

MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION
FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER
EDUCATION
"NORTH CAUCASUS FEDERAL UNIVERSITY"

Suggestions for Teaching

on the implementation of practical classes
by discipline

Circuit Analysis

for students of the field of study / specialty
11.03.02 Infocommunication Technologies and Communication Systems
Profile
"Intelligent Data Processing in Infocommunication
Systems and Networks"

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Introduction

Practical classes are an essential element of the educational process at the university, during which students actually encounter independent practical activity in a particular field for the first time. They are, as it were, an intermediate link between the in-depth theoretical work of students at lectures and the application of their knowledge in practice. These classes successfully combine elements of theoretical research and practical work.

By performing practical work, students better assimilate the program material, since many calculations and formulas that seemed abstract become quite concrete, there is a contact between theory and practice, which generally contributes to the clarification of complex issues of science and the formation of students as specialists.

Practical work activates the independent work of students on the course being studied. It should be noted that the most intensive and rhythmic work during the semester is carried out by students in those disciplines in which there are laboratory classes.

At present, it is generally accepted that the workshop should be creative, research, and not contemplative, reproductive. Therefore, classes should be a school of practical experience, a school of creative skills, and the effective use of science in the chosen profession. Along with this, a laboratory workshop should be a school of creativity and perseverance in achieving a scientific goal.

Practical work is one of the types of independent practical work of trainees, in which, through experiments, theoretical knowledge and skills of trainees are **deepened** and consolidated in the interests of their professional training.

The performance of Practical Work by trainees is aimed at:

- to deepen and consolidate the knowledge of the theoretical course through the practical study of the laws and regulations set forth in the lecture in laboratory conditions;

- to acquire skills in scientific experimentation, analysis of the results of experiments and drawing up reports on them;

- to practically familiarize themselves with measuring equipment and measurement methods, the structure of various experimental apparatus and equipment;

- to acquire primary skills in organizing, planning and conducting scientific research.

Thanks to practical work, students better assimilate the program material, since during the preparation and implementation of experiments, many such details in the theory of the issue are revealed, which students did not encounter either at lectures or in practical classes. In short, the contact of theory and experience, which takes place in the laboratory, not only contributes to the assimilation of educational material, but also develops thinking, giving it rational features and an active character. Properly organized work should require from students not only good knowledge

of theory, but also the display of initiative, observation and independence in conducting experiments, the ability to analyze, generalize and draw conclusions.

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Investigation of electrical circuits by the superposition method and the equivalent generator method

Purpose of the work:

1. Experimental study of electrical circuits by the superposition method.
2. Experimental study of electrical circuits by the method of an equivalent voltage generator.
3. Experimental study of electrical circuits by the method of an equivalent current generator.

Task to prepare for laboratory work:

1. Familiarize yourself with the manual for laboratory work;
2. Perform a preliminary calculation according to the task option (Table 1):
 - 2.1. Calculate currents in the branches of a given circuit using the superposition method.
 - 2.2. Calculate the current in the branch with element R3 of a given circuit using the equivalent voltage generator method.
 - 2.3. Calculate the current in the branch with element R3 of a given circuit using the equivalent current generator method.

Description of the study design

The research is carried out on a PC in the Electronics Workbench environment. The research schemes contain DC and voltage sources, resistors, a voltmeter and ammeters.

Research Assignment

1. To study the distribution of currents in the branches of a DC electric circuit by the superposition method.
2. To determine the current in a given branch of a DC electric circuit by the method of an equivalent voltage generator.
3. Determine the current in a given branch of the DC electric circuit by the method of an equivalent current generator.

Table 1 - Variants of tasks for preliminary calculation and research

Option No	E1, B	E2, B	J, mA	R1, Ohm	R2, Ohm	R3, Ohm
1	20	12	160	110	140	140
2	11	14	170	120	150	150
3	13	16	180	130	160	130
4	15	18	190	140	170	140
5	17	20	200	150	180	150
6	19	11	100	160	190	160
7	12	13	110	170	200	170
8	14	15	120	180	100	180
9	16	17	130	190	110	190
10	18	19	140	200	120	200
11	20	12	150	100	130	100
12	11	14	160	110	140	110
13	18	16	170	120	150	120
14	20	18	180	130	160	130
15	11	20	190	140	170	140
16	13	11	150	150	180	150
17	15	13	160	160	190	130
18	17	15	170	170	130	140
19	19	17	150	180	140	150
20	12	19	160	190	150	160
21	14	11	170	200	160	170
22	16	13	180	100	170	180
23	18	15	190	110	180	130
24	20	17	200	120	190	140
25	11	19	100	130	200	150
26	13	12	110	140	100	160
27	18	14	120	150	110	170
28	14	17	300	128	250	200
29	20	17	180	100	140	150
30	11	19	190	110	150	160
31	23	12	150	180	130	150
32	14	14	160	190	140	160
33	17	16	170	200	150	170
34	22	18	180	100	160	180
35	15	20	190	110	170	190
36	17	16	170	120	150	160

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a) Examination of an electrical circuit by the superimposition method

1. Assemble the circuit diagram (Figure 1). When assembling the circuit, connect the ammeters and voltmeter in compliance with the "polarity"

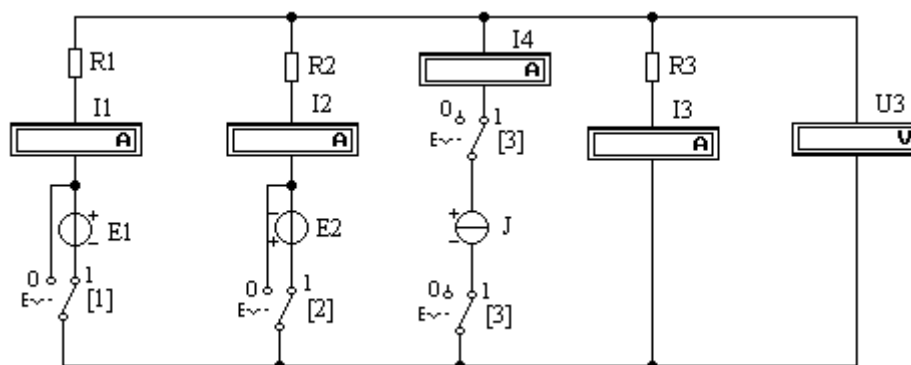


Figure 1

2. Set the values of the EMF and the current of the energy sources, the values of the circuit elements specified according to the option. To do this, the cursor is brought to the desired element and by double-clicking the left mouse button, a window (with the name of the element) is called, in which the required value of the parameter is set and the "Accept" button is pressed.

3. In the diagram (Figure 1), set **all the keys to position 1** (if necessary, press keys 1, 2 and 3 on the keyboard)

•4. After completing the installation of all the parameters of the circuit, move the button  - "0-1" located in the upper right corner of the screen to the 1-"On" position. Upon completion of automatic calculations (a few seconds),  move the button to the 0-"Off" position. Enter the readings of ammeters and voltmeter in Table 2.

- Table 2 - Calculated and experimental data of the superposition chain study

[illegible]

	currents and voltages										
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•5. Switch off the sources E2 and J with switches 2 and 3. To do this, move keys 2 and 3 to position 0 (press keys 2 and 3 on the keyboard). Move the button (0-1) to position "1". Upon completion of automatic calculations, move the button (0-1) to position "0". Enter the readings of ammeters and voltmeter in the table of calculation and experimental data (Table 2). Switch switches 2 and 3 to position 1 (initial position)

•6. Use switches 1 and 3 to turn off sources E1 and J (press keys 1 and 3 on the keyboard, while the keys are moved to position 0). Move the button (0-1) to position "1". Upon completion of automatic calculations, move the button (0-1) to position "0". Switch switches 1 and 3 to position 1

•7. Use switches 1 and 2 to turn off sources E1 and E2 (press keys 1 and 2 on the keyboard, while the keys are moved to position 2). Move the button (0-1) to position "1". Upon completion of automatic calculations, move the button (0-1) to the "0" position. Switch switches 1 and 2 to position 1

8. Determine the algebraic sum of "partial" currents in each branch of the circuit under study (add the currents of items 2-4 of Table 2) and compare them with the measurement results of item 1 of Table 2. 2. Draw conclusions.

9. To compare the results of preliminary calculations of primary parameters with the results of research. To draw conclusions.

b) Experimental study of electrical circuits by the equivalent generator method

1. Assemble the diagram of the electrical circuit (Figure 2). To do this, it is necessary to remove element R3 in the diagram (Figure 1) and add the key K.

2. To determine the parameter **of the equivalent voltage generator** $E_e = U_{xx}$ in the circuit (Figure 2), set **the idle mode**: switch "K" to position 0 (press the K key on the keyboard).

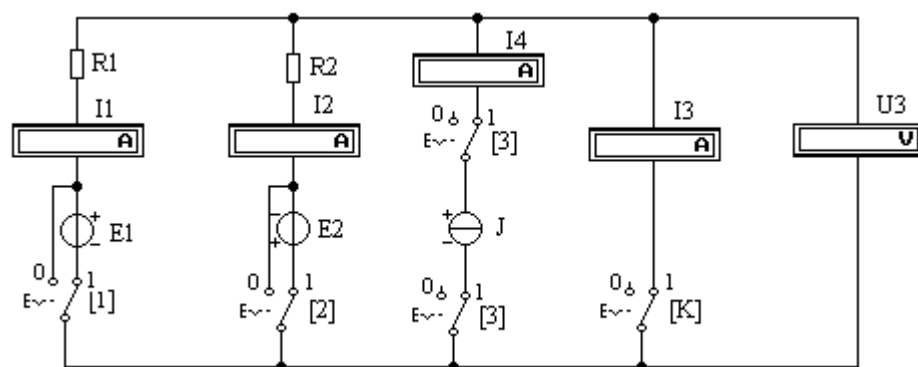


Figure 2

- 3. After completing the installation of all circuit parameters, move the button (0-1) to the "1" position. Upon completion of automatic calculations, move the (0-1) button to the "0" position. Enter the readings of the U3=EE voltmeter in the table of calculated and experimental data.

• Table 3 - Calculated and experimental data

• Research method		• U3 , B	• I3, mA	• Re, Ohm	• In, mA
• Equivalent Voltage Generator Method	• Calculation	•	•	•	•
	• Experiment	•	•	•	•
• Equivalent Current Generator Method	• Calculation	• 0	•	•	•
	• Experiment	• 0	•	•	•

- 4. To determine the value of Je (the parameter **of the equivalent current generator**) in the circuit (Fig.2), set **the short-circuit mode**: switch "K" to position 1 (press the key K on the keyboard). Move the button (0-1) to the position "(1)". Upon completion of automatic calculations, move the button (0-1) to the position "(0)".

- 5. To determine the value of Re (the parameter of the equivalent oscillator) in the circuit (Fig.2), move the switch "K" and keys 1, 2, 3 to position 0 (the circuit is converted into a passive two-pole). Instead of a voltmeter (Figure 2), connect a multimeter  and prepare it for measuring resistance. To do this, move the cursor to its image and activate and press the button "" by double-clicking the left "mouse" buttonΩ. Move the (0-1) button to the "(1)" position. Upon completion of automatic calculations, move the (0-1) button to the "(0)" position.

- The resistance E is determined using the results of the idle and short circuit experiments

$$R_3 = \frac{U_3^{xx}}{I_3^{K3}}. \text{ The results of the Re measurements are compared.}$$

- 6. To determine the load current In=I3 in the circuit (Figure 1), **assemble the diagram of the electrical circuit (Figure 3)** using the equivalent voltage generator method.

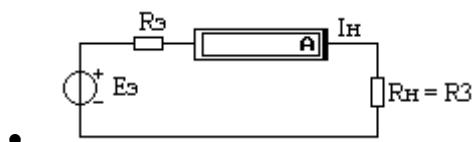


Figure 3

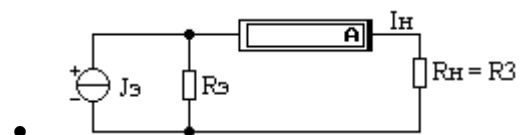


Figure 4

- Move the button (0-1) to the position "(1)". Upon completion of automatic calculations, move the button (0-1) to the position "(0)". Enter the readings of the ammeter in the table of calculated and experimental data.

- 7. To determine the current I_3 in the circuit (Figure 1) **using the equivalent current generator method**, assemble a diagram of an electrical circuit (Figure 4).

- Move the button (0-1) to the position "(1)". Upon completion of automatic calculations, move the button (0-1) to the position "(0)". Enter the readings of the ammeter in the table of calculated and experimental data.

8. Compare the results of preliminary calculations of current I_3 and I_{ne} with the results of research. Draw conclusions.

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- **Contents of the report**

The laboratory report should contain:

- name of the work;
 - the purpose of the research;
 - research program (task);
 - research schemes made in accordance with the requirements of GOSTs;
 - Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;

- - conclusions based on the results of research.

- **Control questions:**

1. Formulate the principle of superposition.
2. Explain the algorithm for calculating an electrical circuit using the superposition method.
3. What is a branch of an electrical circuit?
4. What is meant by an electrical circuit replacement scheme?
5. Formulate Ohm's Law for a Closed Single-Loop Circuit.
6. Formulate a generalized Ohm's law.
7. Explain the algorithm for calculating an electrical circuit using the equivalent voltage generator method.
8. Explain the algorithm for calculating an electrical circuit using the equivalent current generator method.

Practical lesson No2

Investigation of Ideal Elements of Electric Circuits of Sinusoidal Current

Purpose of the work

- 1.1 Experimental study of an electric circuit with an ideal resistor.
- 1.2 Experimental study of an electric circuit with an ideal inductive coil.
- 1.3 Experimental study of an electrical circuit with an ideal capacitor.

Task to prepare for laboratory work

Read the laboratory manual.

Perform a preliminary calculation of the current in the R-, L- and C circuits specified according to the option (Table 1), build vector diagrams of current and voltage.

Description of the study design

Studies are carried out on a PC in the Electronics Workbench environment. The study circuits contain an AC voltage source (functional generator), a current-controlled voltage source, a resistor, an inductive coil, a capacitor, an oscilloscope, an ammeter, and a voltmeter. An oscilloscope is used to determine phase shifts between current and voltage.

Research Assignment

1. Investigate the effect of the parameters of the circuit with an ideal resistor on the current value.
2. Investigate the effect of the parameters of a circuit with an ideal inductive coil on the current value.
3. Investigate the effect of the parameters of the circuit with an ideal capacitor on the current value.

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• Procedure for conducting research

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Examining a Circuit with an Ideal Resistor

1. Assemble the diagram of the electrical circuit (Figure 1).

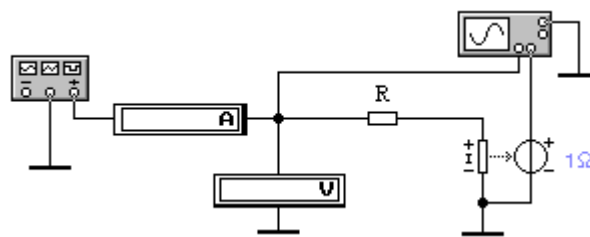


Figure 1- Diagram of the study of a circuit with an ideal resistor

- 2. Set the resistance values of the resistor R, the values of the EMF amplitude and the frequency $f = 10 \text{ kHz}$ of the functional generator specified according to the option (Table 1). To do this, move the cursor to the desired element and double-click the left mouse button to open a window (with the name of the element), in which to set the required parameter value.

- 3. After completing the installation of all the parameters of the circuit, move the button - "0-1" to the position 1 - "On". Upon completion of automatic calculations (a few seconds), move the button to the 0-Off position. Enter the readings of the ammeter and voltmeters in the table of test results (Table 2).

- 4. Double-click the left mouse button on the line of the "A" channel of the oscilloscope to set the desired color of the oscillogram.

- Activate it by double-clicking the left mouse button on the oscilloscope image. Set the switches TIME BASE 0.01 ms/div , CHANNEL A 5v/Div , CHANNEL B 1v/Div on the control panel. Switch the oscilloscope to the "Zoom" mode. Set the sight ruler 1 (red) at the point of intersection of the time axis with the oscillogram of channel "A" when it passes from negative to positive value (voltage oscillogram $u(t)$), and sight ruler 2 - at the point of intersection of the time axis with the oscillogram of channel "B" when it passes from negative to positive value (current oscillogram $i(t)$). The value of the time interval $T_2 - T_1$ is entered in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi = 360^\circ \frac{T_2 - T_1}{T}$. Here $T = 1/f$ is the period of the sinusoidal EMF of the

source

- 5. Set the resistor resistance to $0.5R$, perform steps 3-4.

- 6. Set resistor resistance $2R$, perform steps 3-4.

- 7. Based on the results of the research, build vector diagrams of current and voltage.

•Table 1 - Variants of tasks for preliminary calculation and research

Option No	E, B	R, Ohm	L, mH	S, μ F	Option No	E, B	R, Ohm	L, mH	S, μ F
1	10	50	0.10	1.0	31	15	50	0.16	1.6
2	12	40	0.12	1.5	32	16	40	0.18	2.0
3	14	60	0.13	1.6	33	17	60	0.19	1.8
4	15	70	0.15	2.0	34	18	70	0.20	1.9
5	16	80	0.11	1.8	35	19	80	0.10	1.1
6	17	90	0.14	1.9	36	20	90	0.12	1.2
7	18	55	0.16	1.1	37	13	55	0.13	0.9
8	19	65	0.18	1.2	38	12	65	0.15	2.1
9	20	45	0.19	0.9	39	14	45	0.11	2.0
10	13	35	0.20	2.1	40	15	35	0.14	1.8
11	12	70	0.10	2.0	41	16	70	0.16	1.9
12	14	80	0.12	1.8	42	17	80	0.18	1.5
13	15	90	0.13	1.9	43	18	90	0.19	1.6
14	16	55	0.15	1.5	44	19	55	0.10	2.0
15	17	65	0.11	1.6	45	20	65	0.12	1.8
16	18	45	0.14	2.0	46	13	45	0.13	1.9
17	19	35	0.16	1.8	47	12	35	0.15	1.1
18	20	70	0.18	1.9	48	14	70	0.11	1.2
19	13	80	0.19	1.1	49	15	80	0.11	0.9
20	12	70	0.10	1.2	50	16	70	0.14	2.1
21	14	80	0.12	0.9	51	17	80	0.16	2.0
22	15	90	0.13	2.1	52	10	90	0.18	1.8
23	16	55	0.15	2.0	53	12	55	0.19	1.9
24	17	65	0.11	1.8	54	14	65	0.20	1.5
25	10	45	0.11	1.9	55	15	45	0.16	1.6
26	12	35	0.14	1.5	56	16	35	0.18	2.0
27	14	70	0.16	1.6	57	17	70	0.19	1.8
28	15	80	0.18	2.0	58	15	80	0.20	1.9
29	16	90	0.19	1.8	59	16	90	0.10	1.6
30	17	55	0.20	1.9	60	17	55	0.12	2.0

- 8. Setting the source frequency to $0.2f$, $0.5f$, $2f$, , perform steps 3-4.5f

- Table 2- Results of studies of ideal elements of a sinusoidal current circuit

• Chain type	• Parameters	• I, A	U, B	Z, Ohm	• T2-T1, with	• φ , deg
• Ideal resistor	• $R =$	•	•	•	•	•
	• $0.5 R =$	•	•	•	•	•
	• $2R =$	•	•	•	•	•
	• $0.2f =$	•	•	•	•	•
	• $0.5f =$	•	•	•	•	•
	• $2f =$	•	•	•	•	•
	• $5f =$	•	•	•	•	•
• Perfect Inductive • Coil	• $L =$	•	•	•	•	•
	• $0.5 L =$	•	•	•	•	•
	• $2L =$	•	•	•	•	•
	• $0.2f =$	•	•	•	•	•
	• $0.5f =$	•	•	•	•	•
	• $2f =$	•	•	•	•	•
	• $5f =$	•	•	•	•	•
• The Perfect Capacitor	• $C =$	•	•	•	•	•
	• $0.5 S =$	•	•	•	•	•
	• $2S =$	•	•	•	•	•
	• $0.2f =$	•	•	•	•	•
	• $0.5f =$	•	•	•	•	•
	• $2f =$	•	•	•	•	•
	• $5f =$	•	•	•	•	•

Examination of a Chain with an Ideal Inductive Coil

1. Assemble an electrical circuit diagram (Figure 2).

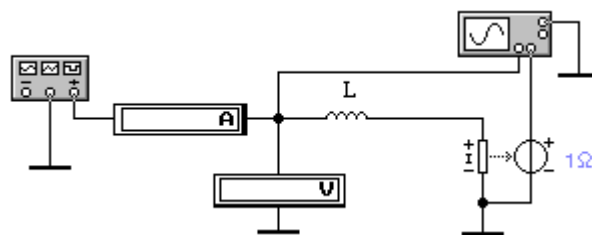


Figure 2 – Diagram of a circuit study with an ideal inductive coil

- 2. Set the inductance value of the coil L , the value of the EMF of the source E and the frequency $f=104$ Hz specified according to the option (Table 1). By double-clicking the left mouse button on the line of the "A" channel of the oscilloscope, set the desired color of the channel (for example, red)

- 3. After all the parameters of the circuit are set,  move the "0-1" button to the 1- "On" position. Upon completion of automatic calculations (a few seconds),  move the

button to the 0-"Off" position. Enter the readings of the ammeter and voltmeters in the table of test results (Table 2).

- 4. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$ and enter it in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f$.

5. Set the inductance of the coil to $0.5L$, perform steps 3-4.

6. Set the inductance of the coil $2L$, perform p.p. 3-4.

7. Based on the results of the research, build vector diagrams of current and voltage.

8. Setting the source frequency to $0.2f$, $0.5f$, $2f$, , and perform steps 3-4.5f

Study of a circuit with an ideal capacitor

1. Assemble the diagram of the electrical circuit (Figure 3).

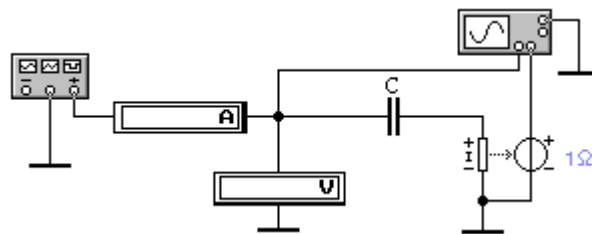


Figure 3 - Diagram of the study of a circuit with an ideal capacitor

- 2. Set the capacitance value of the capacitor C , the value of the EMF of the source E and the frequency $f = 104$ Hz specified according to the option. By double-clicking the left mouse button on the line of the channel "A" of the oscilloscope, set the desired color of the channel (for example, red).

- 3. After completing the setting of all circuit parameters,  move the button - "0-1" to the 1-"On" position. After the completion of automatic calculations (a few seconds),  move the button to the 0-"Off" position. Enter the readings of the ammeter and voltmeters in the table of test results.

- 4. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$ and enter it in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f$.

5. Set the capacitor capacitance to $0.5C$, perform steps 3-4.

6. Set the capacitance of the capacitor $2C$, perform steps 3-4.

7. Based on the results of the research, build vector diagrams of current and voltages

8. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

9. Setting the source frequency to $0.2f$, $0.5f$, $2f$, , perform steps 3-4.5f

• Contents of the report

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The laboratory report should contain:

- research schemes;
- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;
- Vector current and voltage diagrams
 - - conclusions based on the results of research.

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• Control questions

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1. Plot the current $i(t) = 2\sin(\omega t - 1450)$ mA.
2. Write an expression for complex amplitude and effective current if instantaneous current $i(t) = 2\sin(\omega t - 1450)$ mA.
3. Plot a vector diagram for the harmonic current $i = 2\sin(\omega t - 1450)$ mA.
4. Write an expression of Ohm's law in a complex form for a section of the circuit with a resistive element and draw a vector diagram of current and voltage.
5. Write an expression of Ohm's law in complex form for a section of the circuit with an inductive element and depict a vector diagram of current and voltage.
6. Write the expression of Ohm's law in complex form for a section of the circuit with a capacitive element and depict a vector diagram of current and voltage.
7. What is meant by active current?
8. Name the types of power in the sinusoidal current circuit
9. How is the initial phase of sinusoidal current determined?
10. How is the phase shift between current and voltage determined?

Practical lesson №3

Investigation of Unbranched Electrical Circuits of Sinusoidal Current

Purpose of the work:

1. Experimental study of voltage distribution in RL circuits.
2. Experimental study of voltage distribution in RC circuits.
3. Experimental Study of Voltage Distribution in RLC Circuits.

