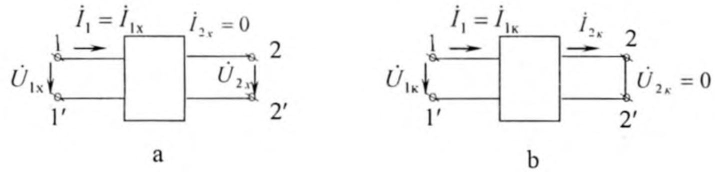


Fig. 8.16.

Idling. Taking into account that
$\dot{I}_2 = 0$, $\underline{Z}_2 = \infty$, equation (8.1) takes the form

$$(\dot{U}_1)_{\dot{I}_2=0} = \dot{U}_{1x} = A_{11}\dot{U}_{2x},$$
$$(\dot{I}_1)_{\dot{I}_2=0} = \dot{I}_{1x} = A_{21}\dot{U}_{2x}.$$

from

$$A_{11} = \frac{\dot{U}_{1x}}{\dot{U}_{2x}} = \frac{U_{1x}}{U_{2x}} e^{j\phi_{11}}, \quad (8.2)$$

$\phi_{11} = \psi_{U1x} - \psi_{U2x}$ - the phase difference of voltage $\dot{U}_{1x}$ and $\dot{U}_{2x}$,
U_{1x} и U_{2x} – the effective voltage.

$$A_{21} = \frac{\dot{I}_{1x}}{\dot{U}_{2x}} = \frac{I_{1x}}{U_{2x}} e^{j\phi_{21}}, \quad (8.3)$$

где $\phi_{21} = \psi_{I1x} - \psi_{U2x}$ - the phase difference of current $\dot{I}_{1x}$ and voltage $\dot{U}_{2x}$,
I_{1x} и U_{2x} – effective values voltage and current.

Short circuit mode. Given that in this case

$\underline{Z}_2 = 0$, $\dot{U}_2 = 0$ (Fig. 8.16b), the ratio of (8.1) has the form

$$(\dot{U}_1)_{\dot{U}_2=0} = \dot{U}_{1к} = A_{12}\dot{I}_{2к},$$
$$(\dot{I}_1)_{\dot{U}_2=0} = \dot{I}_{1к} = A_{22}\dot{I}_{2к}.$$

From

$$A_{12} = \frac{\dot U_{1к}}{\dot I_{2к}} = \frac{U_{1к}}{I_{2к}}\, e^{j\phi_{12}}, \qquad (8.4)$$

где $\phi_{12} = \psi_{U1к} - \psi_{I2к}$ – the phase difference of voltage $\dot U_{1к}$ and current $\dot I_{2к}$,

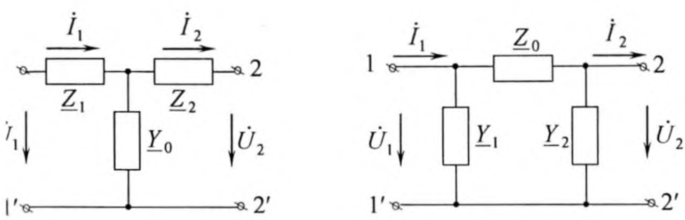
$U_{1к}$ и $I_{2к}$ – effective values voltage and current

$$A_{22} = \frac{\dot I_{1к}}{\dot I_{2к}} = \frac{I_{1к}}{I_{2к}}\, e^{j\phi_{22}}, \qquad (8.5)$$

где $\phi_{22} = \psi_{I1к} - \psi_{I2к}$ – the phase difference of currents $\dot I_{1к}$ и $\dot I_{2к}$,

$I_{1к}$ и $I_{2к}$ – effective values currents

Equivalent circuit quadrupole



a b

Fig. 8.17

Any quadripole can be summarized to the resistance or conductance connected to *T or U-shaped scheme* (Fig. 8.17).

Equivalent circuit of the real quadrupole called simply quadripole three-element (T or U-shaped) having the same or A-parameters as given quadripole.

Three resistance T- or U-circuits should be calculated considering that the equivalent circuit must have the same A-parameters what it has a quadripole replaceable.

Two *quadripole equivalent if they have equivalent A-parameters*. It follows from equations (1). Therefore, if we know parameters A quadrupole , it can be replaced with its equivalent or U-T-figurative equivalent circuit parameters to determine if these equivalent circuits.

In this *T-shaped* equivalent circuit

$$\underline{Y}_0 = A_{21}, \quad \underline{Z}_1 = \frac{A_{11} - 1}{A_{21}}, \quad \underline{Z}_2 = \frac{A_{22} - 1}{A_{21}}. \qquad (8.6)$$

Parameters of the elements *U-shaped* equivalent circuit

$$\underline{Z}_0 = A_{12}, \quad \underline{Y}_1 = \frac{A_{22} - 1}{A_{12}}, \quad \underline{Y}_2 = \frac{A_{11} - 1}{A_{12}}. \qquad (8.7)$$

The transfer functions of the quadrupole

The currents and voltages can be expressed through currents and voltages on the input side and output using the the transfer coefficients

$$k_U = \frac{\dot{U}_2}{\dot{U}_1}, \ k_I = \frac{\dot{I}_2}{\dot{I}_1}.$$

The transfer function - is the ratio of amplitude or effective values of complex electrical quantities for output and input quadrupole mode for a given load.

Expressing these factors through A-parameters, we obtain a transfer efficiency (or transfer function) *Voltage*

$$k_U = \frac{\dot{U}_2}{\dot{U}_1} = \frac{\underline{Z}_2}{A_{11}\underline{Z}_2 + A_{12}} \quad (8.8)$$

current transfer ratio

$$k_I = \frac{\dot{I}_2}{\dot{I}_1} = \frac{1}{A_{21}\underline{Z}_2 + A_{22}} \quad (8.9)$$

Contents of the report:

The report on the implementation of laboratory work should contain

a) the purpose of the work;

b) specification for modeling, ladder diagram, the waveform;

c) calculation A-quadrupole parameters. The phase difference is clear from the screen of the oscilloscope (T2 - T1) with recalculation in radians, taking into account the angle of half-cycle sine wave T / 2 = π = 3,14 rad.

If the parameter signal of the numerator ahead signal of the denominator, the phase difference is positive, otherwise - minus. Effective voltage and current count with instruments in the schemes.

The measurement results record in Table 1.

Diagrams in Figure 8.7 and 8.9. Poles2 - 2 ' - idling

U_{1x} B	U_{2x} B	I_{1x} MA	$\phi_{11} = \psi_{U1x} - \psi_{U2x}$ rad	$\phi_{21} = \psi_{I1x} - \psi_{U2x}$ rad

Diagrams in Figure 8.11 and 8.13. Conclusion 2 - 2 'short-circuited

$U_{1к}$ B	$I_{1к}$ MA	$I_{2к}$ MA	$\phi_{12} = \psi_{U1к} - \psi_{I2к}$ rad	$\phi_{22} = \psi_{I1к} - \psi_{I2к}$ rad

Table 1.

Using formula (8.2) ... (8.5) Calculate A-quadrupole parameters
c) the calculation resistance of equivalent T and U - circuits with the use formulas (8.6) and (8.7). If necessary, use Euler's formula for representation of complex variables with real and imaginary parts.

$$\dot{A} = A\angle\varphi = Ae^{j\varphi} = A\cos\varphi + jA\sin\varphi = a + jb\,.$$

e) the calculation of transfer coefficients of voltage and current using the formula (8.8) and (8.9). Load Resistance take Z 2 =1 k.
f) the conclusions of the work.