Task to prepare for laboratory work:

- familiarize yourself with the manual for laboratory work;
- perform a preliminary calculation of current and voltages in RL-, RC-, and RLC circuits specified according to the option (Table 1), build vector diagrams of current and voltages.

Description of the study design

The research is carried out on a PC in the Electronics Workbench environment. The study circuits contain an AC voltage source, a current-controlled voltage source, a resistor, an inductive coil, a capacitor, an oscilloscope, an ammeter, and voltmeters. An oscilloscope is used to determine phase shifts between current and voltage.

Research task:

1. Investigate the stress distribution in the RL circuit.
2. Investigate the voltage distribution in the RC circuit.
3. Investigate the voltage distribution in the RLC circuit.

Table 1 - Variants of tasks for preliminary calculation and research

Option No	E, B	R, Ohm	L, mH	S, μ F	Option No	E, B	R, Ohm	L, mH	S, μ F
1	100	50	0.10	0.010	31	150	50	0.16	0.015
2	120	40	0.12	0.015	32	160	40	0.18	0.016
3	140	60	0.13	0.016	33	170	60	0.19	0.020
4	150	70	0.15	0.020	34	180	70	0.20	0.018
5	160	80	0.11	0.018	35	190	80	0.10	0.019
6	170	90	0.14	0.019	36	200	90	0.12	0.011
7	180	55	0.16	0.011	37	130	55	0.13	0.012
8	190	65	0.18	0.012	38	120	65	0.15	0.009
9	200	45	0.19	0.009	39	140	45	0.11	0.021
10	130	35	0.20	0.021	40	150	35	0.14	0.020
11	120	70	0.10	0.020	41	160	70	0.16	0.018
12	140	80	0.12	0.018	42	170	80	0.18	0.019
13	150	90	0.13	0.019	43	180	90	0.19	0.011
14	160	55	0.15	0.011	44	190	55	0.10	0.012
15	170	65	0.11	0.012	45	200	65	0.12	0.009
16	180	45	0.14	0.009	46	130	45	0.13	0.021
17	190	35	0.16	0.021	47	120	35	0.15	0.020
18	200	70	0.18	0.020	48	140	70	0.11	0.018
19	130	80	0.19	0.018	49	150	80	0.11	0.010
20	120	70	0.10	0.010	50	160	70	0.14	0.015
21	140	80	0.12	0.015	51	170	80	0.16	0.016
22	150	90	0.13	0.016	52	100	90	0.18	0.020
23	160	55	0.15	0.020	53	120	55	0.19	0.018
24	170	65	0.11	0.018	54	140	65	0.20	0.009
25	100	45	0.11	0.009	55	150	45	0.16	0.021
26	120	35	0.14	0.021	56	160	35	0.18	0.020
27	140	70	0.16	0.020	57	170	70	0.19	0.018
28	150	80	0.18	0.018	58	150	80	0.20	0.019
29	160	90	0.19	0.019	59	160	90	0.10	0.011
30	170	55	0.20	0.011	60	170	55	0.12	0.015

• Procedure for conducting research

a) Research of RL chains.

1. Assemble the diagram of the electrical circuit (Figure 1).
2. Set the values of resistor resistance R and inductance L , EMF E and frequency $f = 105$ Hz of the source specified according to the option. To do this, move the cursor to the desired element and double-click the left mouse button to open a window (with the name of the element), in which to set the required parameter value. By double-clicking the left mouse button on the line of the "A" channel of the oscilloscope, set the desired color of the oscillogram (for example, red)

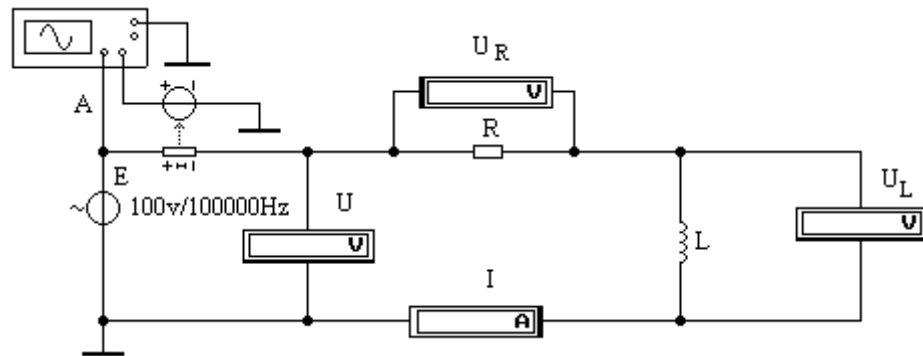


Figure 1 - Diagram of the RL circuit study.

3. After all the parameters of the circuit are set,  move the "0-1" button to the 1- "On" position. Upon completion of automatic calculations (a few seconds),  move the button to the 0- "Off" position. Enter the readings of the ammeter and voltmeters in the table of test results

• Table 2 - Results of studies of unbranched sinusoidal current circuits

• Chain type	• Parameters	• I, A	U, B	UR, B	UL, B	UC, B	• T2-T1, with	• $\varphi(t)$, • Degrees
• RL Chain	0.5L =	•	•	•	•	• -	•	•
	L =	•	•	•	•	• -	•	•
	2L =	•	•	•	•	• -	•	•
• RC chain	0.5C =	•	•	•	• -	•	•	•
	C =	•	•	•	• -	•	•	•
	2C =	•	•	•	• -	•	•	•
• RLC Chain	S < C ut	•	•	•	•	•	•	•
	Cross-section =	•	•	•	•	•	•	•

	C>SI ice	•	•	•	•	•	•	•
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•4. Double-click the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sight ruler 1 (red) at the point of intersection of the time axis with the oscillogram of channel "A" when it transitions from a negative to a positive value (voltage oscillogram $u(t)$), and sight ruler 2 - at the point of intersection of the time axis with the oscillogram of channel "B" when it transitions from a negative value to a positive value (current oscillogram $i(t)$),. The value of the time interval $T_2 - T_1$ is entered in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi(t) = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi(t) = 360^\circ \frac{T_2 - T_1}{T}$

5. Set the inductance of the coil to $0.5L$, perform steps 3-4.

6. Set the inductance of the coil $2L$, perform p.p. 3-4.

7. Based on the results of the research, build vector diagrams of current and voltages

b) Study of the RC chain.

1. Assemble the diagram of the electrical circuit (Figure 2).

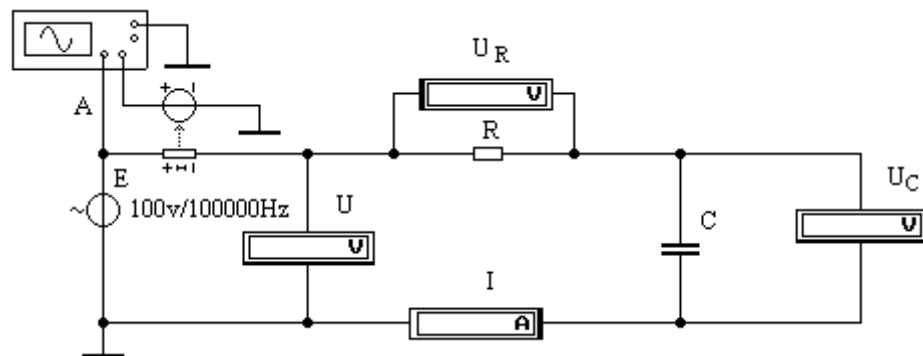


Figure 2 - Diagram of the study of the RC circuit.

•2. Set the values of resistor resistance R and capacitance of capacitor C specified according to the option, the value of the emf of the source $E = 150$ V and the frequency $f = 105$ Hz. By double-clicking the left mouse button on the line of channel "A" of the oscilloscope, set the desired color of the channel (for example, red)

•3. After all the parameters of the circuit are set,  move the "0-1" button to the 1- "On" position. Upon completion of automatic calculations (a few seconds),  move the button to the 0- "Off" position. Enter the readings of the ammeter and voltmeters in the table of test results

•4. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$ and enter it in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi(t) = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi(t) = 360^\circ \frac{T_2 - T_1}{T}$.

5. Set the capacitor capacitance to $0.5C$, perform steps 3-4.

6. Set the capacitance of the capacitor $2C$, perform steps 3-4.

7. Based on the results of the research, build vector diagrams of current and voltages

8. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

c) Study of RLC circuits.

1. Assemble the diagram of the electrical circuit (Figure 3).

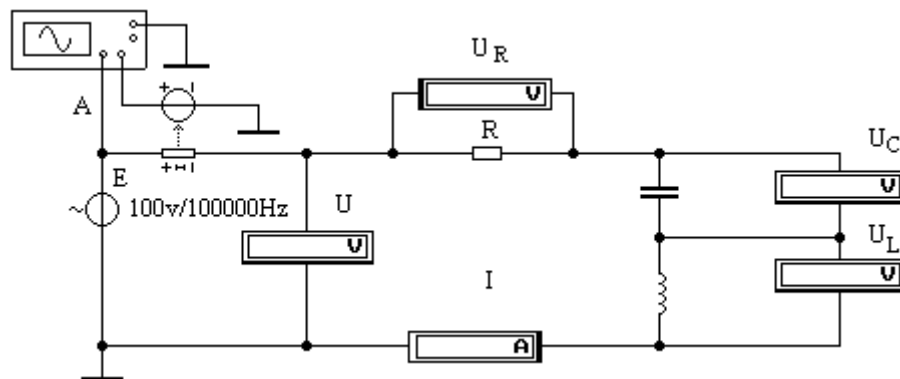


Figure 3 - Scheme of the RLC circuit study.

• 2. Set the values of resistor resistance R , inductance L and capacitance of the capacitor set according to the option $C_{\text{pes}} = \frac{1}{4\pi^2 \cdot 10^{10} \cdot L}$, the value of EMF and frequency $f = 105 \text{ Hz}$ of the source E

•3. After all the parameters of the circuit are set,  move the "0-1" button to the 1- "On" position. Upon completion of automatic calculations (a few seconds),  move the button to the 0- "Off" position. Enter the readings of the ammeter and voltmeters in the table of test results

•4. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$ and enter it in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f$ or $\varphi = 360^\circ \frac{T_2 - T_1}{T}$.

5. Set the capacitance of the capacitor $C < C$, perform points 3-4.

6. Set the capacitance of the capacitor $C > C$, perform steps 3-4.

7. Based on the results of the research, build vector diagrams of current and voltages

8. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

• **Contents of the report.**

The laboratory report should contain:

- research schemes;
- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;
- Vector current and voltage diagrams
 - - conclusions based on the results of research.

• **Control questions:**

1. Plot the current $i(t) = 2\sin(\omega t - 1450)$ mA.
2. Write an expression for complex amplitude and effective current if instantaneous current $i(t) = 2\sin(\omega t - 1450)$ mA.
3. Plot a vector diagram for the harmonic current $i = 2\sin(\omega t - 1450)$ mA.
4. Write an expression of Ohm's law in complex form for a section of the circuit with resistive and inductive elements and draw a vector diagram of current and voltage.
5. Write an expression of Ohm's law in complex form for a section of the circuit with a resistive and capacitive element and depict a vector diagram of current and voltage.
6. Write the expression of Ohm's law in complex form for a section of the circuit with resistive, inductive, and capacitive elements, and draw a vector diagram of current and voltage.
7. Name the sign and condition of stress resonance

Practical lesson №4

Investigation of branched electrical circuits of sinusoidal current

Purpose of the work:

1. Experimental study of the distribution of currents in the RL circuit.
2. Experimental study of current distribution in RC circuits.
3. Experimental study of current distribution in RLC circuits.

Task to prepare for laboratory work:

- familiarize yourself with the manual for laboratory work;
- perform a preliminary calculation of currents in RL-, RC-, and RLC circuits specified according to the option (Table 1), build vector diagrams of currents and voltages.

Description of the study design

Studies are conducted on a PC in an Electronics Workbench environment. The study circuits contain an AC voltage source, a current-controlled voltage source, a resistor, an inductive coil, a capacitor, an oscilloscope, ammeters, and a voltmeter. An oscilloscope is used to determine phase shifts between current and voltage at the input of a circuit.

Research task:

1. Investigate the stress distribution in the RL circuit.
2. Investigate the voltage distribution in the RC circuit.
3. Investigate the voltage distribution in the RLC circuit.

Table 1 - Variants of tasks for preliminary calculation and research

Option No	E, B	R, Ohm	L, mH	S, μ F	Option No	E, B	R, Ohm	L, mH	S, μ F
1	100	50	0.10	0.050	31	150	50	0.16	0.048
2	120	40	0.12	0.055	32	160	40	0.18	0.039
3	140	60	0.13	0.060	33	170	60	0.19	0.050
4	150	70	0.15	0.070	34	180	70	0.20	0.042
5	160	80	0.11	0.048	35	190	80	0.10	0.040
6	170	90	0.14	0.039	36	200	90	0.12	0.060
7	180	55	0.16	0.050	37	130	55	0.13	0.070
8	190	65	0.18	0.042	38	120	65	0.15	0.038
9	200	45	0.19	0.040	39	140	45	0.11	0.035
10	130	35	0.20	0.060	40	150	35	0.14	0.070
11	120	70	0.10	0.070	41	160	70	0.16	0.055
12	140	80	0.12	0.038	42	170	80	0.18	0.060
13	150	90	0.13	0.044	43	180	90	0.19	0.070
14	160	55	0.15	0.070	44	190	55	0.10	0.048
15	170	65	0.11	0.055	45	200	65	0.12	0.039
16	180	45	0.14	0.060	46	130	45	0.13	0.050
17	190	35	0.16	0.070	47	120	35	0.15	0.042
18	200	70	0.18	0.048	48	140	70	0.11	0.040
19	130	80	0.19	0.039	49	150	80	0.11	0.060
20	120	70	0.10	0.050	50	160	70	0.14	0.070
21	140	80	0.12	0.042	51	170	80	0.16	0.038
22	150	90	0.13	0.040	52	100	90	0.18	0.044
23	160	55	0.15	0.060	53	120	55	0.19	0.070
24	170	65	0.11	0.070	54	140	65	0.20	0.055
25	100	45	0.11	0.038	55	150	45	0.16	0.060
26	120	35	0.14	0.035	56	160	35	0.18	0.070
27	140	70	0.16	0.070	57	170	70	0.19	0.048
28	150	80	0.18	0.055	58	150	80	0.20	0.039
29	160	90	0.19	0.060	59	160	90	0.10	0.050
30	170	55	0.20	0.070	60	170	55	0.12	0.042

• Procedure for conducting research

a) Research of RL chains.

1. Assemble a diagram of an electrical circuit (Fig. 1).

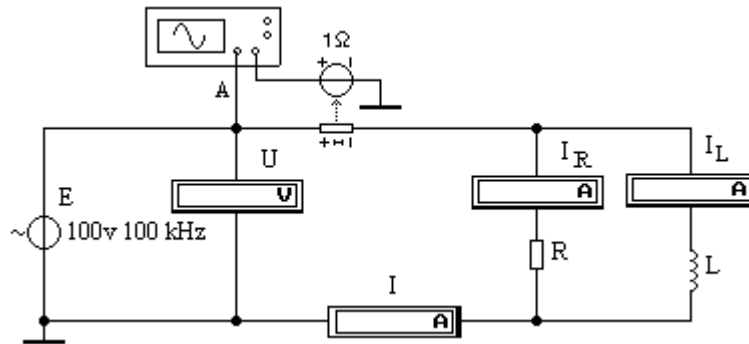


Figure 1 - Diagram of the RL circuit study.

•2. Set the values of resistor resistance R and inductance L, EMF E and frequency $f = 105$ Hz of the source specified according to the option. To do this, move the cursor to the desired element and double-click the left mouse button to open a window (with the name of the element), in which to set the required parameter value. By double-clicking the left mouse button on the line of the "A" channel of the oscilloscope, set the desired color of the oscillogram (for example, red)

•3. After the completion of setting all the parameters of the circuit , move the "0-1" button to the 1-"On" position. After the automatic calculations are completed (a few seconds), the button  is moved to the 0-"Off" position. Enter the readings of the ammeters and voltmeter in the table of test results (Table 2)

•4. Double-click the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sighting ruler 1 (red) at the point of intersection of the time axis with the oscillogram of channel "A" when it transitions from negative to positive value (voltage oscillogram $u(t)$), and sight ruler 2 - at the point of intersection of the time axis with the oscillogram of channel "B" when it transitions from negative to positive value (current oscillogram $i(t)$).

$$\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f \quad \varphi = 360^\circ \frac{T_2 - T_1}{T}$$

5. Set the inductance of the coil to $0.5L$, perform steps 3-4.

6. Set the inductance of the coil $2L$, perform p.p. 3-4.

7. Based on the results of the research, build vector diagrams of currents and voltages

•Table 2 - Results of studies of branched circuits of sinusoidal current

Chain type	Parameters	U, B	I, A	I _R , A	I _L , A	I _C , A	T ₂ -T ₁ , with	φ , Degree
RL - Chain	$0.5L =$					-		
	$L =$					-		
	$2L =$					-		

RC - chain	0.5C=				-			
	C=				-			
	2C=				-			
RLC Chain	S<Cut							
	Cross-section=							
	C>Slice							

b) Study of the RC chain.

1. Assemble the diagram of the electrical circuit (Fig. 2).

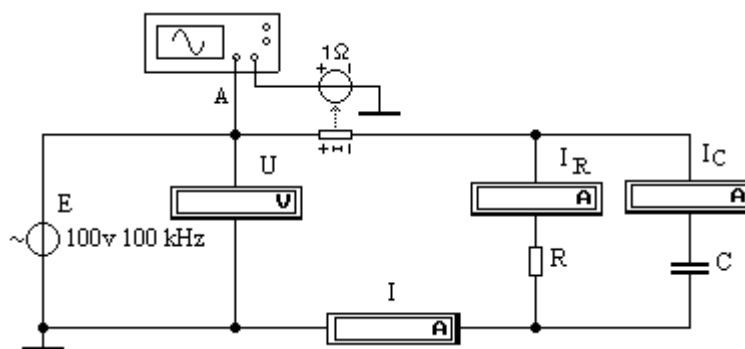


Figure 2 - Diagram of the study of the RC circuit.

•2. Set the values of resistor resistance R and capacitance of capacitor C specified according to the option, the value of the emf of the source $E = 150\text{ V}$ and the frequency $f = 105\text{ Hz}$. By double-clicking the left mouse button on the line of channel "A" of the oscilloscope, set the desired color of the channel (for example, red)

•3. After all the parameters of the circuit are set,  move the "0-1" button to the 1- "On" position. Upon completion of automatic calculations (a few seconds),  move the button to the 0- "Off" position. Enter the readings of ammeters and voltmeters in the table of test results

•4. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$ and enter it in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f$.

5. Set the capacitor capacitance to $0.5C$, perform steps 3-4.

6. Set the capacitance of the capacitor $2C$, perform steps 3-4.

7. Based on the results of the research, build vector diagrams of currents and voltages

8. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

c) Study of RLC circuits.

1. Assemble the diagram of the electrical circuit (Figure 3).

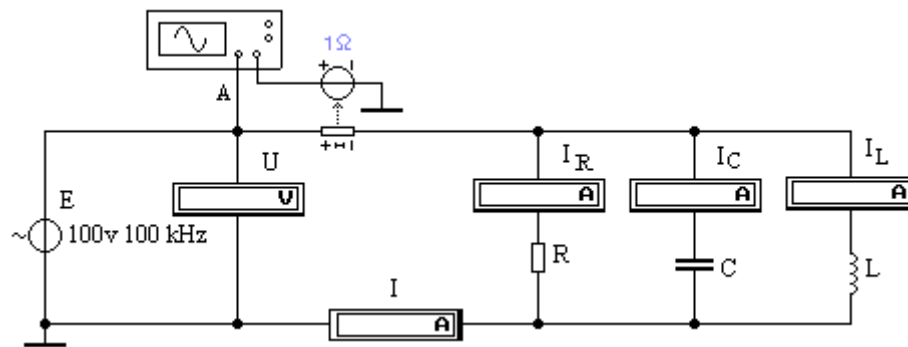


Figure 3 - Scheme of the RLC circuit study

- 2. Set the values of resistor resistance R , inductance L and capacitance of the capacitor, at which current resonance occurs in the circuit $C_{\text{рез}} = \frac{1}{4\pi^2 \cdot 10^{10} \cdot L}$, the value of EMF and frequency $f = 105 \text{ Hz}$ of the source E

- 3. After all the parameters of the circuit are set,  move the "0-1" button to the 1-"On" position. Upon completion of automatic calculations (a few seconds),  move the button to the 0-"Off" position. Enter the readings of ammeters and voltmeters in the table of test results

- 4. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$ and enter it in Table 2. Calculate the phase displacement between the voltage $u(t)$ and the current $i(t)$ in degrees according to the formula $\varphi = 360^\circ \cdot (T_2 - T_1) \cdot f$.

5. Set the capacitance of the capacitor $C < C$, perform points 3-4.

6. Set the capacitance of the capacitor $C > C$, perform steps 3-4.

7. Based on the results of the research, build vector diagrams of current and voltages

8. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

•

• **Contents of the report.**

The laboratory report should contain:

- research schemes;
- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;
- Vector diagrams of currents and voltages for each point of research;
- - conclusions based on the results of research.

• **Control questions:**

1. Plot the current $i(t) = 2\sin(\omega t - 1450)$ mA.
2. Write an expression for complex amplitude and effective current if instantaneous current $i(t) = 2\sin(\omega t - 1450)$ mA.
3. Plot a vector diagram for the harmonic current $i = 2\sin(\omega t - 1450)$ mA.
4. Write an expression of Ohm's law in a complex form for a section of the circuit with a resistive element and draw a vector diagram of current and voltage.
5. Write an expression of Ohm's law in complex form for a section of the circuit with an inductive element and depict a vector diagram of current and voltage.
6. Write the expression of Ohm's law in complex form for a section of the circuit with a capacitive element and depict a vector diagram of current and voltage.

Laboratory Work No5

Research of three-phase circuits

Objective: 1. Experimental study of three-phase circuits under symmetrical and asymmetrical loads.

2. Experimental study of three-phase circuits in emergency modes.

Task to prepare for laboratory work:

- familiarize yourself with the manual for laboratory work;
- perform a preliminary calculation according to the task option (Table 1):

Calculate currents, voltages, and power in a three-phase circuit with an asymmetrical receiver whose phases are connected by a star. Perform calculations of currents when a neutral wire is broken. Construct vector diagrams of currents and voltages.

Description of the study design

Studies are carried out on a PC in the Electronics Workbench environment. Study schemes contain AC voltage sources, resistors, oscilloscopes, voltmeters and ammeters. An oscilloscope is used to determine phase shifts of harmonic voltage.

Research task:

1. To study a three-phase circuit with a symmetrical and unbalanced receiver, the phases of which are connected according to the star scheme with a neutral wire. To construct vector diagrams of currents and voltages.

2. To study a three-phase circuit with a symmetrical and unbalanced receiver when a neutral wire is broken. To construct vector diagrams of currents and voltages.

3. Examine a three-phase circuit with an asymmetrical receiver when a line wire is broken. Construct vector diagrams of currents and voltages.

4. Investigate a three-phase circuit with an unbalanced receiver at a short circuit of the phase. Construct vector diagrams of currents and voltages

Table 1 - Variants of tasks for preliminary calculation and research

Option No	U _I , V	R _a , Ohm	R _â , Ohm	R _c , Ohm
1	360	10	15	20
2	120	20	15	30
3	150	50	40	30
4	170	60	40	20
5	225	80	60	50
6	300	50	25	30

7	100	20	35	40
8	110	60	30	45
9	125	50	80	70
10	220	20	25	30
11	360	10	15	20
12	120	20	15	30
13	150	50	40	30
14	170	60	40	20
15	225	80	60	50
16	300	80	60	50
17	100	50	25	30
18	110	20	35	40
19	125	60	30	45
20	220	50	80	70
21	360	20	25	30
22	120	10	15	20
23	150	20	15	30
24	170	50	40	30
25	225	60	40	20
26	300	80	60	50
27	100	80	60	50
28	110	20	25	30
29	125	10	15	20
30	220	20	15	30
31	360	50	40	30
32	120	60	40	20
33	150	80	60	50
34	200	60	80	65
35	300	30	25	35
36	100	20	15	25

Procedure for conducting research

a) Study of a three-phase circuit, connection of the phases of the receiver according to the scheme "star with neutral wire"

1. Assemble the diagram of the electrical circuit (Figure 1).

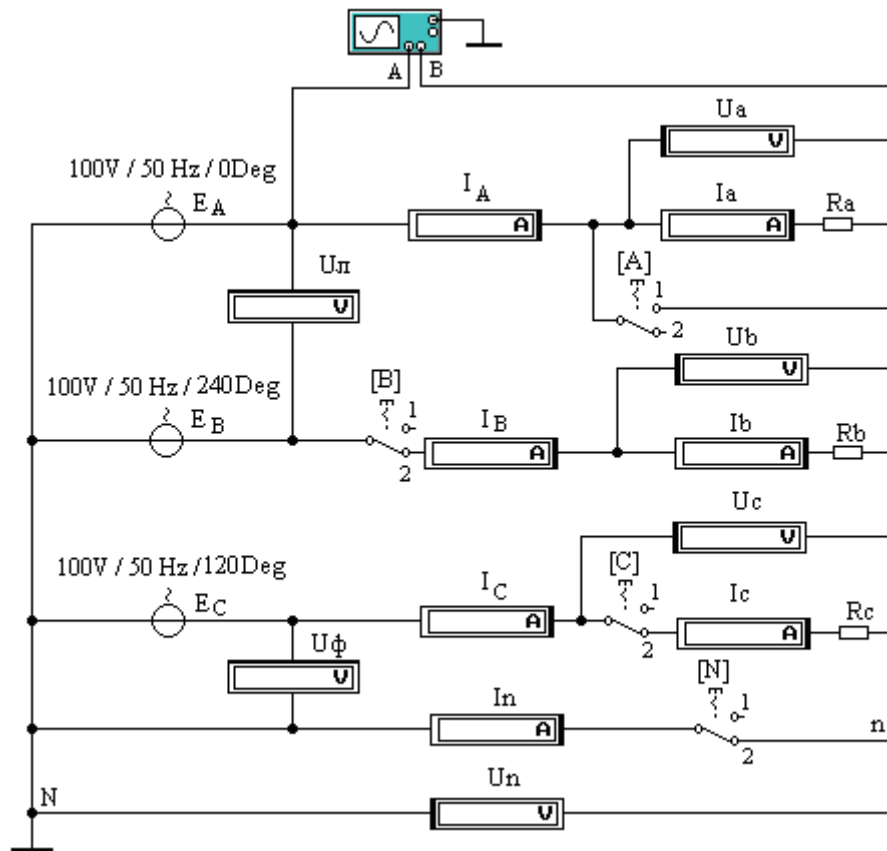


Figure 1 - Diagram of a three-phase circuit, a connection according to the "star" scheme

•2. Set the EMF values of phases, frequencies, initial phases of sources, values of phase resistances of receivers $R_a=R_b=R_c$ (symmetrical load) specified according to the option. For this purpose, the cursor is brought to the desired element and a window (with the name of the element) is called by double-clicking the left mouse button, in which the required parameter value is set and the "Accept" button is pressed. By double-clicking the left mouse button, set the red color of the channel on the line of channel A of the oscilloscope, and the blue color on the line of channel B.

•3. After the installation of all the parameters of the circuit is completed , the button - "0-1" located in the upper right corner of the screen is moved to the 1-"On" position. Upon completion of automatic calculations, the button  is moved to the 0-"Off" position. The readings of ammeters and voltmeters are entered into the table of calculated and experimental data.

Table 1 - Results of calculations and studies of a three-phase circuit (connection of receiver phases according to the star scheme)

Circuit diagram	Circuit Modes		Network voltages, V				Linear currents, A			Currents in receiver phases, A			Receiver phase voltages, V		
			U _l	U _f	U _n	I _n	I _A	I _B	I _C	I _a	I _b	I _c	U _a	U _b	U _c
Neutral Wire Star	Symmetrical Load	Calculation													
		Experiment													
Star without neutral wire	Symmetrical Load	Calculation													
		Experiment													
Neutral Wire Star	Asymmetrical Load	Calculation													
		Experiment													
	Receiver "c" phase break	Calculation													
		Experiment													
	Break in line wire "B"	Calculation													
		Experiment													
Star without neutral wire	Asymmetrical Load	Calculation													
		Experiment													
	Receiver Phase A Short Circuit	Calculation													
		Experiment													
	Cliff Receiver Phase C	Calculation													
		Experiment													
	Break in line wire "B"	Calculation													
		Experiment													

- 4. Based on the measurement results, build vector diagrams of currents and voltages.
- 5. In the diagram of the electrical circuit (Fig. 1), switch N to position 1 (press the N key on the keyboard).
- 6. Perform steps 3, 4.
- 7. To draw conclusions based on the results of research.
- 8. In the circuit diagram (Fig. 1), switch N is moved to position 2
- 9. Set the phase resistance values of the receivers R_a, R_b, R_c (unbalanced load) set according to the option.
- 10. Perform steps 3, 4, 7.
- 11. In the diagram of the electrical circuit (Fig. 1), switch C should be moved to position 1 (press the C key on the keyboard). In the diagram there is an open phase C.

- 12. Perform steps 3, 4, 7.

13. In the electrical circuit diagram (Fig. 1), switch C should be moved to position 2 and line wire B should be disconnected (switch B should be moved to position 1).

14. Complete steps 3, 4, 7.

15. Switch B to position 2.

b) Study of a three-phase circuit, connection of receiver phases according to the "star without neutral wire" scheme.

1. In the circuit diagram (Fig. 1), switch N to position 1 (press the N key on the keyboard).

•2. Move the button (0-1) to position (1). Upon completion of automatic calculations, the button (0-1) is moved to position (0). The readings of ammeters and voltmeters are entered into the table of calculated and experimental data.

•3. Double-click the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sighting ruler 1 (red) at the point of intersection of the time axis with the oscillogram of channel A when it transitions from negative to positive value, and the sight ruler 2 (blue) at the point of intersection of the time axis with the oscillogram of channel B when it transitions from negative to positive value. In the lower right window of the oscilloscope, the value of the time interval $T_2 - T_1$ will appear. The phase shift between the voltages U_A and U_n in degrees is calculated using the formula $\psi_{12} = -360^\circ \cdot (T_2 - T_1) \cdot f$. Here, f is the frequency of the sinusoidal EMF of the source.

•4. Based on the measurement results, build vector diagrams of currents and voltages.

•5. To draw conclusions based on the results of research.

Study of a three-phase circuit, connection of receiver phases according to the "star without neutral wire" scheme in case of a short circuit of one of the phases.

6. In the diagram of the electrical circuit (Fig. 1), switch A to position 1 (press the A key on the keyboard)

•7. Complete steps 3, 4, 5.

8. Switch A to position 2

Study of a three-phase circuit, connection of receiver phases according to the "star" scheme in case of receiver phase interruption

9. In the circuit diagram (Fig. 1), switch C to position 1 (press the C key on the keyboard).

•10. Perform steps 2, 3, 4, 5.

11. Switch C to position 2

Study of a three-phase circuit, connection of receiver phases according to the "star" scheme in case of a line wire break

10. In the diagram of the electrical circuit (Fig. 2), switch B to position 1 (press the key B on the keyboard).

- 11. Complete steps 2, 3, 4, 5.

-

- **Contents of the report.**

The laboratory report should contain:

- research schemes;
- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;
- - conclusions based on the results of research.

- **Control questions:**

1. What are the advantages of a three-phase system of currents and voltages?
2. Under what conditions is a three-phase system symmetrical?
3. How are currents calculated in an asymmetrical receiver whose phases are connected in a star-neutral wire pattern?
4. How are currents calculated in an unbalanced receiver whose phases are connected according to the star scheme without a neutral wire?
5. What role does a neutral wire play in a three-phase system?
6. How is the neutral offset voltage (U_n) calculated for a single-ended receiver whose phases are connected in a star pattern without a neutral wire?

Investigation of frequency characteristics of aperiodic circuits

Purpose of the work:

1. Experimental Study of Amplitude-Frequency and Phase-Frequency Characteristics of First-Order Electrical Circuits
2. Experimental study of frequency characteristics of second-order electrical circuits.
- 3.

Task to prepare for laboratory work:

- perform a preliminary calculation according to the task option (Table 1):
 - a) the amplitude-frequency and phase-frequency characteristics (AFC and PFC) of the low-frequency link of the first order (LF-1) and plot their graphs.
 - b) amplitude-frequency and phase-frequency characteristics (AFC and PFC) of the first-order high-frequency link (HF-1) and plot their graphs.
 - c) the amplitude-frequency and phase-frequency characteristics of the bandwidth link (PD) and plot them.

Description of the study design

Studies are carried out on a PC in the Electronics Workbench environment. Study schemes contain AC voltage sources, resistors, capacitors, oscilloscopes, voltmeters. An oscilloscope is used to determine phase shifts of harmonic voltages.

Research task:

1. To study the amplitude-frequency and phase-frequency characteristics of the low-frequency link of the first order (LF-1) and to plot their graphs.
2. To study the amplitude-frequency and phase-frequency characteristics of the high-frequency link of the first order (HF-1) and to plot their graphs.
3. To study the amplitude-frequency and phase-frequency characteristics of the bandwidth link (PD) and to build graphs.

Table 1 Variants of tasks for preliminary calculation and research

Option No	R1, kΩ	C1, μF	R2, kΩ	C2, μF	Option No	R1, kΩ	C1, μF	R2, kΩ	C2, μF
1	1.1	1.0	10	0.2	31	1.0	2.0	20	0.3
2	1.2	2.0	15	0.1	32	1.2	0.1	30	0.4
3	1.5	0.1	20	2.0	33	1.5	0.2	40	0.4
4	1.7	0.2	30	1.0	34	1.7	0.8	25	0.7
5	2.5	0.8	40	0.5	35	2.5	5.0	35	0.1
6	3.0	5.0	25	0.3	36	3.0	2.0	30	0.2
7	1.0	2.0	35	0.4	37	1.0	6.0	80	0.3
8	1.1	6.0	30	0.4	38	1.1	5.0	25	0.4
9	1.2	5.0	80	0.7	39	1.2	2.0	15	0.2
10	2.2	2.0	25	0.1	40	2.2	1.0	15	1.0
11	3.6	1.0	15	0.2	41	3.6	2.0	40	1.1
12	1.2	2.0	15	0.3	42	1.2	5.0	50	1.2
13	1.5	5.0	40	0.4	43	1.5	6.0	60	2.2
14	1.7	6.0	50	0.2	44	1.7	1.0	60	3.6
15	2.5	1.0	60	1.0	45	2.5	1.1	25	1.2
16	3.0	1.1	60	1.1	46	3.0	1.2	35	1.5
17	1.0	1.2	25	1.2	47	1.0	2.2	30	1.7
18	1.1	2.2	35	2.2	48	1.1	3.6	80	2.5
19	1.2	3.6	30	3.6	49	1.2	2.0	25	3.0
20	2.2	1.2	80	1.2	50	2.2	0.1	15	1.0
21	3.6	1.5	25	1.5	51	1	0.2	15	1.1
22	1.2	1.7	15	1.7	52	1.2	0.8	40	1.2
23	1.5	2.5	15	2.5	53	1.5	5.0	40	2.2
24	1.7	3.0	40	3.0	54	1.7	2.0	60	0.3
25	2.5	1.0	40	1.0	55	2.5	6.0	60	0.4
26	3.0	1.1	60	1.1	56	3.0	5.0	20	0.4
27	1.0	1.2	60	1.2	57	1.0	2.0	30	0.7
28	1.1	2.2	25	2.2	58	1.1	1.0	40	0.1
29	1.2	3.6	15	3.6	59	1.2	2.0	25	0.2
30	2.2	1.2	15	1.2	60	2.2	5.0	35	0.3

a) Study of the amplitude-frequency phase-frequency characteristics (AFC and PFC) of the low-frequency link of the first order (LF-1)

•2. Calculate $f_{\text{rp}} = \frac{1}{2 \cdot \pi \cdot R1 \cdot C1}$. Fill in line 2 of Table 2.

•3. After completing the installation of all circuit parameters, move the button  - "0-1" to the 1-"On" position. Upon completion of automatic calculations, move the button to the 0-"Off" position. Enter the voltmeter readings in the table of test results

[illegible]

- 4. Double-click the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sighting ruler 1 (red) at the point of intersection of the time axis with the oscillogram of channel "A" when it transitions from negative to positive value, and sight ruler 2 at the point of intersection of the time axis with the oscillogram of channel "B" when it transitions from negative to positive value. $\psi(f) = -360^\circ \cdot (T_2 - T_1) \cdot f$

- 5. Changing the frequency f of the source according to Table 2, perform points 3-4.

6. Based on the results of the research, build graphs of the frequency response and frequency response of the LF-1 link

b) Study of amplitude-frequency and phase-frequency characteristics (AFC and PFC) of the first-order high-frequency link (HF-1)

1. Assemble an electrical circuit diagram (Figure 2).

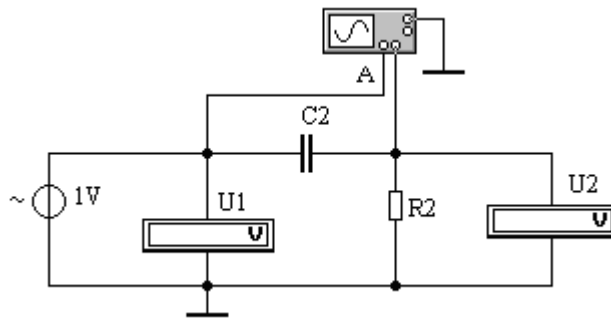


Figure 2 - Scheme for studying the frequency characteristics of the VCh-1

- 2. Calculate $f_{ip} = \frac{1}{2 \cdot \pi \cdot R_2 \cdot C_2}$. Fill in line 2 of the table of calculated and experimental data.

data.

- 3. Set the value of the resistance of the resistor R_2 and the capacitance of the capacitor C_2 specified according to the option, the value of the EMF of the source $E = 1B$ and the frequency $f = 0.01f_{gr}$.

- 4. After completing the installation of all the parameters of the circuit,  move the button - "0-1" located in the upper right corner of the screen to the 1-"On" position. Upon completion of automatic calculations , move the button to the 0-"Off" position. Enter the voltmeter readings in the table of calculated and experimental data.

- 5. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$. Calculate and enter into the table the phase shift between the voltages U_2 and U_1 in degrees according to the formula $\psi(f) = -360^\circ \cdot (T_2 - T_1) \cdot f$.

6. Changing the frequency f of the source according to Table 2, perform points 4-5.

7. Based on the results of the research, build graphs of the frequency response and frequency response of the HF-1 link

c) Study of the amplitude-frequency and phase-frequency characteristics (frequency response and phase-frequency characteristics) of the bandwidth link

1. Assemble the diagram of the electrical circuit (Figure 3).

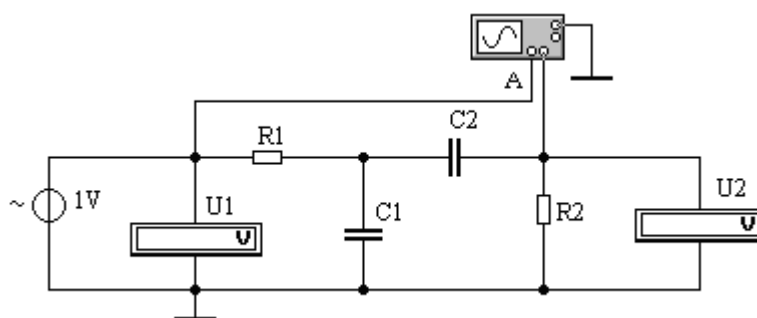


Figure 3 - Scheme for studying the frequency characteristics of the bandwidth link

•2. Calculate $f_0 = \frac{1}{2\pi\sqrt{R_1 \cdot C_1 \cdot R_2 \cdot C_2}}$.

• Fill in line 2 of the table of calculated and experimental data.

•3. Set the values of resistances of resistors R1, R2 and capacitances of capacitors C1, C2 specified according to the option, the value of the EMF of the source $E = 1V$ and the frequency $f = 0.01f_0$.

•4. After completing the installation of all the parameters of the circuit,  move the button - "0-1" located in the upper right corner of the screen to the 1-"On" position. Upon completion of automatic calculations , move the button to the 0-"Off" position. Enter the voltmeter readings in the table of calculated and experimental data.

•5. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$. Calculate the phase shift between the voltages U2 and U1 in degrees using the formula $\psi(f) = -360^\circ \cdot (T_2 - T_1) \cdot f$

6. Changing the frequency f of the source according to the table, perform points 4-5.

7. Based on the results of the research, build graphs of the frequency response and frequency response of the bandwidth link. Determine the bandwidth according to the frequency response graph. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

•Contents of the report

The laboratory report should contain:

- research schemes;
- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;
- Frequency response and HF graphs of links;
 - conclusions based on the results of research.
 - Control questions:**
 1. Draw a diagram of a low-frequency link of the first order.
 2. Define the complex transfer characteristic of a chain.
 3. Write an expression for the complex transfer function of a first-order low-frequency link.
 4. Define the amplitude-frequency response of a circuit.
 5. Plot the amplitude-frequency and phase-frequency characteristics of the first-order low-frequency link.
 6. How can the boundary frequency be determined from the graph of the amplitude-frequency response of the first-order low-frequency link?
 7. Write down the expression for the complex transfer function of the band link.
 8. How can you determine the boundary frequencies from the graph of the amplitude-frequency response of the bandwidth?

Laboratory Work No7

Investigation of Frequency Characteristics of Single Oscillating Circuits

Purpose of the work:

1. Experimental Study of Amplitude-Frequency and Phase-Frequency Characteristics of a Sequential Oscillatory Circuit
2. Experimental Study of Amplitude-Frequency and Phase-Frequency Characteristics of a Parallel Oscillating Circuit

Task to prepare for laboratory work:

- perform a preliminary calculation according to the task option (Table 1):
 - a) the amplitude-frequency and phase-frequency characteristics (frequency response and phase-frequency characteristics) of the sequential oscillating circuit and plot them.
 - b) the amplitude-frequency and phase-frequency characteristics (AFC and PFC) of the parallel oscillating circuit and plot them.

Description of the study design

Studies are carried out on a PC in the Electronics Workbench environment. Study schemes contain AC voltage sources, resistors, capacitors, oscilloscopes, voltmeters. An oscilloscope is used to determine phase shifts of harmonic voltages.

Research task:

1. To study the amplitude-frequency and phase-frequency characteristics of a sequential oscillating circuit and to plot them.
2. To study the amplitude-frequency and phase-frequency characteristics of a parallel oscillating circuit and to plot their graphs.

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- Table 1

• Option No	• R, Ohm	• L, μ H	• S, pF	• E, B	• Ri, kOhm
• 0	• 50	• 500	• 2000	• 10	• 10
• 1	• 10	• 300	• 2000	• 12	• 10
• 2	• 4	• 310	• 1600	• 7	• 8
• 3	• 7	• 200	• 1200	• 15	• 12
• 4	• 16	• 400	• 1700	• 11	• 9
• 5	• 5	• 360	• 2400	• 16	• 14
• 6	• 6	• 370	• 1650	• 5	• 15
• 7	• 8	• 250	• 1300	• 6	• 17
• 8	• 9	• 335	• 2400	• 14	• 18
• 9	• 3	• 400	• 2500	• 18	• 13
• 10	• 7	• 380	• 1700	• 13	• 10
• 11	• 10	• 390	• 2650	• 16	• 12
• 12	• 4	• 210	• 2250	• 22	• 16
• 13	• 7	• 200	• 1260	• 17	• 8
• 14	• 16	• 400	• 1520	• 25	• 12
• 15	• 5	• 360	• 2270	• 10	• 9
• 16	• 6	• 330	• 1240	• 12	• 14
• 17	• 8	• 250	• 1465	• 15	• 15
• 18	• 9	• 435	• 1300	• 16	• 17
• 19	• 3	• 630	• 2400	• 17	• 18
• 20	• 6	• 425	• 1700	• 12	• 13
• 21	• 10	• 300	• 2450	• 14	• 12
• 22	• 7	• 200	• 1600	• 10	• 7
• 23	• 16	• 500	• 1200	• 12	• 12
• 24	• 5	• 360	• 2470	• 7	• 9
• 25	• 6	• 400	• 1630	• 15	• 14

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• Procedure for conducting research

a) Study of the amplitude-frequency phase-frequency characteristics (AFC and PFC) of a sequential oscillating circuit

1. Assemble the diagram of the electrical circuit (Figure 1).

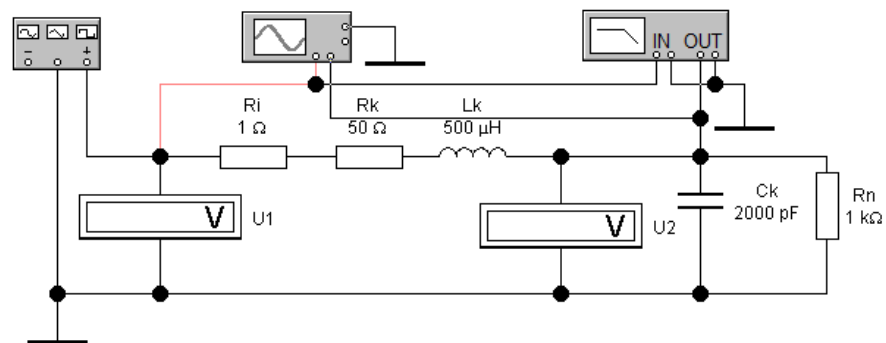


Figure 1 - Scheme for studying the frequency characteristics of a sequential oscillating circuit

- 2. Calculate $f_0 = \frac{1}{2 \cdot \pi \cdot \sqrt{L_k \cdot C_k}}$. Fill in line 2 of Table 2.

•Set the value of the EMF of the source $E=1B$ and its frequency $f = f_0$ specified according to the variant of resistor resistance R_1 and capacitance C_1 . Switch the voltmeters to the AC measurement mode. Double-click the left mouse button on the line of channel "A" of the oscilloscope, set the color red, on the line of channel "B" - blue.

- 3. After completing the installation of all circuit parameters, move the button  - "0-1" to the 1-"On" position. Upon completion of automatic calculations , move the button to the 0-"Off" position. Enter the voltmeter readings in the table of test results

•Table 2 - Results of studies of the sequential oscillating circuit

• f, Hz	• •	• • •	• • f0=	• •	• • •	• •
• U2, B	• • 0.1U2max	• • • 0.7U2max	• • U2max	• • 0.7U2max	• • • 0.1U2max	• •
• U1, B	• •	• • •	• •	• •	• • •	• •
• H(f)	• •	• • •	• •	• •	• • •	• •
• T2- T1, with	• •	• • •	• •	• •	• • •	• •
• $\psi(f)$,degree	• •	• • •	• •	• •	• • •	• •

- 4. Double-click the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sighting ruler 1 (red) at the point of intersection of the time axis with the oscillogram of channel "A" when it transitions from negative to positive value, and sight ruler 2 at the point of intersection of the time axis with the oscillogram of channel "B" when it transitions from negative to positive value. $\psi(f) = -360^\circ \cdot (T_2 - T_1) \cdot f$

- 5. Changing the frequency f of the source according to Table 2, perform points 3-4.

6. Based on the results of the research, build graphs of frequency response and frequency response.

b) Study of the amplitude-frequency and phase-frequency characteristics (frequency response and phase-frequency characteristics) of a parallel oscillating circuit

1. Assemble an electrical circuit diagram (Figure 2).

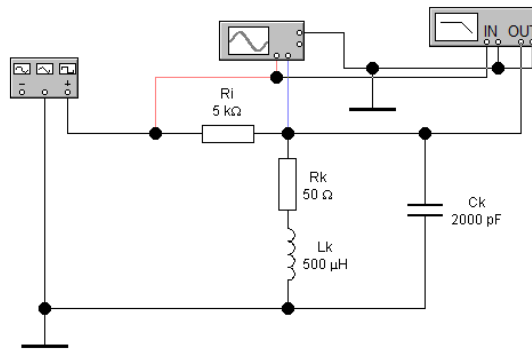


Figure 2 - Scheme for studying the frequency characteristics of a parallel oscillating circuit

- 2. Calculate $f_0 = \frac{1}{2 \cdot \pi \cdot \sqrt{L_k \cdot C_k}}$. Fill in line 2 of the table of calculated and experimental data.
- 3. Set the values of the resistance of the resistor R2 and the capacitance of the capacitor C2 according to the option, the value of the EMF of the source $E=1B$ and the frequency $f = f_0$.
- 4. After completing the installation of all the parameters of the circuit,  move the button - "0-1" located in the upper right corner of the screen to the 1-"On" position. Upon completion of automatic calculations , move the button to the 0-"Off" position. Enter the voltmeter readings in the table of calculated and experimental data.
- 5. Using an oscilloscope, determine the value of the time interval T_2-T_1 . Calculate and enter into the table the phase shift between the voltages U_2 and U_1 in degrees according to the formula $\psi(f) = -360^\circ \cdot (T_2 - T_1) \cdot f$.
- 6. Changing the frequency f of the source according to Table 2, perform points 4-5.
- 7. Based on the results of the research, build graphs of frequency response and frequency response

•Contents of the report

The laboratory report should contain:

- research schemes;
- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;
- Graphs of frequency response and frequency response of circuits;
- - conclusions based on the results of research.

•Control questions:

Draw a diagram of a parallel oscillating circuit

1. Define the complex transfer characteristic of a chain.

2. Write down the expression for the complex transfer function of a parallel oscillating loop
3. Define the amplitude-frequency response of a circuit.
4. Plot the amplitude-frequency and phase-frequency characteristics of the oscillating circuit.
5. How can the bandwidth be determined from the graph of the amplitude-frequency response of the loop?

Study of the Temporal Characteristics of Aperiodic Chains

Purpose of the work:

1. Experimental Study of Transient and Impulse Characteristics of Electrical Circuits of the First Order
2. Experimental study of transient and impulse characteristics of second-order electrical circuits.

Task to prepare for laboratory work:

- perform a preliminary calculation according to the task option (Table 1):
 - a) transient and impulse characteristics of the low-frequency link of the first order (LF-1) and plot their graphs.
 - b) transient and impulse characteristics of the first-order high-frequency link (HF-1) and plot their graphs.
 - c) transient and impulse characteristics of the strip link (BZ) and plot graphs.

Description of the study design

Studies are carried out on a PC in the Electronics Workbench environment. Study schemes contain AC voltage sources, resistors, capacitors, oscilloscopes, voltmeters. An oscilloscope is used to determine phase shifts of harmonic voltages.

Research task:

1. To study the transient and impulse characteristics of the low-frequency link of the first order (LF-1) and to plot their graphs.
2. To study the transient and impulse characteristics of the first-order high-frequency link (HF-1) and to plot their graphs.
3. To study the transient and impulse characteristics of the bandwidth link (BZ) and to build graphs.

Option No	R1, kΩ	C1, μF	R2, kΩ	C2, μF	Option No	R1, kΩ	C1, μF	R2, kΩ	C2, μF
1	1.1	1.0	10	0.2	31	1.0	2.0	20	0.3
2	1.2	2.0	15	0.1	32	1.2	0.1	30	0.4
3	1.5	0.1	20	2.0	33	1.5	0.2	40	0.4
4	1.7	0.2	30	1.0	34	1.7	0.8	25	0.7
5	2.5	0.8	40	0.5	35	2.5	5.0	35	0.1
6	3.0	5.0	25	0.3	36	3.0	2.0	30	0.2
7	1.0	2.0	35	0.4	37	1.0	6.0	80	0.3
8	1.1	6.0	30	0.4	38	1.1	5.0	25	0.4
9	1.2	5.0	80	0.7	39	1.2	2.0	15	0.2
10	2.2	2.0	25	0.1	40	2.2	1.0	15	1.0
11	3.6	1.0	15	0.2	41	3.6	2.0	40	1.1
12	1.2	2.0	15	0.3	42	1.2	5.0	50	1.2
13	1.5	5.0	40	0.4	43	1.5	6.0	60	2.2
14	1.7	6.0	50	0.2	44	1.7	1.0	60	3.6
15	2.5	1.0	60	1.0	45	2.5	1.1	25	1.2
16	3.0	1.1	60	1.1	46	3.0	1.2	35	1.5
17	1.0	1.2	25	1.2	47	1.0	2.2	30	1.7
18	1.1	2.2	35	2.2	48	1.1	3.6	80	2.5
19	1.2	3.6	30	3.6	49	1.2	2.0	25	3.0
20	2.2	1.2	80	1.2	50	2.2	0.1	15	1.0
21	3.6	1.5	25	1.5	51	1	0.2	15	1.1
22	1.2	1.7	15	1.7	52	1.2	0.8	40	1.2
23	1.5	2.5	15	2.5	53	1.5	5.0	40	2.2
24	1.7	3.0	40	3.0	54	1.7	2.0	60	0.3
25	2.5	1.0	40	1.0	55	2.5	6.0	60	0.4
26	3.0	1.1	60	1.1	56	3.0	5.0	20	0.4
27	1.0	1.2	60	1.2	57	1.0	2.0	30	0.7
28	1.1	2.2	25	2.2	58	1.1	1.0	40	0.1
29	1.2	3.6	15	3.6	59	1.2	2.0	25	0.2
30	2.2	1.2	15	1.2	60	2.2	5.0	35	0.3

Procedure for conducting research

(a) Transient and impulse response study of the first-order low-frequency link (LF-1)

1. Assemble the diagram of the electrical circuit (Figure 1).

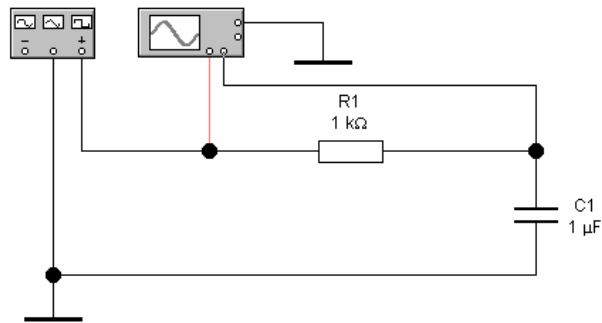
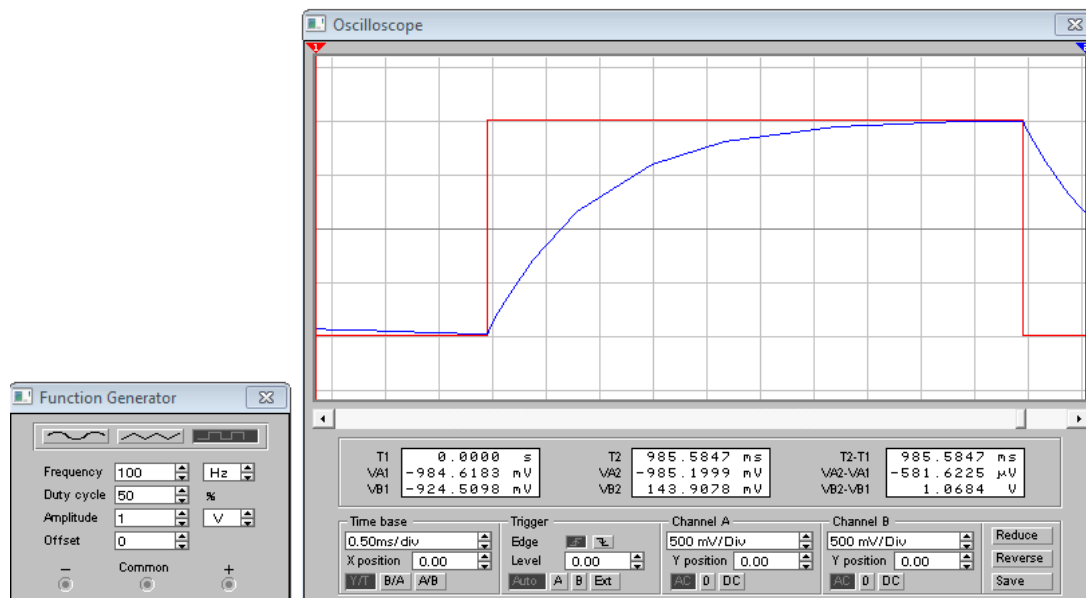


Figure 1 - Scheme of the study of the time characteristics of the NP-1

2. Set the parameters of the generator and oscilloscope according to Figure 2.



3. Take an oscillogram of the transient response. Using the transient response graph, determine the constant of the circuit time, the duration of the transient process.
4. Increase the resistance $R1$ by 2 times. Repeat step 3
5. Reduce the resistance $R1$ by 2 times. Repeat step 3
6. To draw a conclusion about the effect of $R1$ on the time characteristic of the circuit
7. Set the oscillator to a pulse duty cycle of 0.1%

8. Take an oscillogram of the impulse response. Use the impulse response graph to determine the time constant of the circuit, the duration of the transition process.

9. Repeat p. 4-6

b) Study of the time characteristics of the first-order high-frequency link (HF-1)

1. Assemble an electrical circuit diagram (Figure 2).

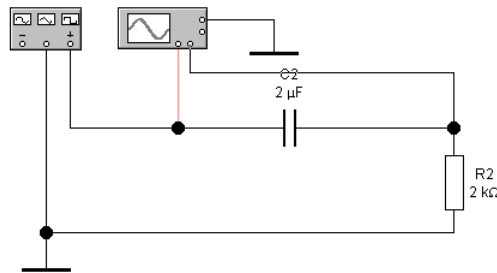


Figure 2 - Scheme of the study of the temporal characteristics of the VCh-1

2. Repeat p. 3-9

c) Study of the time characteristics of the strip link

1. Assemble the diagram of the electrical circuit (Figure 3).

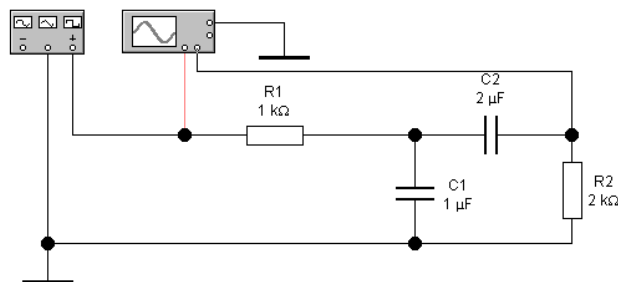


Figure 3 - Scheme of the study of the time characteristics of the strip link

2. Repeat p. 3-9

•Contents of the report

The laboratory report should contain:

- research schemes;
- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;
- graphs of time characteristics of links;
 - - conclusions based on the results of research.

•Control questions:

1. Draw a diagram of a low-frequency link of the first order.
2. Draw a diagram of a high-frequency link of the first order.
3. Define the transient response of a circuit.
4. Write an expression for the transient response of the first-order low-frequency link.
5. Define the impulse response of a circuit.
6. Write down the expression for the first-order low-frequency link impulse response.

Laboratory Work No 9

Four-Pole Study

Purpose of the work:

1. Experimental determination of the primary parameters of four-poles.
2. Experimental determination of the secondary parameters of four-poles.
3. Experimental study of four-poles under matched and uncoordinated loads.

Task to prepare for laboratory work:

1. Familiarize yourself with the manual for laboratory work;
2. Perform a preliminary calculation according to the task option (Table 1):
 - 2.1. Calculate the A-parameters of four-poles.
 - 2.2. Calculate the secondary parameters of four-poles.
 - 2.3. Calculate the operating parameters of four-pole valves.

Description of the study design

Studies are carried out on a PC in the Electronics Workbench environment. Study schemes contain AC voltage sources, resistors, oscilloscopes, voltmeters and ammeters. An oscilloscope is used to determine phase shifts of harmonic voltage.

Research task:

- a) Determine the A-parameters of the specified four-poles.
- b) Determine the secondary (characteristic) parameters of the given four-poles.
- c) Examine the operating parameters of the specified four-poles.

Table 1 - Variants of tasks for preliminary calculation and research

Option No	Eg, V	f, kHz	R1, Ohm	C2, μ F	R3, Ohm	Rg, Ohm	Rh, Ohm
0	100	10	10	3.183	10	10	20
1	110	12	15	2.9	15	12	25
2	120	14	20	3.1	20	18	30
3	130	16	25	2.2	25	20	26
4	140	18	20	2.5	20	11	28
5	150	20	30	2.6	30	13	20

6	160	11	26	2.8	26	15	10
7	170	13	28	3.5	28	17	20
8	180	15	20	3.0	20	19	30
9	190	17	10	2.7	10	18	26
10	200	19	20	2.5	20	20	28
11	100	12	25	3.1	25	10	25
12	110	14	20	2.2	20	15	30
13	120	16	30	2.5	30	20	26
14	130	18	26	2.6	26	25	28
15	140	20	28	2.8	28	20	20
16	150	11	20	3.5	20	30	10
17	160	13	10	3.0	10	26	20
18	170	15	20	2.7	20	28	30
19	180	17	25	2.5	25	20	26
20	190	19	30	3.1	30	19	28
21	200	11	26	2.2	26	18	25
22	100	13	28	2.5	28	20	30
23	110	15	20	2.5	20	10	26
24	120	17	10	3.1	10	15	28
25	130	19	20	2.2	20	20	20
26	140	12	25	2.5	25	25	20
27	150	14	20	2.6	20	20	30
28	180	17	30	2.8	30	30	26
29	190	19	26	3.5	26	26	28
30	200	11	28	3.0	28	28	25
31	100	13	20	2.7	20	20	30
32	110	15	10	2.5	10	25	26
33	120	17	20	3.1	20	20	28
34	120	18	15	3.0	15	15	28
35	130	16	20	2.0	20	20	10

•

• Procedure for conducting research

a) Determination of A-parameters of given four-poles

1. Assemble the diagram of the electrical circuit (Figure 1).

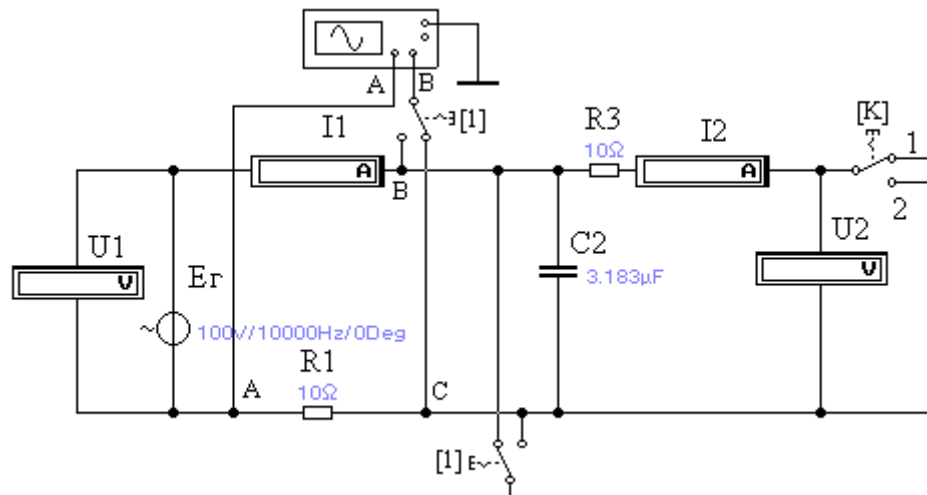


Figure 1

2. Set the EMF values, source frequency, and values of the four-pole circuit elements specified according to the option. For this purpose, the cursor is brought to the desired element and by double-clicking the left mouse button, a window (with the name of the element) is called, in which the required parameter value is set and the "Accept" button is pressed. Use switch 1 to connect the oscilloscope channel "B" to the C clamp (press the 1 key on the keyboard if necessary). By double-clicking the left mouse button on the oscilloscope channel A line, set the channel color to red, and on the channel B line - the channel color blue.

3. In the diagram, set the **idle mode**: switch "K" to position 1 (press the K key on the keyboard).

•4. After the installation of all the parameters of the scheme is completed , the button - "0-1" located in the upper right corner of the screen is moved to the 1-"On" position. Upon completion of automatic calculations, the button  is moved to the 0-"Off" position.

•The readings of ammeters and voltmeters should be entered in the table of calculated and experimental data (Table 2).

•Table 2 - Calculated and experimental data

• Mode • Single • Course	• U 1, B	• I1 , A	• I 2, A	• U 2, B	• T2- T1, S	• ψ_{12} , deg	• T2- T1, S	• φ_{ui} , Deg	• A - parameters			
									• A11		• A21	
									• e xp	• C calcul atio n	• e xp	• C calcul atio n
	•	•	•	•	•	•	•	•	•	•	•	•
	•											
• Mode • Short circuit	• U 1, B	• I1 , A	• I 2, A	• U 2, B	• T2- T1, S	• ψ_{12} , deg	• T2- T1, S	• φ_{ui} , Deg	• A - parameters			
									• A12		• A22	
									• e xp	• C calcul atio n	• e xp	• C calcul atio n
	•	•	•	•	•	•	•	•	•	•	•	•
	•											

• Press the left mouse button on the oscilloscope image to activate it and switch it to the "Zoom" mode. Set the sight ruler 1 (red) at the point of intersection of the time axis with the oscillogram of channel A when it transitions from negative to positive value, and sight ruler 2 (blue) at the point of intersection of the time axis with the oscillogram of channel B when it transitions from negative to positive value. In the lower right window of the oscilloscope, the value of the time interval T2-T1 will appear. The phase shift between the voltages U1xx and U2xx in degrees is calculated using the formula $\psi_{12} = 360^0 \cdot (T2 - T1) \cdot f$. Here f is the frequency of the sinusoidal EMF of the source.

5. Use switch 1 to connect the "B" channel of the oscilloscope to the "B" clamp (press the 1 key on the keyboard). Using the oscilloscope, determine the value of the time interval $T_2 - T_1$. Calculate the phase shift between the current I_{1xx} and the voltage U_{2xx} in degrees according to the formula $\varphi_{ui} = 180 + 360^\circ \cdot (T_2 - T_1) \cdot f$.

•6. Based on the results of measuring the voltages U_{1xx} , U_{2xx} , current I_{1xx} and phase shifts, calculate the primary parameters $\underline{A}_{11} = \frac{U_1^{xx}}{U_2^{xx}} e^{j\psi_{12}}$ and $\underline{A}_{21} = \frac{I_1^{xx}}{U_2^{xx}} e^{j\varphi_{ui}}$.

7. In the diagram (Figure 1), set **the short-circuit mode**: switch "K" to the "On" position (press the K key on the keyboard).

8. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$. Calculate the phase shift between the current I_{1kz} and the current I_{2kz} in degrees using the formula $\psi_{ii} = 180 + 360^\circ \cdot (T_2 - T_1) \cdot f$

9. Use switch 1 to connect channel "B" of the oscilloscope to the clip "C" of the circuit (press the key 1 on the keyboard). Using the oscilloscope, determine the value of the time interval $T_2 - T_1$. Calculate the phase shift between the voltage U_{1kz} and the current I_{2kz} in degrees using the formula $\varphi_{iu} = 360^\circ \cdot (T_2 - T_1) \cdot f$

10. Write down the readings of voltmeters and ammeters. Based on the results of measuring the voltage U_{1kz} , currents I_{1kz} , I_{2kz} and phase shifts, calculate the primary parameters $\underline{A}_{12} = \frac{U_1^{K3}}{I_2^{K3}} e^{j\varphi_{iu}}$ and $\underline{A}_{22} = \frac{I_1^{K3}}{I_2^{K3}} e^{j\psi_{ii}}$. Check the correctness of the determination of the primary parameters using the equation of connection $\underline{A}_{11} \underline{A}_{22} - \underline{A}_{12} \underline{A}_{21} = 1$.

11. Compare the results of preliminary calculations of primary parameters with the results of research. Draw conclusions.

b) Determination of secondary parameters of specified four-poles

1. Assemble the diagram of the electrical circuit (Figure 2).

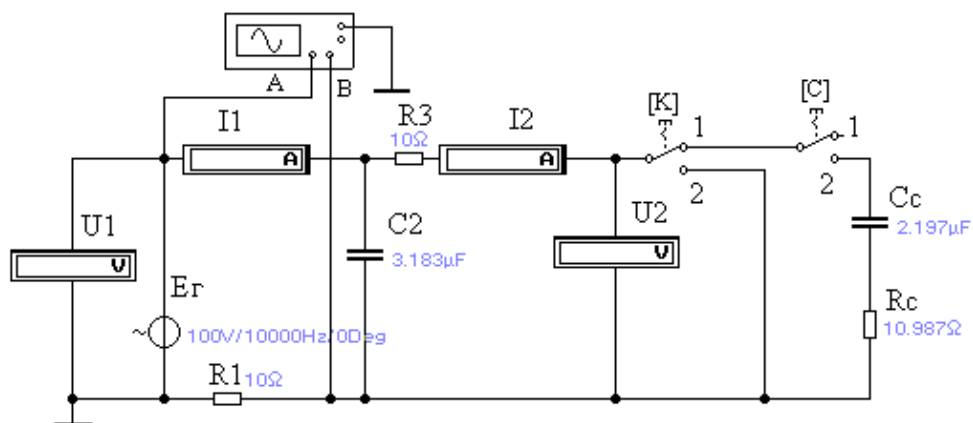


Figure 2

2. Set the EMF values, source frequency, and values of the four-pole circuit elements specified according to the option.

3. In the diagram, set the **idle mode**: switch "K" to position 1 "Off" (press the K key on the keyboard).

• 4. After all the parameters of the circuit are set, move the button (0-1) to the "On (1)" position. Upon completion of automatic calculations, the button (0-1) is moved to the "Off (0)" position. The readings of ammeters and voltmeters, the value of the time interval $T_2 - T_1$ should be entered into the table of calculated and experimental data. The phase shift between the voltage U_{1xx} and the current I_{1xx} in degrees should be calculated using the formula $\varphi_{ui} = 360^\circ \cdot (T_2 - T_1) \cdot f$

• 7. Calculate the complex resistance based on the results of measurements of voltage U_{1xx} , current I_{1xx} and phase displacement $\underline{Z}_{1x} = \frac{U_{1xx}}{I_{1xx}} e^{j\varphi_{ui}}$.

8. In the diagram (Figure 2), set **the short-circuit mode**: switch "K" to position 2 "on" (press the K key on the keyboard).

9. Using an oscilloscope, determine the value of the time interval $T_2 - T_1$. Calculate the phase shift between the voltage U_{1kz} and the current I_{1kz} using the formula $\varphi_{ui} = 360^\circ \cdot (T_2 - T_1) \cdot f$

10. Record the voltmeter and ammeter readings. Based on the results of measurements of voltage U_{1kz} , current I_{1kz} and phase displacement, calculate a complex

$$\text{resistance } \underline{Z}_{1k} = \frac{U_{1kz}}{I_{1kz}} e^{j\varphi_{ui}}.$$

11. Calculate the characteristic resistance of the four-pole. $\underline{Z}_c = \sqrt{\underline{Z}_{1x} \cdot \underline{Z}_{1k}} = Z \cdot e^{j\varphi} = Z \cos \varphi + j Z \sin \varphi = R_c + j X_c$ Determine the value of the capacitance of the capacitor for the characteristic resistance $C_c = \frac{1}{2 \cdot \pi \cdot f \cdot X_c}$. Here f is the frequency of oscillations of the EMF source.

12. Establish the calculated values of the load elements of the four-pole circuit (Figure 2) (resistor resistance R_c , capacitance of capacitor C_c).

13. In the diagram (Fig.2), set **the mode of the matched load: connect $Z_h = Z_c$ to the output of the four-pole** (switch "C" is switched to the "On" position (press the key C on the keyboard)). After all the parameters of the circuit are set, move the button (0-1) to the "On (1)" position. Upon completion of automatic calculations, the button (0-1) is moved to the "Off (0)" position. Enter the readings of ammeters and voltmeters, the value of the time interval $T_2 - T_1$ in the table of calculated and experimental data. Calculate the phase displacement between the voltage U_{1c} and the current I_{1c} according to the formula $\varphi_{ui} = 360^\circ \cdot (T_2 - T_1) \cdot f$

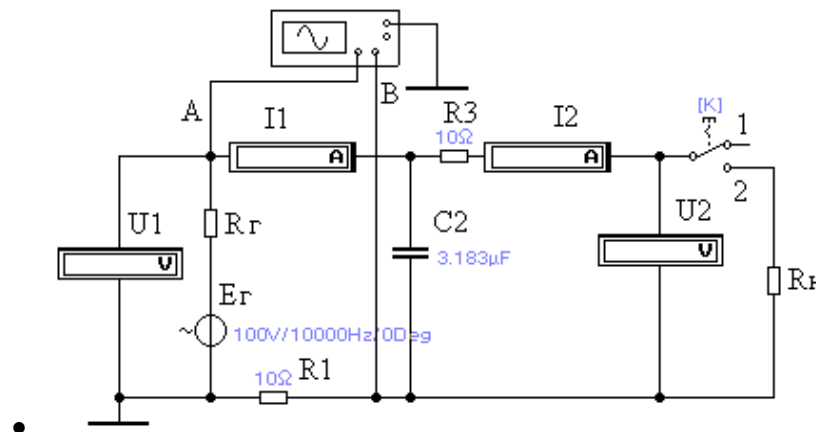
14. Calculate the input complex impedance based on the results of measurements of voltage U_{1c} and current I_1 and phase displacement $\underline{Z}_{\text{in}} = \frac{U_{1c}}{I_1} e^{j\varphi_{ui}}$. Compare the values of characteristic and input impedances.

15. Based on the results of measurements of voltages U_{1c} , U_{2c} , currents I_{1c} and I_{2c} , calculate the characteristic (own) constant of the attenuation of the fourpole in feathers $A_c = \frac{1}{2} \ln \frac{U_{1c} I_{1c}}{U_{2c} I_{2c}}$ or in decibels $A_c = 10 \lg \frac{U_{1c} I_{1c}}{U_{2c} I_{2c}}$.

16. Compare the results of preliminary calculations of the secondary parameters of the fourpole with the results of research. Draw conclusions.

c) Examination of four-poles under uncoordinated load. Determination of the operating parameters of specified four-poles

1. Assemble the diagram of the electrical circuit (Figure 3).



•Figure 3

2. Set the EMF values, source frequency, values of four-pole circuit elements, resistance R_g and R_h specified according to the option.

3. In the diagram, set **the mode of uncoordinated load**: switch "K" to position 2 "On" (press the K key on the keyboard).

•4. After all the parameters of the circuit are set, move the button (0-1) to the "1" position. Upon completion of automatic calculations, the (0-1) button is moved to the "0" position. Enter the readings of ammeters and voltmeters in the table of calculation and experimental data.

• Based on the results of measurements of voltage U_2 , current I_2 , calculate the total power in the load $S_n = U_2 I_2$

5. Assemble the diagram of the electrical circuit (Fig. 4). To do this, it is enough to select and remove the elements of the four-pole in the diagram (Figure 3), voltmeter V_1 , ammeter I_1 , oscilloscope

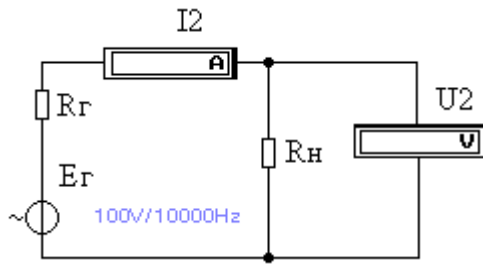


Figure 4

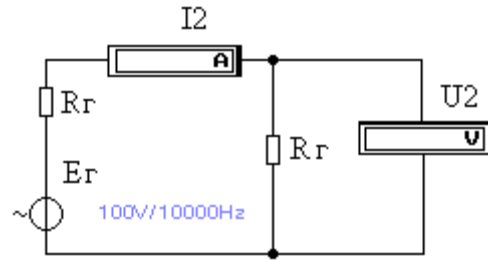


Figure 5

•6. After completing the installation of all circuit parameters, move the button (0-1) to the "On (1)" position. Enter the readings of the ammeter and voltmeter in the table of calculated and experimental data.

• 7. Based on the results of measurements of voltage U_{2n} , current I_{2n} , calculate the total power in the load not coordinated with the source $S_{2h} = U_{2h} I_{2n}$

Based on the results of measurements of voltages U_2 , U_{2h} , currents I_2 and I_{2h} or apparent powers, calculate the insertion attenuation in non-feathers $A_{BH} = \frac{1}{2} \ln \frac{U_{2h} I_{2h}}{U_2 I_2} = \frac{1}{2} \ln \frac{S_{2h}}{S_2}$ or decibels $A_{BH} = 10 \lg \frac{U_{2h} I_{2h}}{U_2 I_2} = 10 \lg \frac{S_{2h}}{S_2}$.

8. Assemble the diagram of the electrical circuit (Fig. 5). To do this, it is enough to set $R_h = R_g$ in the diagram (Fig. 4) (the mode of coordinated load with the source, in which the maximum power is allocated in the load).

•9. After completing the installation of all the parameters of the circuit, move the button (0-1) to the "1" position.

• 10. Based on the results of measurements of voltage U_{2max} , current I_{2max} , calculate the total power in the load coordinated with the source $S_{2max} = U_{2max} I_{2max}$

11. Based on the results of measurements of voltages U_2 , U_{2max} , currents I_2 and I_{2max} or full power, calculate the working attenuation in feathers $A_p = \frac{1}{2} \ln \frac{U_{2max} I_{2max}}{U_2 I_2} = \frac{1}{2} \ln \frac{S_{2max}}{S_2}$ or decibels $A_p = 10 \lg \frac{U_{2max} I_{2max}}{U_2 I_2} = 10 \lg \frac{S_{2max}}{S_2}$.

12. Compare the results of preliminary calculations of the four-pole operating parameters with the results of research. Draw conclusions.

•

•Contents of the report.

The laboratory report should contain:

- research schemes;

- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;

- conclusions based on the results of research.

•**Control questions:**

1. What is called a four-pole?
2. Give examples of four-pole communication equipment.
3. Name the main forms of the four-pole equation systems.
4. Write down the equation of the four-pole in the form of A-parameters.
5. Why are these parameters called primary?
6. How can the parameters A_{11} and A_{21} be determined?
7. How can the parameters A_{12} and A_{22} be determined?
8. Name the characteristic parameters of four-poles.
9. What is the characteristic resistance of a symmetrical four-pole?
10. Write down the expression to determine the characteristic resistance from the A-parameters of the four-pole.
11. What is called the characteristic transmission constant of a four-pole?
12. What is called the characteristic (own) weakening of the quadripolar?
13. Write down the expression to determine the characteristic attenuation from the A-parameters of the four-pole.
14. What is called the applied attenuation of the four-pole?
16. What is called the working weakening of the four-pole?

Laboratory Work No10

Investigation of the frequency characteristics of LC filters

Purpose of the work:

1. Experimental study of the frequency characteristics of LPF
2. Experimental study of the frequency characteristics of HPF

Task to prepare for laboratory work:

- according to the variant of the task (Table 1), perform a preliminary calculation:

- a) the frequency characteristics of LPF and plot them.
- b) frequency characteristics of HPF and plot them.

Table 1 - Variants of tasks for preliminary calculation and research

Option No	Rc, Ohm	fc, Hz	Scheme	n
1	600	2500	P	0.6
2	700	2000	T	0.9
3	800	1000	P	2
4	900	4000	T	1.5
5	1000	5000	P	1.2
6	1500	1500	T	0.7
7	550	3500	P	0.65
8	650	2500	T	0.5
9	750	4500	P	1.25
10	850	5500	T	1.4
11	600	2500	P	0.6
12	700	2000	T	0.9
13	800	1000	P	2
14	900	4000	T	1.5
15	1000	5000	P	1.2
16	1500	1500	T	0.7
17	550	3500	P	0.65
18	650	2500	T	0.5
19	750	4500	P	1.25
20	850	5500	T	1.4
21	600	2500	P	0.6
22	700	2000	T	0.9
23	800	1000	P	2
24	900	4000	T	1.5
25	1000	5000	P	1.2
26	1500	1500	T	0.7
27	550	3500	P	0.65
28	650	2500	T	0.5
29	750	4500	P	1.25
30	850	5500	T	1.4
31	600	2500	P	0.6
32	700	2000	T	0.9
33	800	1000	P	2

Studies are carried out on a PC in the Electronics Workbench environment. The research schemes contain AC voltage sources, resistors, capacitors, voltmeters. A Bode plotter is used to determine frequency characteristics.

Research Assignment

1. To study the frequency characteristics of LPF.
2. To study the frequency characteristics of HPF.

• Procedure for conducting research

(a) Investigation of the frequency characteristics of LPF

1. Assemble the diagram of the electrical circuit (Figure 1).

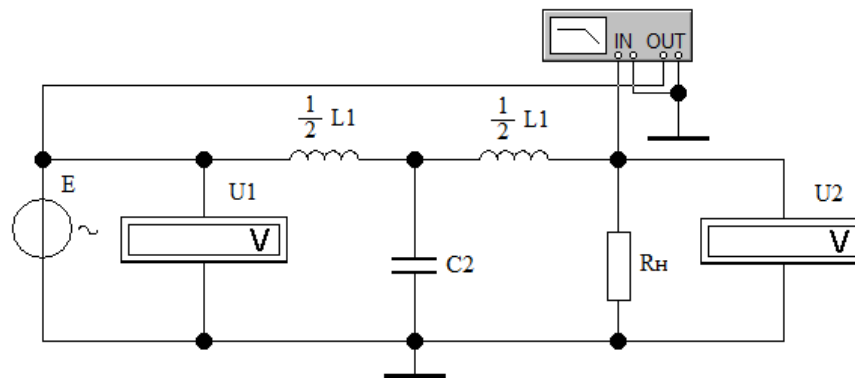


Figure 1 - Scheme of the study of the frequency characteristics of LPF

- 2. According to the specified R_c and f_c options, calculate and set on the diagram the calculated values of inductance L_1 and capacitance of the capacitor C_2 , the value of the EMF of the source $E = 1V$, the resistance $L_1 = \frac{R_c}{\pi f_c} C_2 = \frac{1}{\pi f_c R_c} R_H = R_c$
- 3. Fill in the second line of Table 2 (line f, Hz)
4. By changing the frequency f of the source according to Table 2, measure the voltages U_2 and U_1 Enter the voltmeter readings in the table of test results.

- Table 2 - Results of LPF studies

[illegible]

- 5. Perform the calculation . Based on the results of the research, build a graph $A(f).A(f) = 20\lg(\frac{U_1}{U_2})$
- 6. Using a plotter (Bode-plotter), obtain a graph $A(f)$ and compare it with the graph p.5
- 6. To conduct a study of frequency characteristics at $R_h = 0.5R_c$, $R_h = 2R_c$,
- $R_h = 10R_c$.
- 7. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

b) Study of the frequency characteristics of HPF

1. Assemble the diagram of the electrical circuit (Figure 2).

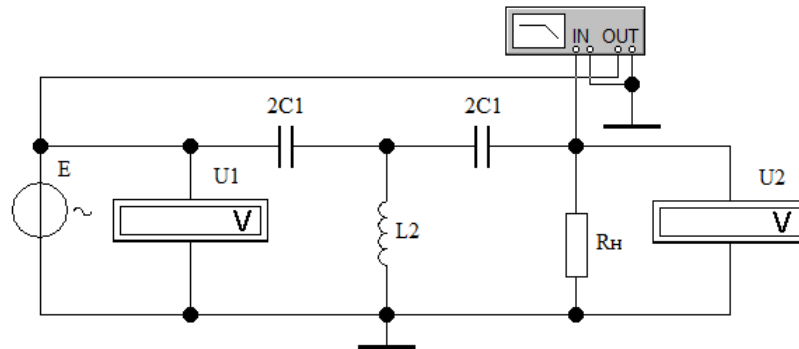


Figure 2 - Scheme for studying the frequency characteristics of HPF

- 2. According to the given R_c and f_c options, calculate and . Set on the diagram the calculated values of inductance L_2 and capacitance of the capacitor C_1 , the value of the EMF of the source $E = 1V$, resistance $L_2 = \frac{R_c}{4\pi f_c} C_1 = \frac{1}{4\pi f_c R_c} R_H = R_c$

- 3. Fill in the second line of Table 3 (line f , Hz)
4. By changing the frequency f of the source according to Table 3, measure the voltages U_2 and U_1 Enter the voltmeter readings in the table of research results.

• Table 3 - Results of HPV studies

• f/f_c	• 0.01	• 0.4	• 0.6	• 0.8	• 1.0	• 1.2	• 1.4	•
• f , Hz	•	•	•	•	•	•	•	•
• U_2 , B	•	•	•	•	•	•	•	•
• U_1 , B	•	•	•	•	•	•	•	•
• $A_1(f)$, dB	•	•	•	•	•	•	•	•
• U_2 , B	•	•	•	•	•	•	•	•
• $A_2(f)$, dB	•	•	•	•	•	•	•	•
• U_2 , B	•	•	•	•	•	•	•	•
• $A_3(f)$, dB	•	•	•	•	•	•	•	•
• U_2 , B	•	•	•	•	•	•	•	•
• $A_4(f)$, dB	•	•	•	•	•	•	•	•

•

- 5. Perform the calculation . Based on the results of the research, build a graph $A(f)$. $A(f) = 20\lg(\frac{U_1}{U_2})$

- 6. Using a plotter (Bode plotter), obtain a graph $A(f)$ and compare it with the graph p.5

- 6. To conduct a study of frequency characteristics at $R_h = 0.5R_c$, $R_h = 2R_c$,

- $R_h = 10R_c$.

7. Compare the results of the research with the results of the preliminary calculation. Draw conclusions.

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•Contents of the report

•

The laboratory report should contain:

- research task;

- research schemes;

- Completed tables of calculation and experimental data, calculation formulas and detailed calculation of all required parameters;

- Frequency response graphs

- conclusions based on the results of research.

•Control questions:

1. What is an Electric Filter?

2. Draw a T-shaped LPF scheme.

3. Draw a U-shaped HPF scheme.

4. Formulate the filtering conditions for passive LC filters.

5. How can the bandwidth of passive LC filters be determined?

6. How can you determine the bandwidth cutoff frequencies? Explain using the example of a low-pass filter of type "k".

7. How can the attenuation frequency response of passive LC filters be determined? Explain using a low-pass filter as an example.

8. Write down the expression for the frequency response of LPF attenuation.

9. Plot the frequency response of LPF attenuation.

10. Write down the expression for the LPF constant phase.

11. Write down the expression for the characteristic resistance of the LPF.

12. Record the expression for the frequency response of HPF attenuation.

13. Write down the expression for the constant phase of HPF.

14. Write down the expression for the characteristic resistance of HPF.
15. Plot the frequency response of HPF attenuation.

References

1. Nikulin V. I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. Moscow, RIOR Publ., 2016.
2. Popov V.P. Osnovy teorii tsepey [Fundamentals of the theory of chains]. Moscow, Vysshaya shkola Publ., 2005
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MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION
FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER
EDUCATION
"NORTH CAUCASUS FEDERAL UNIVERSITY"

Suggestions for Teaching

for the performance of practical work
on the discipline "Theory of Electrical and Radio Engineering Circuits"
for students of the field of study / specialty
11.03.02 Infocommunication Technologies and Communication Systems
Profile
"Intelligent Data Processing in Infocommunication
Systems and Networks"

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Introduction

Practical classes in the discipline "Theory of Electrical and Radio Engineering Circuits" provide a connection between the theory of electrical circuits and the practice of calculating electrical circuits and radio engineering devices, the development of the ability to apply the knowledge gained at lectures and in the course of independent work.

Practical classes are aimed at:

- to help systematize, consolidate and deepen knowledge of the theory of DC electrical circuits;

- to show the connection of theoretical material with practice and to teach them to apply Ohm's law, the first and second laws of Kirchhoff to solving practical problems on linear and nonlinear circuits of direct current, to teach cadets to solve problems by methods of transformations, contour currents, superposition, nodal potentials;

- to develop and improve mathematical training, the ability to conduct engineering calculations using modern computer technology;

- master the methodology of working with scientific material on the theory of circuits and certain practical skills that are most typical for the discipline "Fundamentals of Circuit Theory";

- to help students in the development of independent work; to teach them to work with educational literature, electrical diagrams, to use reference literature and GOSTs.

To achieve this goal, students are obliged to:

- in preparation for the lesson, study the recommended literature, prepare and answer control questions, the list of which is given in each task for the lesson, analyze the solution of typical tasks for this lesson;

- during the practical lesson, perform individual tasks according to the version. When performing tasks, the following order of actions is recommended: analysis of the conditions of the problem; evaluation of available data (what is given, what needs to be found, what data are redundant); selection of a method for solving the problem; drawing up a plan (algorithm) for the solution; performing calculations; checking the solution; drawing up a report.

When performing calculations, it is advisable to use a PC or programmable microcalculators. The report is drawn up in accordance with the requirements for written works and submitted to the teacher for checking. Examples of the report are given in each practical lesson.

For each completed task of the practical lesson, the teacher gives a grade on a 10-point system.

Assessment criteria for the task:

The maximum number of points is given if the solution algorithm is optimal and the problem is solved correctly in full, neatly formatted,

the number of points is reduced by 2 if the task is solved in full, neatly formatted, but contains minor errors,

the number of points is reduced by 5 if the solution algorithm is not optimal and the problem is solved correctly in general or contains errors,

The number of points is reduced to 0 if there is no solution to the problem, the problem is solved incorrectly or contains gross errors.

Evaluation criteria for a practical lesson:

The mark is EXCELLENT if the number of points $\geq 90\%$ of the maximum possible number of points for a practical lesson;

The grade is GOOD if the number of points $\geq 80\%$ of the maximum possible number of points for a practical lesson;

A SATISFACTORY grade is given if the number of points $\geq 60\%$;

the grade is UNSATISFACTORY if the number of points $< 60\%$. Students who have received GOOD and EXCELLENT grades during all practical classes, on the recommendation of the teacher, are exempted by the head of the department from the exam in the discipline "Electrical Engineering and Electronics" with the grade "EXCELLENT".

1. Calculation of electrical circuits by the transformation method

Study questions:

1. Calculation of equivalent resistances of passive circuits.
2. Calculation of equivalent EMF of active circuits.
3. Calculation of parameters of equivalent current sources.

Assignment for students to prepare for the lesson

1. Study:

1. Nikulin V.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. Moscow, RIOR Publ., 2016, pp. 6-23.
2. Bakalov V.P., Vorobienko P.P., Kruk B.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. Moscow, Radio i svyaz Publ., 1998, pp. 26-31.
3. Shebes M. R. Zadachnik po teorii lineynykh elektricheskikh tsepey [Task book on the theory of linear electric circuits].- Moscow: Vysshaya shkola, 1982. - pp. 4, 9-11, 12-13.

2. Answer the questions:

1. What is an electrical circuit?
2. What is Electric Current?
3. What is Electrical Voltage?
4. What is EMF?
5. What is a branch of an electrical circuit?
6. What is a section of an electrical circuit?
7. How is the equivalent resistance determined when resistive elements are connected in series?
8. How is the equivalent resistance determined when resistive elements are connected in parallel?

9. How is the equivalent EMF determined when EMF sources are connected in series?
10. How is the equivalent current determined when current sources are connected in parallel?
11. What is meant by an electrical circuit replacement scheme?
12. Draw a scheme for replacing a real EMF source
13. Draw a diagram of the replacement of a real current source.
14. How can the transition from a real EMF source to a replacement scheme with a current source be made?

3. Analyze the solution of the following tasks:

No1.1 (Shebes M. R. Task book on the theory of linear electric circuits. - Moscow: Higher School, 1982. - p.14)

During the practical lesson, complete the tasks:

Task No1 Calculate the equivalent resistance R_e for the passive electrical circuits specified according to the option, the diagrams and parameters of which are given in Table 1.1.

Task No2 Calculate equivalent EMF and resistances for the specified active circuits according to the variant (Table 1.2)

Task No3 Calculate the parameters of equivalent current sources (E and R_e) for the specified active electrical circuits (Table 1.3)

Table 1.1

Variant №	Scheme , Figure No	R1, Om	R2, Om	R3, Om	R4, Om	R5, Om	R6, Om	R7, Om	R8, Om	Definition pour
0	1.1	200	200	400	500	400	100	200	100	Rab
1	1.2	100	150	200	100	150	300	100	100	Rab
2	1.3	10	15	20	10	15	30	10	10	Rab
3	1.4	200	200	400	500	400	100	200	100	Rad
4	1.1	100	100	200	150	200	100	300	200	Rad
5	1.2	15	10	25	10	20	15	20	30	Rad
6	1.3	200	250	100	200	150	250	160	300	Rae
7	1.4	20	25	10	15	25	35	20	15	Rae
8	1.1	250	300	450	300	200	150	250	300	Rae
9	1.2	150	180	240	250	240	190	200	250	Rbf
10	1.3	25	20	45	20	40	50	25	60	Rbf
11	1.4	100	150	200	100	150	300	100	100	Rbf
12	1.1	10	15	20	10	15	30	10	10	Rbc
13	1.2	200	200	400	500	400	100	200	100	Rbc
14	1.3	100	100	200	150	200	100	300	200	Rbc
15	1.4	15	10	25	10	20	15	20	30	Rbd
16	1.1	200	250	100	200	150	250	160	300	Rbd
17	1.2	20	25	10	15	25	35	20	15	Rbd
18	1.3	250	300	450	300	200	150	250	300	Rde
19	1.4	150	180	240	250	240	190	200	250	Rde
20	1.1	25	20	45	20	40	50	25	60	Rde
21	1.2	100	150	200	100	150	300	100	100	Rdc
22	1.3	10	15	20	10	15	30	10	10	Rdc
23	1.4	200	200	400	500	400	100	200	100	Rdf
24	1.1	100	100	200	150	200	100	300	200	Rdf
25	1.2	15	10	25	10	20	15	20	30	Rdf
26	1.3	200	250	100	200	150	250	160	300	Rdf
27	1.4	20	25	10	15	25	35	20	15	Rfe
28	1.1	250	300	450	300	200	150	250	300	Rce

29	1.2	150	180	240	250	240	190	200	250	Rce
30	1.3	25	20	45	20	40	50	25	60	Raf
31	1.4	100	150	200	100	150	300	100	100	Raf
32	1.1	10	15	20	10	15	30	10	10	Rab
33	1.2	200	200	400	500	400	100	200	100	Rbd
34	1.3	100	100	200	150	200	100	300	200	Rde
35	1.4	15	10	25	10	20	15	20	30	Rde
36	1.1	200	250	100	200	150	250	160	300	Rde
37	1.2	20	25	10	15	25	35	20	15	Rdc
38	1.3	250	300	450	300	200	150	250	300	Rdc
39	1.4	150	180	240	250	240	190	200	250	Rdb
40	1.1	25	20	45	20	40	50	25	60	Rdf
41	1.4	100	150	200	100	150	300	100	100	Raf
42	1.1	10	15	20	10	15	30	10	10	Rab
43	1.2	200	200	400	500	400	100	200	100	Rbd
44	1.3	100	100	200	150	200	100	300	200	Rde
45	1.4	15	10	25	10	20	15	20	30	Rde

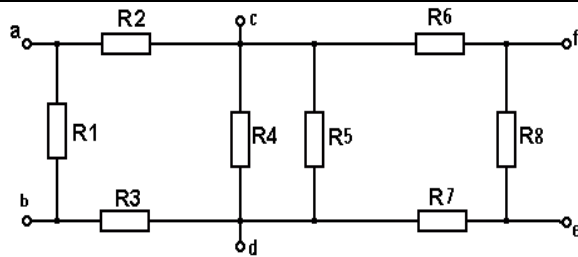


Figure 1.1

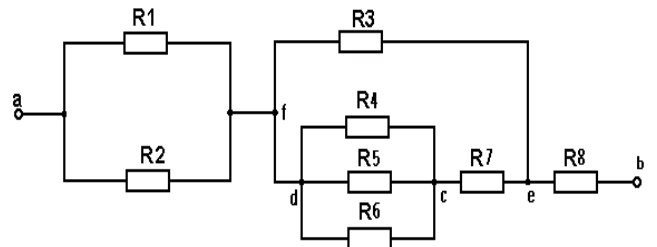


Figure 1.2

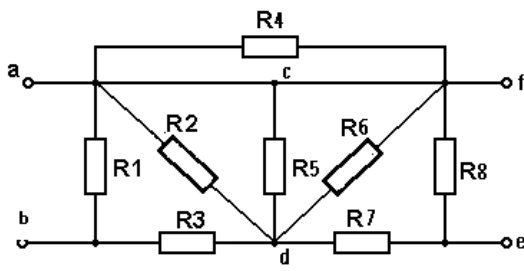


Figure 1.3

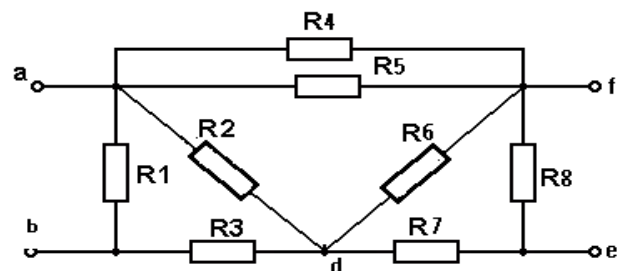


Figure 1.4

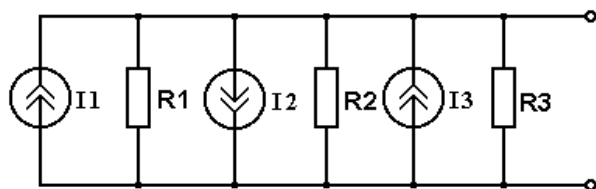


Figure 1.5

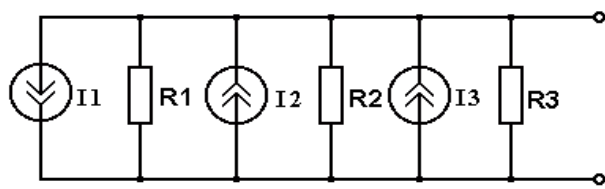


Figure 1.6

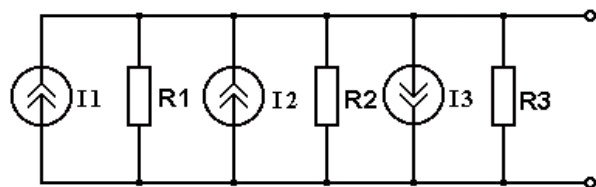


Figure 1.7

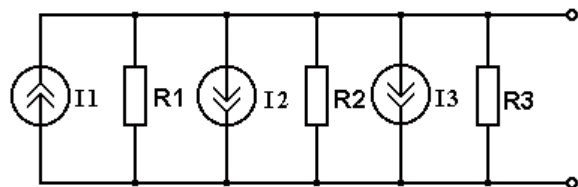


Figure 1.8

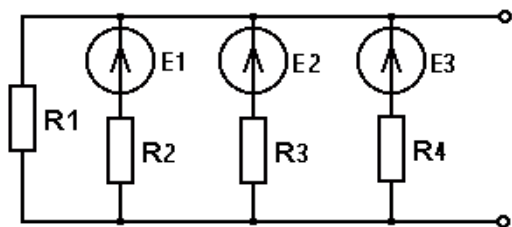


Figure 1.9

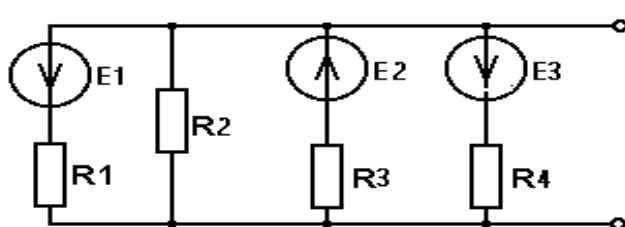


Figure 1.10

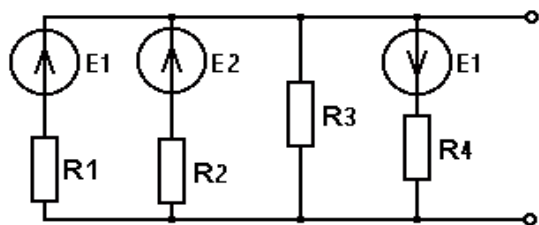


Figure 1.11

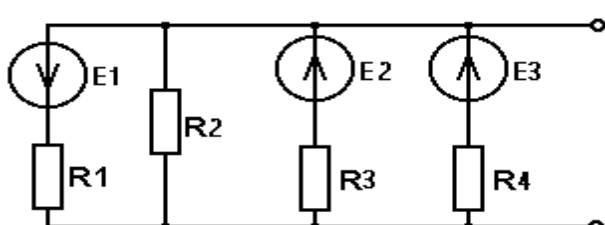


Figure 1.12

Table 1.2

Variant №	Scheme, FigureNo	R1, Om	R2, Om	R3, Om	I1, mA	I2, mA	I3, mA
0	1.5	100	100	50	10	20	15
1	1.6	150	200	250	20	10	15
2	1.7	200	50	150	5	7	10
3	1.8	200	100	50	4	8	6
4	1.5	250	150	100	8	5	7
5	1.6	400	300	200	10	25	15
6	1.7	150	200	250	20	10	15
7	1.8	200	50	150	5	7	10
8	1.5	200	100	50	4	8	6
9	1.6	250	150	100	8	5	7
10	1.7	400	300	200	10	25	15
11	1.8	150	200	250	20	10	15
12	1.5	200	50	150	5	7	10
13	1.6	200	100	50	4	8	6
14	1.7	250	150	100	8	5	7
15	1.8	400	300	200	10	25	15
16	1.5	150	200	250	20	10	15
17	1.6	200	50	150	5	7	10
18	1.7	200	100	50	4	8	6
19	1.8	250	150	100	8	5	7
20	1.5	400	300	200	10	25	15
21	1.6	150	200	250	20	10	15
22	1.7	200	50	150	5	7	10
23	1.8	200	100	50	4	8	6
24	1.5	250	150	100	8	5	7
25	1.6	400	300	200	10	25	15
26	1.7	150	200	250	20	10	15
27	1.8	200	50	150	5	7	10
28	1.5	200	100	50	4	8	6
29	1.6	250	150	100	8	5	7
30	1.7	400	300	200	10	25	15

31	1.8	150	200	250	20	10	15
32	1.5	200	50	150	5	7	10
33	1.6	200	100	50	4	8	6
34	1.7	250	150	100	8	5	7
35	1.8	400	300	200	10	25	15
36	1.5	150	200	250	20	10	15
37	1.6	200	50	150	5	7	10
38	1.7	200	100	50	4	8	6
39	1.8	250	150	100	8	5	7
40	1.5	400	300	200	10	25	15
41	1.6	250	350	100	15	25	15
42	1.7	150	200	250	20	10	15
43	1.7	150	200	250	20	10	15
44	1.8	200	50	150	5	7	10
45	1.5	200	100	50	4	8	6
46	1.6	250	150	100	8	5	7

Table 1.3

Variant №	Scheme FigureNo	R1, Om	R2, Om	R3, Om	R4, Om	E1, In	E2, In	E3, In
0	1.9	75	100	50	150	20	10	15
1	1.10	50	100	200	50	10	12	20
2	1.11	100	250	300	200	10	15	25
3	1.12	200	400	500	300	10	14	18
4	1.9	450	250	300	200	20	30	40
5	1.10	500	750	650	400	40	25	30
6	1.11	50	100	200	50	10	12	20
7	1.12	100	250	300	200	10	15	25
8	1.9	200	400	500	300	10	14	18
9	1.10	450	250	300	200	20	30	40
10	1.11	500	750	650	400	40	25	30
11	1.12	50	100	200	50	5	10	7
12	1.9	100	250	300	200	10	12	20
13	1.10	200	400	500	300	10	15	25
14	1.11	450	250	300	200	10	14	18
15	1.12	500	750	650	400	20	30	40
16	1.9	50	100	200	50	40	25	30
17	1.10	100	250	300	200	10	12	20
18	1.11	200	400	500	300	10	15	25
19	1.12	450	250	300	200	10	14	18
20	1.9	500	750	650	400	20	30	40
21	1.10	50	100	200	50	10	12	20
22	1.11	100	250	300	200	10	15	25
23	1.12	100	250	300	200	10	14	18
24	1.9	200	400	500	300	20	30	40
25	1.10	450	250	300	200	40	25	30
26	1.11	500	750	650	400	10	12	20
27	1.12	50	100	200	50	10	15	25
28	1.9	100	250	300	200	10	14	18
29	1.10	200	400	500	300	20	30	40
30	1.11	450	250	300	200	40	25	30

31	1.12	500	750	650	400	5	10	7
32	1.9	50	100	200	50	10	12	20
33	1.10	100	250	300	200	10	15	25
34	1.11	200	400	500	300	10	14	18
35	1.12	450	250	300	200	20	30	40
36	1.9	500	750	650	400	40	25	30
37	1.10	50	100	200	50	10	12	20
38	1.11	100	250	300	200	10	15	25
39	1.12	200	400	500	300	10	14	18
40	1.9	450	250	300	200	20	30	40
41	1.10	100	250	300	200	10	14	18
42	1.11	200	400	500	300	20	30	40
43	1.12	450	250	300	200	40	25	30
44	1.9	500	750	650	400	5	10	7
45	1.10	50	100	200	50	10	12	20
46	1.11	100	250	300	200	10	15	25

Example of completing tasks (option No0)

Task No1. Calculate the equivalent resistance R_{ab} of a passive electrical circuit, the diagram and parameters of which are given in Table 1.1. Option No0.

Solution

1. Resistive elements R_6 , R_7 , R_8 are connected in series (see Fig. 1.1). They form the first section of the circuit. Equivalent resistance of the first section of the circuit

$$R_{e1} = R_6 + R_7 + R_8 = 100 + 200 + 100 = 400 \text{ Ohm.}$$

2. Resistive elements R_4 and R_5 and a section of the circuit with elements R_6 , R_7 , R_8 are connected in parallel (Figure 1.13). These elements form the 2nd section of the circuit. Equivalent conductivity of this section

$$G_{\text{э2}} = \frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{R_{\text{э1}}} = \frac{1}{500} + \frac{1}{400} + \frac{1}{400} = 0.002 + 0.0025 + 0.0025 = 0.007 \text{ См.}$$

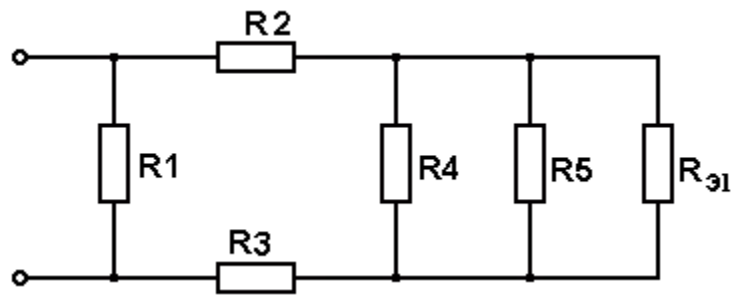


Figure 1.13

3. The equivalent resistance of the second section of the circuit will be defined as the inverse of the equivalent conductivity G_{e2}

$$R_{\text{э}2} = \frac{1}{G_{\text{э}2}} = \frac{1}{0.007} = 142.86 \text{ Ом.}$$

4. Elements R_2 , R_3 and the second section of the circuit are connected in series (Figure 1.14). They form the third section of the circuit. Equivalent resistance of the third section of the circuit

$$R_{e3} = R_2 + R_{e2} + R_3 = 200 + 142.86 + 400 = 742.86 \text{ Ohm.}$$

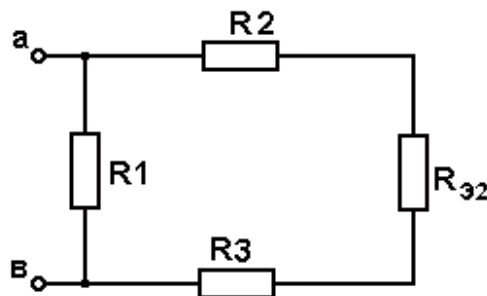


Figure 1.14

5. The resistive element R_1 and the third section of the circuit are connected in parallel with respect to the pins "a, b" (Fig. 1.15). Conductivity of this section of the circuit

$$G_{\text{э}} = \frac{1}{R_1} + \frac{1}{R_{\text{э}3}} + \frac{1}{200} + \frac{1}{742.86} = 6.35 \cdot 10^{-3} \text{ См.}$$

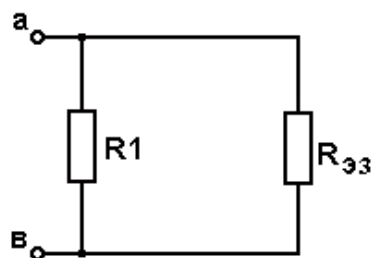


Figure 1.15

6. Equivalent Circuit Resistance $R_{ab} = \frac{1}{G_3} = \frac{1}{6.35 \cdot 10^{-3}} = 157.58 \text{ Ohm}.$

Task No2. Determine the parameters of the equivalent current source (I_e , R_e) of the active circuit Figure 1.5, the parameters of which are specified (Table 1.2, option No 0).

Solution

1. Let's present the initial scheme (Figure 1.5) as follows (Figure 1.16)

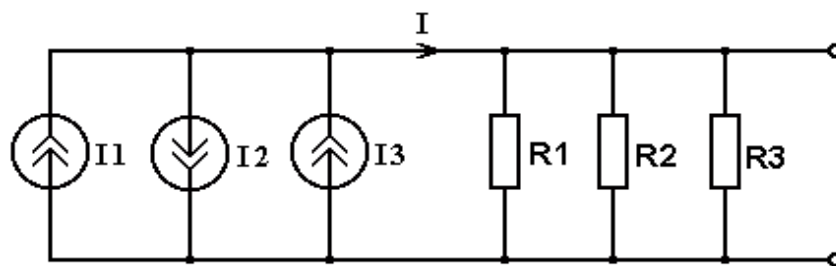


Figure 1.16

2. Current I is determined by Kirchhoff's law 1

$$I = I_1 - I_2 + I_3 = 10 - 20 + 15 = 5 \text{ mA}.$$

3. Three current sources (Figure 1.16) can be replaced by one, the current of which is equal to $I_e = I = 5 \text{ mA}.$

4. Resistive elements R_1 , R_2 , R_3 are connected in parallel with respect to the output poles. The equivalent conductivity of the passive section of the circuit is determined by the expression

$$G_3 = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{100} + \frac{1}{100} + \frac{1}{50} = 0,04 \text{ Cm}.$$

5. The equivalent resistance of the circuit section with the elements R_1 , R_2 , R_3 will be determined by the expression

$$R_3 = \frac{1}{G_3} = \frac{1}{0,04} = 25 \text{ Ohm}.$$

6. An equivalent circuit diagram with a single current source is shown in Figure 1.17

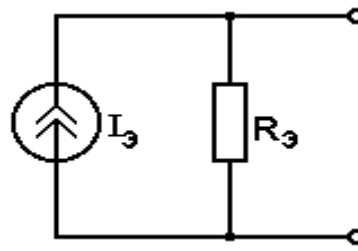


Figure 1.17

Task No3. Calculate the equivalent EMF of the circuit (see Figure 1.9), the parameters of which are given in Table 1.3. 1.3 Option No 0.

Solution

1. The circuit sections containing EMF sources and resistive elements shall be replaced equivalently with circuit sections with a current source (Figure 1.18)

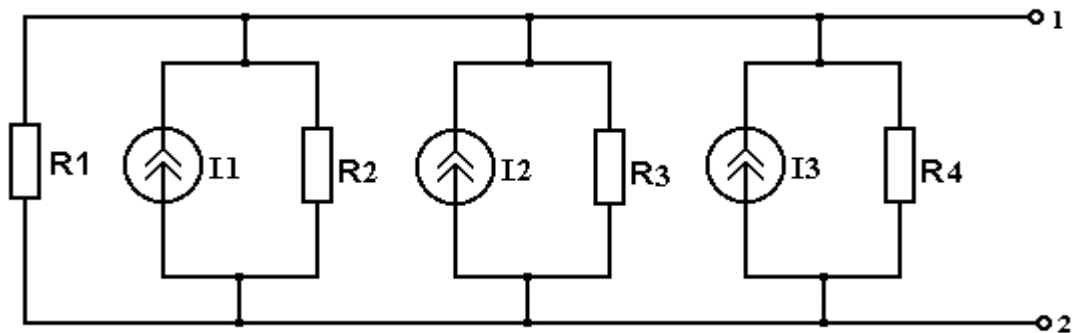


Figure 1.18

2. Let us determine the values I_1 , I_2 , I_3 as short-circuit currents of the corresponding branches with EMF sources

$$I_1 = \frac{E_1}{R_2} = \frac{20}{100} = 0,2 \text{ A}, \quad I_2 = \frac{E_2}{R_3} = \frac{10}{50} = 0,2 \text{ A}, \quad I_3 = \frac{E_3}{R_4} = \frac{15}{150} = 0,1 \text{ A}.$$

3. The circuit diagram can be represented as (Figure 1.19)

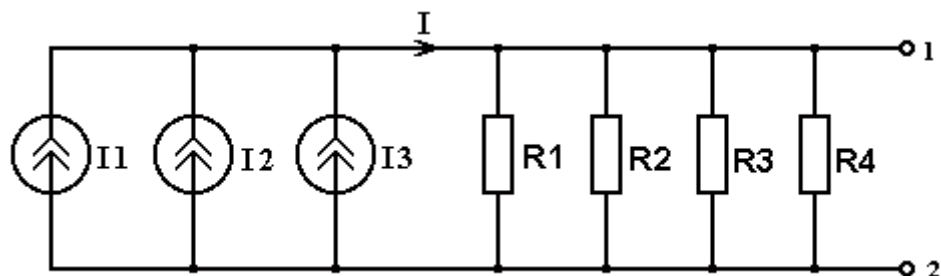


Figure 1.19

4. Current I in the circuit in accordance with Kirchhoff's first law will be equal to the algebraic sum of currents I_1 , I_2 , I_3 , i.e. $I = I_1 + I_2 + I_3 = 0.2 + 0.2 + 0.1 = 0.5 \text{ A}$.

Therefore, three current sources can be equivalent to one with current I .

5. Resistive elements R_1 , R_2 , R_3 , R_4 are connected in parallel. Their equivalent conductivity is $G_3 = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{75} + \frac{1}{100} + \frac{1}{50} + \frac{1}{150} = 0.05$

Cm ,

and resistance $R_3 = \frac{1}{G_3} = \frac{1}{0.05} = 20 \text{ Ohm}$.

6. An equivalent circuit diagram (Figure 1.20) may be represented by a current source and equivalent conductivity

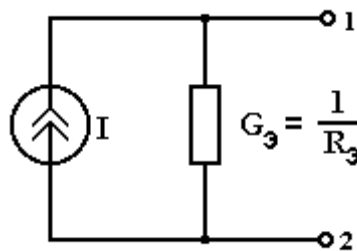


Figure 1.20

7. Replace the diagram (Figure 1.20) equivalently with the diagram with an EMF source (Figure 1.21)

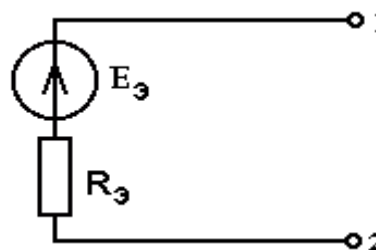


Figure 1.21

8. The equivalent EMF is determined by the expression

$$E_3 = I \cdot \frac{1}{G_3} = I \cdot R_3 = 0.5 \cdot 20 = 10 \text{ B.}$$

2. Calculation of linear electrical circuits by the method of contour currents

Study questions:

1. Calculation of an electrical circuit with EMF sources
2. Calculation of an electrical circuit with current sources.
3. Calculation of the electrical circuit with EMF and current sources.

Assignment for students to prepare for the lesson

1. Study:

1. Nikulin V.I. Theory of Electrical Circuits. - Moscow: RIOR, 2016, pp. 32-35.
2. Bakalov V.P., Vorobienko P.P., Kruk B.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. - Moscow: Radio i svyaz, 1998, pp. 45-53.
3. Shebes M. R. Task book on the theory of linear electric circuits. - Moscow: Vysshaya shkola, 1982-p.6.

2. Answer the questions:

1. Formulate Kirchhoff's first law.
2. Formulate Kirchhoff's second law.
3. How is the number of equations determined in the calculation of a chain by the method of direct application of Kirchhoff's laws?
4. How is the number of equations determined when calculating a circuit with EMF sources using the contour current method?
5. How is the system of equations compiled when calculating a circuit with EMF sources using the contour current method? Explain using the example of a specific circuit.
6. How is the number of equations determined when calculating a circuit with EMF sources and current using the contour current method?

7. How is the system of equations compiled when calculating a circuit with EMF and current sources using the contour current method? Explain using the example of a specific circuit.
8. What are the methods of solving systems of linear equations known to you?
9. Explain the algorithm for calculating an electrical circuit using the method of contour currents.

3. Analyze the solution of the following tasks:

No1.30, No1.32 (Shebes M. R. Task book on the theory of linear electric circuits, Moscow: Vysshaya shkola, 1982. - pp. 38-41)

During the practical lesson, complete the tasks:

Task No1. Calculate the currents in the branches by the method of contour currents for a given electrical circuit with EMF sources according to the variant (Table 1.4)

Task No2. Calculate the currents in the branches by the method of contour currents for a given electric circuit with current sources according to the variant (Table 1.5)

Task No3. Calculate the currents in the branches by the method of contour currents for a given electric circuit with EMF and current sources according to the variant (Table 1.6)

Table 1.4

Variant №	Figure №	R1, Om	R2, Om	R3, Om	R4, Om	E1, In	E2, In	E3, In
0	1.22	100	300	150	250	10	20	15
1	1.23	200	100	150	300	15	10	20
2	1.24	50	40	20	50	5	3	10
3	1.25	30	50	60	20	30	50	25
4	1.26	60	100	80	30	50	25	30
5	1.27	90	60	50	40	70	35	40
6	1.28	35	70	50	50	40	20	15
7	1.29	40	30	40	60	60	30	40
8	1.30	30	20	50	70	50	25	75
9	1.31	60	40	90	80	40	20	30
10	1.22	100	200	300	100	70	30	50
11	1.23	100	300	150	250	10	15	20
12	1.24	200	100	150	300	15	10	20
13	1.25	50	40	20	50	5	3	10
14	1.26	30	50	60	20	30	50	25
15	1.27	60	100	80	30	50	25	30
16	1.28	90	60	50	40	70	35	40
17	1.29	35	70	50	50	40	20	15
18	1.30	40	30	40	60	60	30	40
19	1.31	30	20	50	70	50	25	75
20	1.23	60	40	90	80	40	20	30
21	1.24	60	100	80	30	50	25	30
22	1.25	90	60	50	40	70	35	40
23	1.26	35	70	50	50	40	20	15
24	1.27	40	30	40	60	60	30	40
25	1.28	30	20	50	70	50	25	75
26	1.29	60	40	90	80	40	20	30
27	1.30	100	200	300	100	70	30	50
28	1.31	100	300	150	250	10	15	20
29	1.23	200	100	150	300	15	10	20
30	1.24	50	40	20	50	5	3	10

31	1.25	90	60	50	40	70	35	40
32	1.26	35	70	50	50	40	20	15
33	1.27	40	30	40	60	60	30	40
34	1.28	30	20	50	70	50	25	75
35	1.29	60	40	90	80	40	20	30
36	1.30	60	100	80	30	50	25	30
37	1.31	90	60	50	40	70	35	40
38	1.23	35	70	50	50	40	20	15
39	1.24	40	30	40	60	60	30	40
40	1.25	30	20	50	70	50	25	75
41	1.23	30	20	50	70	15	10	20
42	1.24	60	40	90	80	5	3	10
43	1.25	60	100	80	30	30	50	25
44	1.26	35	70	50	50	50	25	30
45	1.27	90	60	50	40	40	20	30

Table 1.5

Variant №	Figure №	R1, Om	R2, Om	R3, Om	R4, Om	J1, A	J2, A	J3, A
0	1.32	10	20	15	35	10	25	20
1	1.33	200	100	150	300	1.5	1	2
2	1.34	50	40	20	50	5	3	1
3	1.35	30	50	60	20	3	5	2.5
4	1.36	60	100	80	30	5	2	3
5	1.37	90	60	50	40	7	3	4
6	1.38	35	70	50	50	4	2	1.5
7	1.39	40	30	40	60	6	3	4
8	1.40	30	20	50	70	5	2	5
9	1.41	60	40	90	80	4	2	3
10	1.32	100	200	300	100	7	3	5
11	1.33	100	300	150	250	1	1.5	2
12	1.34	200	100	150	300	1.5	1	2
13	1.35	50	40	20	50	5	3	1
14	1.36	30	50	60	20	3	5	2.5
15	1.37	60	100	80	30	5	2	3

16	1.38	90	60	50	40	7	3	4
17	1.39	35	70	50	50	4	2	1.5
18	1.40	40	30	40	60	6	3	4
19	1.41	30	20	50	70	5	2	5
20	1.32	60	40	90	80	4	2	3
21	1.33	60	100	80	30	7	3	5
22	1.34	90	60	50	40	7	3	5
23	1.35	35	70	50	50	1	1.5	2
24	1.36	40	30	40	60	1.5	1	2
25	1.37	30	20	50	70	5	3	1
26	1.38	60	40	90	80	3	5	2.5
27	1.39	100	200	300	100	5	2	3
28	1.40	100	300	150	250	7	3	4
29	1.41	200	100	150	300	4	2	1.5
30	1.32	50	40	20	50	6	3	4
31	1.33	90	60	50	40	5	2	5
32	1.34	35	70	50	50	7	3	5
33	1.35	40	30	40	60	1	1.5	2
34	1.36	30	20	50	70	1	1.5	2
35	1.37	60	40	90	80	1.5	1	2
36	1.38	60	100	80	30	5	3	1
37	1.39	90	60	50	40	3	5	2.5
38	1.40	35	70	50	50	5	2	3
39	1.41	40	30	40	60	7	3	4
40	1.32	30	20	50	70	4	2	1.5
41	1.33	90	60	50	40	7	3	5
42	1.34	35	70	50	50	7	3	5
43	1.35	40	30	40	60	1	1.5	2
44	1.36	30	20	50	70	6	3	4
45	1.37	30	20	50	70	5	2	5

Table 1.6

Variant №	Figure №	R1, Om	R2, Om	R3, Om	R4, Om	E1, In	E2, In	J, A
0	1.42	100	300	150	250	10	15	0.1
1	1.43	200	100	150	300	15	10	0.05
2	1.44	50	40	20	50	5	3	0.2
3	1.45	30	50	60	20	30	50	0.1
4	1.46	60	100	80	30	50	25	0.5
5	1.47	90	60	50	40	70	35	1
6	1.48	35	70	50	50	40	20	1
7	1.49	40	30	40	60	60	30	1.5
8	1.50	30	20	50	70	50	25	2
9	1.51	60	40	90	80	40	20	1
10	1.42	100	200	300	100	70	30	0.1
11	1.43	100	300	150	250	10	15	0.5
12	1.44	200	100	150	300	15	10	0.2
13	1.45	50	40	20	50	5	3	0.1
14	1.46	30	50	60	20	30	50	0.5
15	1.47	60	100	80	30	50	25	1
16	1.48	90	60	50	40	70	35	1
17	1.49	35	70	50	50	40	20	1.5
18	1.50	40	30	40	60	60	30	2
19	1.51	30	20	50	70	50	25	1
20	1.42	60	40	90	80	40	20	0.1
21	1.43	60	100	80	30	50	25	0.5
22	1.44	90	60	50	40	70	35	1
23	1.45	35	70	50	50	40	20	0.1
24	1.46	40	30	40	60	60	30	0.5
25	1.47	30	20	50	70	50	25	0.2
26	1.48	60	40	90	80	40	20	0.1
27	1.49	100	200	300	100	70	30	0.5
28	1.50	100	300	150	250	10	15	1
29	1.51	200	100	150	300	15	10	1
30	1.42	50	40	20	50	5	3	1.5

31	1.43	90	60	50	40	70	35	2
32	1.44	35	70	50	50	40	20	1
33	1.45	40	30	40	60	60	30	0.1
34	1.46	30	20	50	70	50	25	1
35	1.47	60	40	90	80	40	20	0.1
36	1.48	60	100	80	30	50	25	0.5
37	1.49	90	60	50	40	70	35	0.2
38	1.50	35	70	50	50	40	20	0.1
39	1.51	40	30	40	60	60	30	2
40	1.42	30	20	50	70	50	25	0.5
41	1.43	100	300	150	250	10	15	0.5
42	1.44	30	20	50	70	15	10	0.2
43	1.45	60	40	90	80	5	3	0.1
44	1.46	60	100	80	30	40	20	0.1
45	1.47	30	20	50	70	60	30	2
46	1.48	90	60	50	40	50	25	0.5

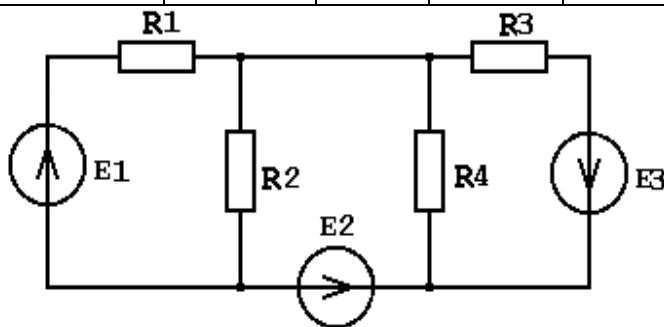


Figure 1.22

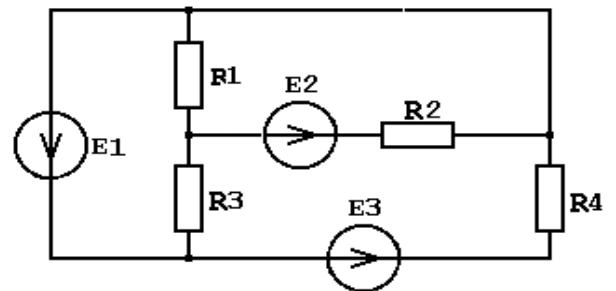


Figure 1.23

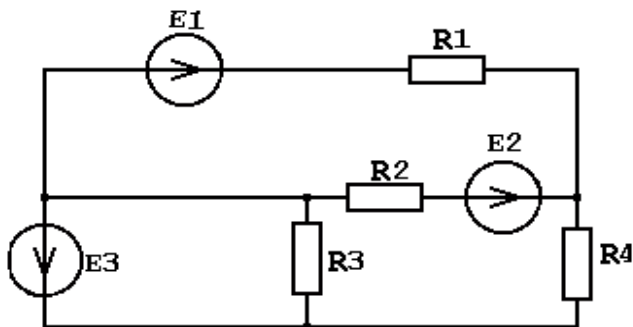


Figure 1.24

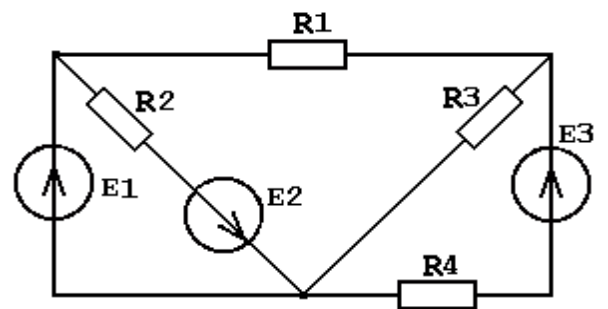


Figure 1.25

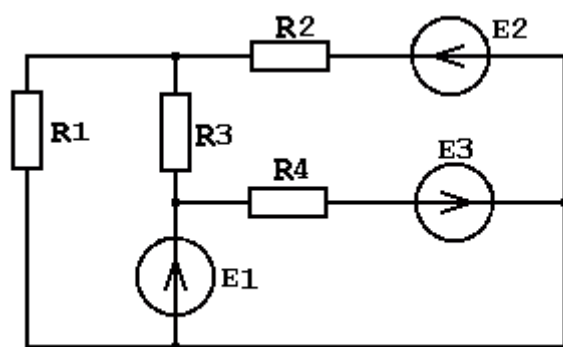


Figure 1.26

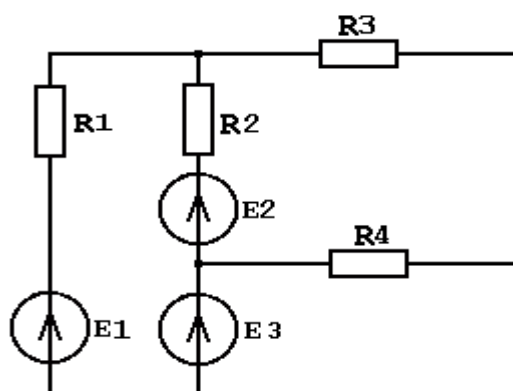


Figure 1.27

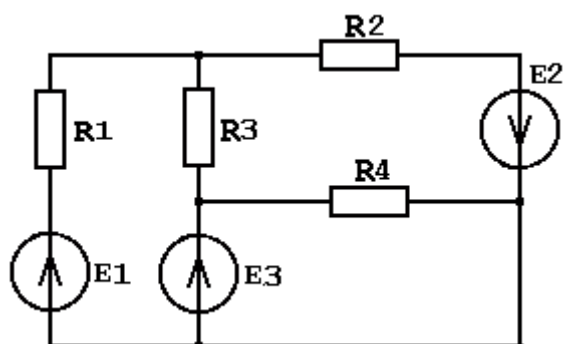


Figure 1.28

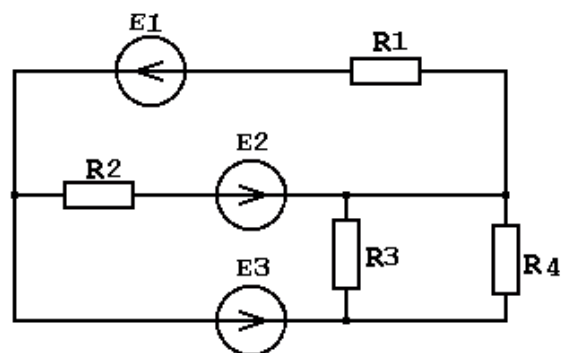


Figure 1.29

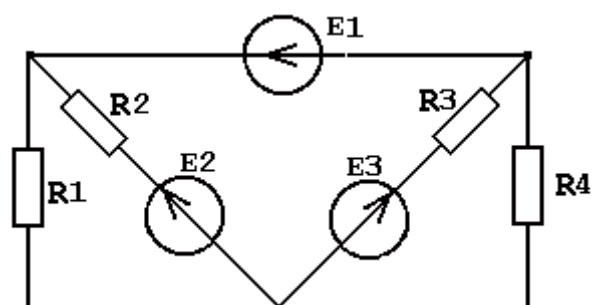


Figure 1.30

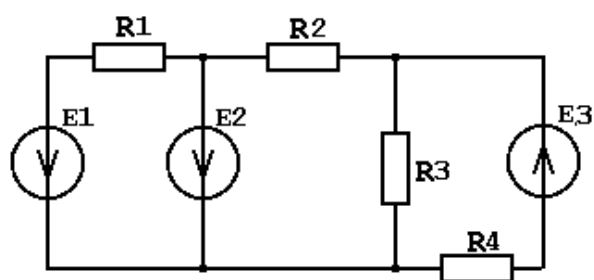


Figure 1.31

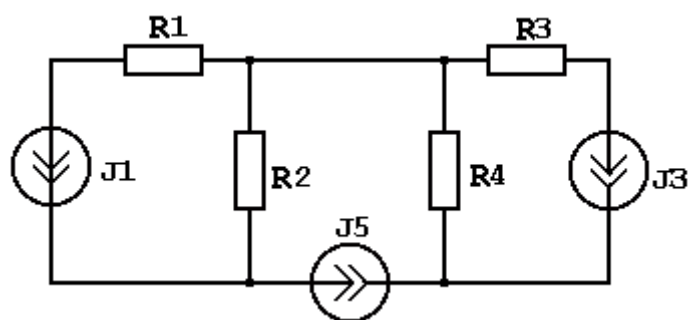


Figure 1.32

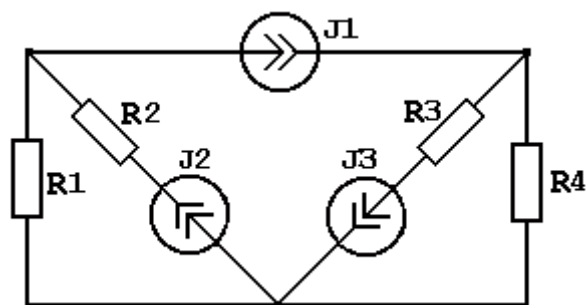


Figure 1.33

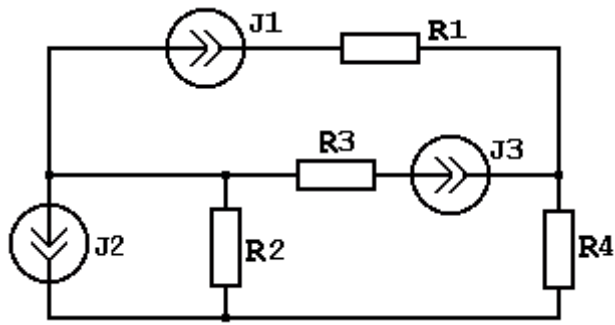


Figure 1.34

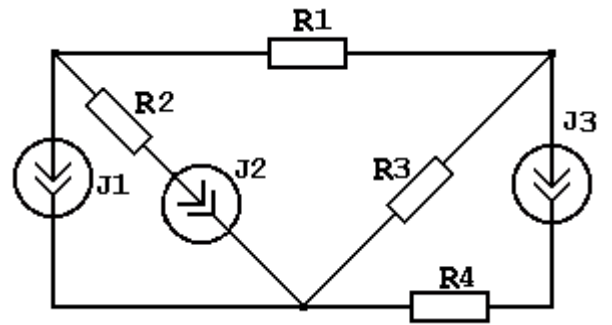


Figure 1.35

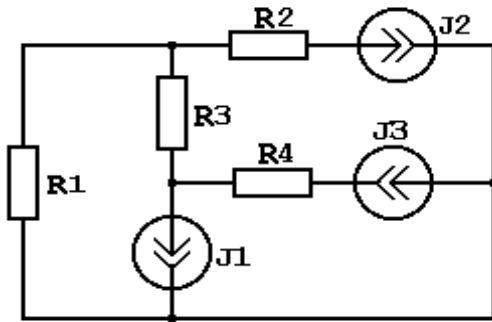


Figure 1.36

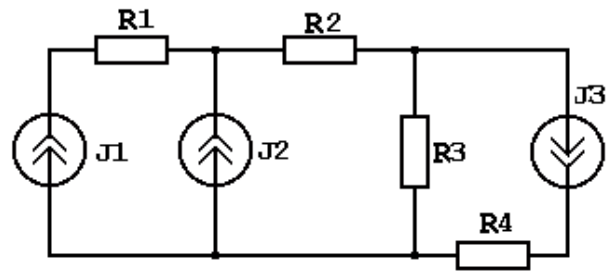


Figure 1.37

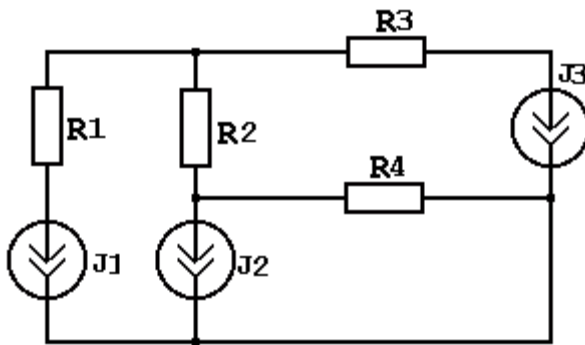


Figure 1.38

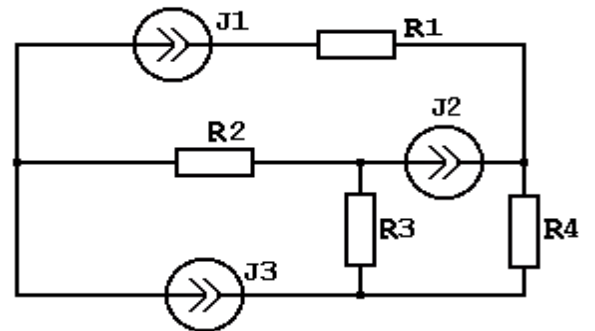


Figure 1.39

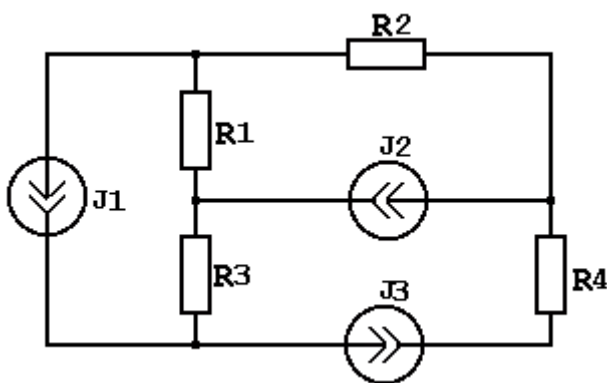


Figure 1.40

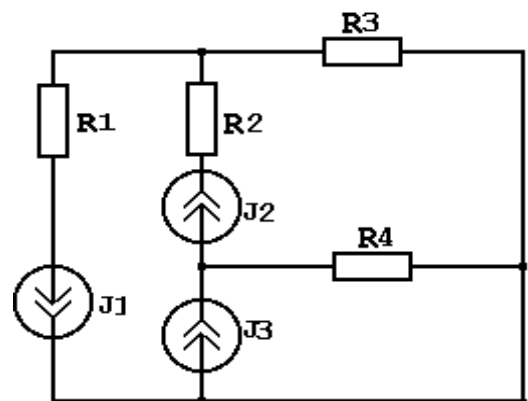


Figure 1.41

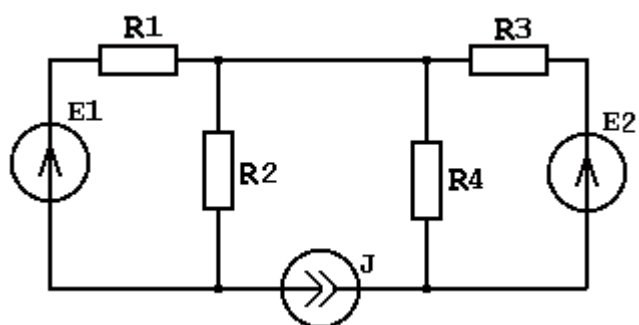


Figure 1.42

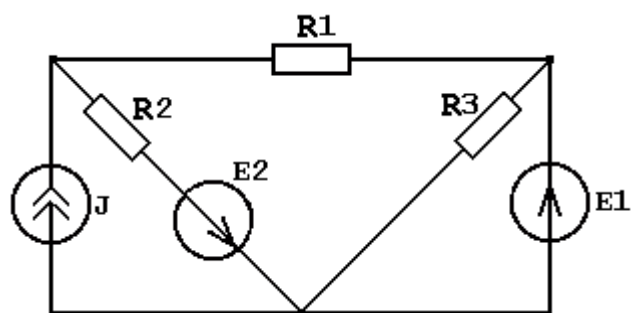


Figure 1.43

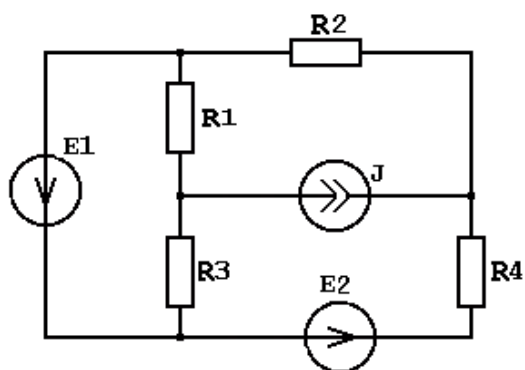


Figure 1.44

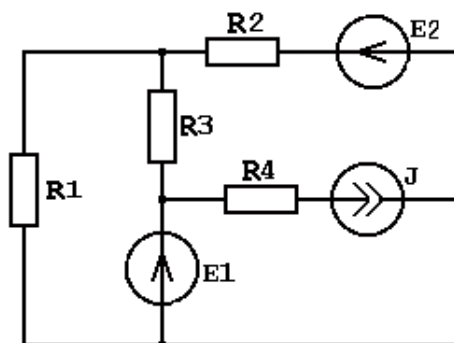


Figure 1.45

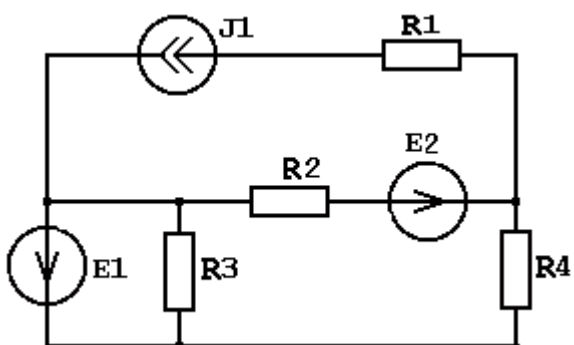


Figure 1.46

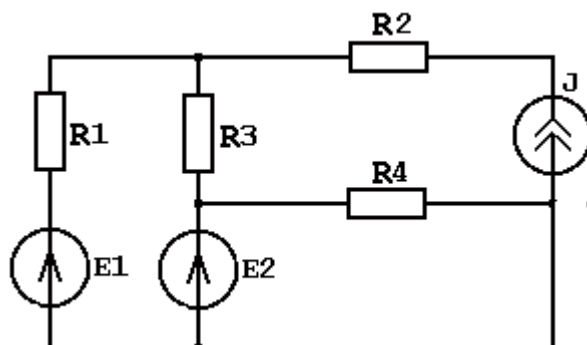


Figure 1.47

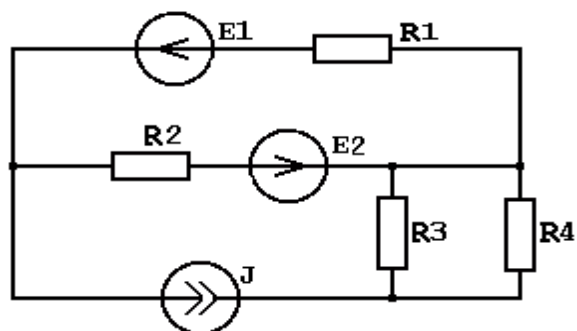


Figure 1.48

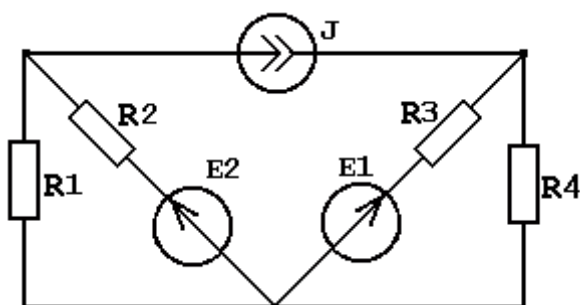


Figure 1.49

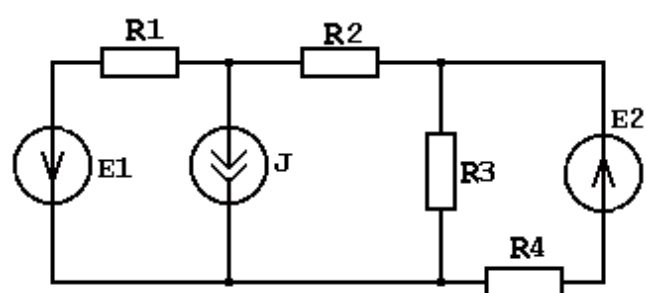


Figure 1.50

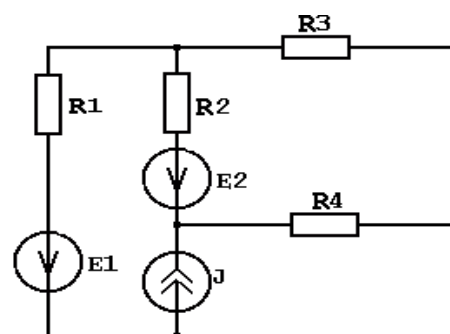


Figure 1.51

Example of completing tasks (option No0)

Task No1. Use the contour current method to calculate the currents in the branches of an electric circuit (Figure 1.22) if $R_1 = 100 \text{ Ohm}$, $R_2 = 300 \text{ Ohm}$, $R_3 = 150 \text{ Ohm}$, $R_4 = 250 \text{ Ohm}$, $E_1 = 10 \text{ V}$, $E_2 = 20 \text{ V}$, $E_3 = 15 \text{ V}$.

Solution

- 1. Determine the number of independent circuits (the number of circuit currents) in the electrical circuit (Figure 1.22) $N = n_B - n_y + 1 = 5 - 3 + 1 = 3$
- 2. Determine the number of equations $N_k = n_b - n_y + 1 - n_J = 5 - 3 + 1 - 0 = 3$

Here, n_b is the number of branches in the circuit, n_y is the number of nodes, and n_J is the number of branches containing current sources.

- 3. The system of equations with $N_k = 3$ and $n_J = 0$ has the form

$$R_{11} \cdot I_{1k} + R_{12} \cdot I_{2k} + R_{13} \cdot I_{3k} = E_{11}$$

$$R_{21} \cdot I_{1k} + R_{22} \cdot I_{2k} + R_{23} \cdot I_{3k} = E_{22}$$

$$R_{31} \cdot I_{1k} + R_{32} \cdot I_{2k} + R_{33} \cdot I_{3k} = E_{33}$$

- 4. Indicate the conditionally positive directions of the circuit currents in the circuit branches (Figure 1.75)

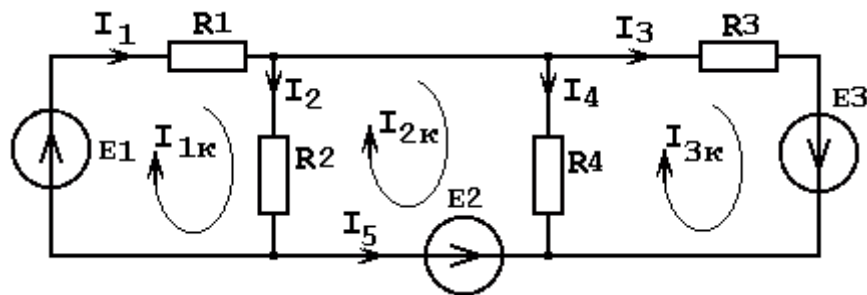


Figure1.75

- 5. Define the eigenresistances of the circuits as the sum of the resistances of the elements included in the circuit

$$R_{11} = R_1 + R_2 = 100 + 300 = 400 \text{ OM},$$

$$R_{22} = R_2 + R_4 = 300 + 250 = 550 \text{ OM},$$

$$R_{33} = R_3 + R_4 = 150 + 250 = 400 \text{ OM}.$$

6. Determine the total resistances R_{ij} of the circuits j and i . With the sign "+" we take the resistances of the elements in which the contour currents coincide in the direction

$$R_{12} = R_{21} = -R_2 = -300 \text{ Ом}, \quad R_{13} = R_{31} = 0, R_{23} = R_{32} = -R_4 = -250 \text{ Ом}.$$

7. Define contour EMF as the algebraic sum of EMF included in this circuit. With the sign "+" the sum includes EMF that coincide in direction with the contour current $E_{11} = E_1 = 10 \text{ В}$, $E_{22} = -E_2 = -20 \text{ В}$,

$$E_{33} = E_3 = 15 \text{ В}.$$

8. After substituting the calculated values into the system of equations, we get

$$\begin{cases} 400 \cdot I_{1k} - 300 \cdot I_{2k} + 0 \cdot I_{3k} = 10 \\ -300 \cdot I_{1k} + 550 \cdot I_{2k} - 250 \cdot I_{3k} = -20 \\ 0 \cdot I_{1k} - 250 \cdot I_{2k} + 400 \cdot I_{3k} = 15 \end{cases}$$

9. To solve the resulting system of linear equations, you can use various methods known from the mathematics course. To calculate currents, we use Cramer's rules.

9.1. Find the determinants:

$$\Delta = \begin{vmatrix} 400 & -300 & 0 \\ -300 & 550 & -250 \\ 0 & -250 & 400 \end{vmatrix} = \begin{vmatrix} 400 & -300 & 0 & 400 & -300 \\ -300 & 500 & -250 & -300 & 550 \\ 0 & -250 & 400 & 0 & -250 \end{vmatrix} = 400 \cdot 550 \cdot 400 + (-300) \cdot (-250) -$$

$$-0 \cdot 550 \cdot 0 - 400(-250) \cdot (-250) - (-300) \cdot (-300) \cdot (400) = 2 \cdot 7 \cdot 10^7 \text{ Ом}^3,$$

$$\Delta_1 = \begin{vmatrix} 10 & -300 & 0 \\ -20 & 550 & -250 \\ 15 & -250 & 400 \end{vmatrix} = 3 \cdot 10^5 \text{ В} \cdot \text{Ом}^2, \quad \Delta_2 = \begin{vmatrix} 400 & 10 & 0 \\ -300 & -20 & -250 \\ 0 & 15 & 400 \end{vmatrix} = -5 \cdot 10^5 \text{ В} \cdot \text{Ом}^2,$$

$$\Delta_3 = \begin{vmatrix} 400 & -300 & 10 \\ -300 & 550 & -20 \\ 0 & -250 & 15 \end{vmatrix} = 7 \cdot 10^5 \text{ В} \cdot \text{Ом}^2.$$

9.2. Finding Circuit Currents

$$I_{1k} = \frac{\Delta_1}{\Delta} = \frac{3 \cdot 10^5}{2.7 \cdot 10^7} = 0.011 \text{ A},$$

$$I_{2k} = \frac{\Delta_2}{\Delta} = \frac{-5 \cdot 10^5}{2.7 \cdot 10^7} = -0.019 \text{ A},$$

$$I_{3k} = \frac{\Delta_3}{\Delta} = \frac{7 \cdot 10^5}{2.7 \cdot 10^7} = 0.026 \text{ A}.$$

10. Define the current in each branch as the algebraic sum of the contour currents in that branch

$$I_1 = I_{1k} = 0.011 \text{ A},$$

$$I_2 = I_{1k} - I_{2k} = 0.011 - (-0.019) = 0.03 \text{ A},$$

$$I_3 = I_{3k} = 0.026 \text{ A},$$

$$I_4 = I_{2k} - I_{3k} = -0.019 - 0.026 = -0.044 \text{ A},$$

$$I_5 = -I_{2k} = 0.019 \text{ A}.$$

Task No2. Using the contour current method, calculate the currents in a given electrical circuit Figure 1.32 if $R_1 = 10 \text{ Ohm}$, $R_2 = 20 \text{ Ohm}$, $R_3 = 15 \text{ Ohm}$, $R_4 = 35 \text{ Ohm}$, $J_1 = 10 \text{ A}$, $J_3 =$, $J_2 = 0.25 \text{ A}$

Solution

- 1. Determine the number of independent circuits (number of circuit currents)

$$N = n_b - n_y + 1 = 5 - 3 + 1 = 3$$

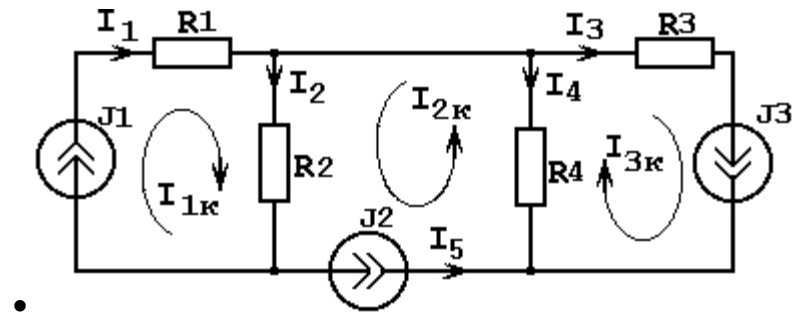
- 2. Determine the number of equations $N_k = n_b - n_y + 1 - n_J = 5 - 3 + 1 - 3 = 0$

Here, n_b is the number of branches in the circuit, n_y is the number of nodes, and n_J is the number of branches containing current sources.

The number of equations is zero, since each loop current is determined by the current of the corresponding current source and is therefore equal to this current, i.e. $I_{1k} = J_1 = 10 \text{ A}$, $I_{2k} = J_2 =$, $I_{3k} = J_3 = 0.25 \text{ A}$

- 3. Indicate the conditionally positive directions of currents in the branches and contour currents in the diagram (Figure 1.76). In this case, it is advisable to choose the directions of the contour currents coinciding with the direction of the

currents in the corresponding current sources. Moreover, each branch with a current source should have only one contour current.



•Figure 1.76

4. Determine the currents in the branches

$$I_1 = I_{1k} = 10 \text{ A}, \quad I_2 = I_{1k} + I_{2k} = 10 + 25 = 35 \text{ A}, \quad I_3 = I_{3k} = 20 \text{ A}, \quad I_4 = -I_{2k} - I_{3k} = -45 \text{ A}$$

Task No3. Using the loop current method, calculate the currents in the branches of a given electrical circuit (Figure 1.42) if $R_1 = 100 \text{ Ohm}$, $R_2 = 300 \text{ Ohm}$, $R_3 = 150 \text{ Ohm}$, $R_4 = 250 \text{ Ohm}$, $E_1 = 10 \text{ V}$, $E_2 = 15 \text{ V}$, $J = 0.10 \text{ A}$.

Solution

•1. Determine the number of independent circuits (number of circuit currents)

$$N = n_b - n_y + 1 = 5 - 3 + 1 = 3$$

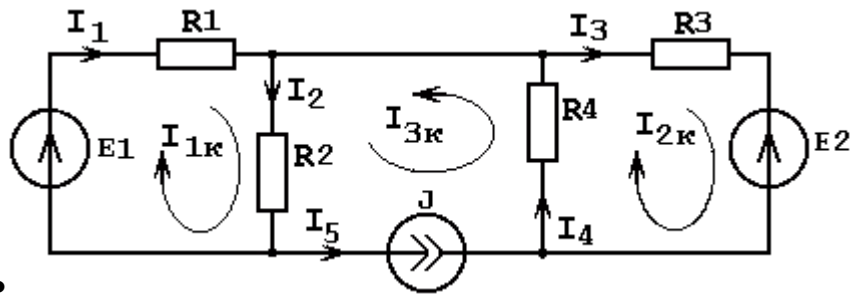
2. Determine the number of equations $N_k = n_b - n_y + 1 - n_J = 5 - 3 + 1 - 1 = 2$

2

3. Write down a system of 2 equations for three loop currents

$$\begin{cases} R_{11} \cdot I_{1k} + R_{12} \cdot I_{2k} + R_{13} \cdot I_{3k} = E_{11} \\ R_{21} \cdot I_{1k} + R_{22} \cdot I_{2k} + R_{23} \cdot I_{3k} = E_{22} \end{cases}$$

•4. Indicate the conditionally positive directions of the circuit currents and currents in the circuit branches (Figure 1.77). In this case, the circuit currents are selected in such a way that only one circuit current passes through the branch with the current source.



•Figure 1.77

- 5. Determine the natural resistances of the circuits

$$R_{11} = R_1 + R_2 = 100 + 300 = 400 \text{ ohms,}$$

$$R_{22} = R_3 + R_4 = 150 + 250 = 400 \text{ ohms.}$$

6. Determine the total resistances R_{ij} for circuits i and j

$$R_{12} = R_{21} = 0, R_{13} = R_{31} = R_2 = 300 \text{ OM, } R_{23} = R_4 = 250 \text{ OM}$$

7. Determine the contour EMF $E_{11} = E_1 = 10 \text{ V, } E_{22} = -E_3 = -15 \text{ V.}$

8. After substituting the calculated values into the system of equations, taking

into account that $I_{3k} = J$ we get

$$\begin{cases} 400 \cdot I_{1k} + 0 \cdot I_{2k} + 300 \cdot 0.1 = 10 \\ 0 \cdot I_{1k} + 400 \cdot I_{2k} + 250 \cdot 0.1 = -15 \end{cases}$$

9. Solving a system of equations

$$\begin{cases} 400 \cdot I_{1k} = 10 - 30 \\ 250 \cdot I_{2k} = -15 - 25 \end{cases},$$

We will get

$$I_{1k} = -\frac{20}{400} = -0.05 \text{ A,}$$

$$I_{2k} = -\frac{40}{400} = -0.1 \text{ A.}$$

10. Determine the currents in the branches

$$I_1 = I_{1k} = -0.05 \text{ A,}$$

$$I_2 = I_{1k} + I_{3k} = -0.05 + 0.1 = +0.5 \text{ A,}$$

$$I_3 = I_{2k} = -0.1 \text{ A,}$$

$$I_4 = I_{2k} + I_{3k} = -0.1 + 0.1 = 0 \text{ A,}$$

$$I_5 = I_{3k} = 0.1 \text{ A.}$$

•3. Calculation of linear electrical circuits by the method of nodal potentials

Study questions:

1. Calculation of an electrical circuit with EMF sources
2. Calculation of an electrical circuit with current sources.
3. Calculation of the electrical circuit with EMF and current sources.

Assignment for students to prepare for the lesson

1. Study:

1. Nikulin V.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. - Moscow: RIOR, 2016, pp. 35-38.
2. Bakalov V.P., Vorobienko P.P., Kruk B.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. - Moscow: Radio i svyaz, 1998, pp. 45-53.
3. Shebes M. R. Zadachnik po teorii lineynykh elektricheskikh tsepey [Task book on the theory of linear electric circuits]. - Moscow: Vysshaya shkola, 1982. - pp. 5, 7-8.

2. Answer the questions:

1. Formulate Ohm's law for a closed single-loop circuit.
2. Formulate Ohm's Law for a branch of resistive elements that does not contain EMF sources
3. Formulate a generalized Ohm's law. Write down the formula of a generalized Ohm's law using a specific chain as an example.
4. How is the number of equations determined when calculating a circuit with EMF sources using the nodal potential method?
5. How is a system of equations compiled when calculating by the method of nodal potentials of a circuit containing separate branches with only idealized sources of EMF? Explain using the example of a specific circuit.

6. How is the number of equations determined when calculating a circuit with EMF and current sources using the nodal potential method?
7. How is the system of equations compiled when calculating a circuit with sources of EMF and current using the nodal potential method? Explain using the example of a specific circuit.
8. What are the methods of solving systems of linear equations known to you?
9. Explain the algorithm for calculating an electrical circuit using the nodal potential method.
10. How are the currents in the branches determined when calculating the circuit using the nodal potential method?
11. How is the current in a branch containing only an idealized EMF source determined in the nodal potential calculation?

3. Analyze the solution of the following tasks:

No1.30, No1.32 (Shebes M. R. Task book on the theory of linear electric circuits, Moscow: Vysshaya shkola, 1982. - pp. 38-41)

During the practical lesson, complete the tasks:

Task No1. Calculate the currents in the branches using the nodal potential method for a given electrical circuit with EMF sources according to the variant (Table 1.4)

Task No2. Calculate the currents in the branches by the method of nodal potentials of currents for a given electric circuit with current sources according to the variant (Table 1.5)

Task No3. Calculate the currents in the branches using the nodal potential method for a given electrical circuit with emf and current sources according to the variant (Table 1.6)

Example of completing tasks (option No0)

Task No1. Using the nodal potential method, calculate the currents in the branches of a given electrical circuit (Figure 1.22) if $R_1 = 100 \text{ Ohm}$, $R_2 = 300 \text{ Ohm}$, $R_3 = 150 \text{ Ohm}$, $R_4 = 250 \text{ Ohm}$, $E_1 = 10 \text{ V}$, $E_2 = 20 \text{ V}$, $E_3 = 15 \text{ V}$.

Solution

1. Indicate the numbers of the nodes on the diagram (Figure 1.78).

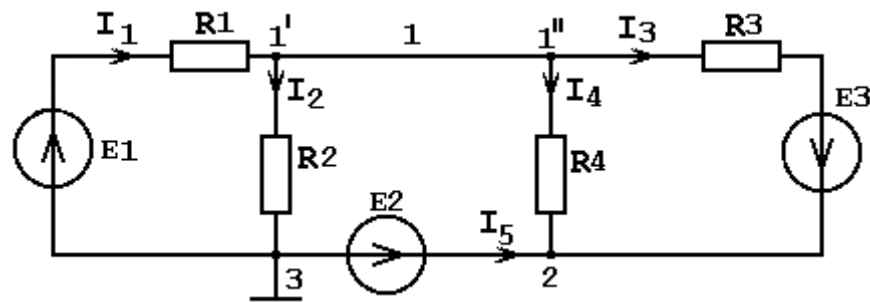


Figure 1.78

Select the support node, which is recommended to be the one with the largest number of branches consisting only of ideal EMF sources. In Figure 1.78, we can select 2 or 3 as the reference node. Select 3 as the reference node and assume its potential $\varphi_3 = 0$. In Figure 1.78, we show its connection to the housing. Nodes 1' and 1 should be considered as one node, since they are connected by an ideal conductor and, therefore, their potentials are equal to each other.

2. Determine the number of equations $N = n_y - 1 - n_{\text{EMF}} = 3 - 1 - 1 = 1$

Here n_y is the number of nodes in the chain

n_{EMF} is the number of branches consisting only of idealized EMF sources. In the diagram (Figure 1.78) the branch with the source E_2 .

3. Determine the potential of node 2. Since the EMF is directed from node 3 to node 2, the potential φ_2 will be greater than potential φ_3 by the value of E_2 .

$$\varphi_2 = \varphi_3 + E_2 = 0 + 20 = 20 \text{ B.}$$

4. Let's make an equation to determine the potential of node 1

$$G_{11}\varphi_1 - G_{12}\varphi_2 = \sum_1 EG,$$

Here, G_{11} is the sum of the conductivities of the branches attached to node 1;

G12 is the sum of the conductivities of the branches connecting node 1 and 2;

$\sum_1 EG$ is the algebraic sum of the products of the EMF of the branches

adjacent to node 1 on their conductivity. In this case, those products in the branches of which the EMF act in the direction of node 1 are taken with a plus sign.

5. Determine the values necessary for the calculation

$$G_{11} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{100} + \frac{1}{300} + \frac{1}{150} + \frac{1}{250} = 0.024 \text{ CM},$$

$$G_{12} = \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{150} + \frac{1}{250} = 0.01066 \text{ CM},$$

$$\sum_1 EG = E_1 \cdot \frac{1}{R_1} - E_3 \cdot \frac{1}{R_3} = 10 \cdot \frac{1}{100} - 15 \cdot \frac{1}{150} = 0$$

6. Solving the Equation $0.024 \cdot \varphi_1 - 0.01066 \cdot 20 = 0$

$$\varphi_1 = \frac{0.213}{0.024} = 8.889 \text{ B.}$$

7. In the diagram of Figure 1.78, we indicate arbitrarily conditionally positive directions of currents in the branches.

8. According to Ohm's law, for a section of the circuit with an EMF source, determine

$$I_1 = \frac{\varphi_3 - \varphi_1 + E_1}{R_1} = \frac{0 - 8.889 + 10}{100} = 0.011 \text{ A},$$

$$I_3 = \frac{\varphi_1 - \varphi_2 + E_3}{R_3} = \frac{8.889 - 20 + 15}{150} = 0.026 \text{ A}.$$

9. According to Ohm's law, for the section of the circuit with the resistive element, we find

$$I_2 = \frac{\varphi_1 - \varphi_3}{R_2} = \frac{8.889 - 0}{300} = 0.03 \text{ A},$$

$$I_4 = \frac{\varphi_1 - \varphi_2}{R_4} = \frac{8.889 - 0}{250} = -0.044 \text{ A}.$$

10. Using Kirchhoff's law 1 for node 2, we find

$$I_5 = -I_3 - I_4 = -0.026 - (-0.044) = 0.019 \text{ A}.$$

11. To check the correctness of the calculations, let's determine the balance of capacities.

11.1. Power generated by energy sources:

$$P_{\text{ист}} = E_1 \cdot I_1 + E_3 \cdot I_3 + E_2 \cdot I_5 = 10 \cdot 0.011 + 15 \cdot 0.026 + 20 \cdot 0.019 = 0.87 \text{ Вт}.$$

11.2. Power Consumed by Passive Circuit Elements

$$P_{\text{пр}} = I_1^2 \cdot R_1 + I_2^2 \cdot R_2 + I_3^2 \cdot R_3 + I_4^2 \cdot R_4 = \\ = (0.011)^2 \cdot 100 + (0.03)^2 \cdot 300 + (-0.026)^2 \cdot 150 + (-0.044)^2 \cdot 250 = 0.87 \text{ Вт}.$$

Since $P_{\text{ист}} = P_{\text{пр}} = 0.87 \text{ Вт}$, the power balance condition is met in the circuit.

Task No2. Using the nodal potential method, calculate the currents in a given electrical circuit (Figure 1.32), if $R_1 = 10 \text{ Ohm}$, $R_2 = 20 \text{ Ohm}$,

$R_3 = 15 \text{ ohms}$, $R_4 = 35 \text{ ohms}$, $J_1 = 10 \text{ A}$, $J_2 = 0.5 \text{ A}$, $J_3 = .20 \text{ A}$

Solution

1. Specify the numbers of the nodes and select 3 (Figure 1.79) as the support node and its potential $\varphi_3 = 0$.

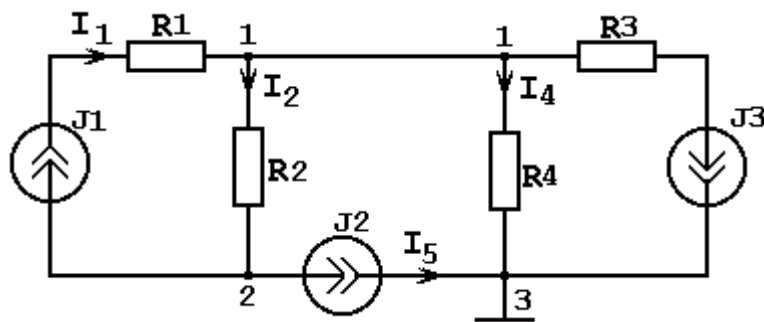


Figure 1.79

2. Number of equations $N = n_y - 1 - n_{\text{эдс}} = 3 - 1 - 0 = 2$

3. Make a system of equations

$$\begin{cases} G_{11} \cdot \varphi_1 - G_{12} \cdot \varphi_2 = \sum_1 J \\ -G_{12} \cdot \varphi_1 + G_{22} \cdot \varphi_2 = \sum_2 J \end{cases}$$

Here $\sum_1 J$ is the algebraic sum of the currents of the current sources connected to node 1,

$\sum_2 J$ - algebraic sum of currents of current sources connected to node 2.

4. Determine the quantities necessary to solve the system of equations, taking into account that the conductivity of the branch containing the current source is zero.

$$G_{11} = \frac{1}{R_2} + \frac{1}{R_4} = \frac{1}{20} + \frac{1}{35} = 0.079 \text{ C}_M,$$

$$G_{12} = G_{21} = \frac{1}{R_2} = \frac{1}{20} = 0.05 \text{ C}_M,$$

$$G_{22} = \frac{1}{R_2} = \frac{1}{20} = 0.05 \text{ C}_M.$$

$$\sum_1 J = J_1 - J_3 = 10 - 20 = -10 \text{ A},$$

$$\sum_2 J = -J_1 - J_2 = -10 - 25 = -35 \text{ A}.$$

5. Solving a System of Equations
$$\begin{cases} 0.079 \cdot \varphi_1 - 0.05 \cdot \varphi_2 = -10 \\ -0.05 \cdot \varphi_1 + 0.05 \cdot \varphi_2 = -35 \end{cases}$$

Find $\varphi_1 = -1575 \text{ B},$
 $\varphi_2 = -2275 \text{ B}.$

6. Indicate on the diagram Figure 1.79 conditionally positive directions of currents.

7. Find currents in the branches

7.1. According to Ohm's law:

$$I_2 = \frac{\varphi_1 - \varphi_2}{R_2} = \frac{-1575 - (-2275)}{20} = 35 \text{ A}, \quad I_4 = \frac{\varphi_1 - \varphi_3}{R_4} = \frac{-1575}{35} = -45 \text{ A}.$$

7.2. The current in a branch containing a current source is determined by the amount of current generated by this source.

$$I_1 = J_1 = 10 \text{ A}, \quad I_3 = J_3 = 20 \text{ A}, \quad I_5 = J_5 = 25 \text{ A}.$$

8. For node 2, let's check the fulfillment of Kirchhoff's law 1

$$I_2 - I_1 - I_5 = 0$$

$$35 - 10 - 25 = 0$$

Task No3. Using the nodal potential method, calculate the currents in the branches of a given electrical circuit (Figure 1.42) if $R_1 = 100 \text{ Ohm}$, $R_2 = 300 \text{ Ohm}$, $R_3 = 150 \text{ Ohm}$, $R_4 = 250 \text{ Ohm}$, $E_1 = 10 \text{ V}$, $E_3 = 15 \text{ V}$, $J_2 = 0.1 \text{ A}$.

Solution

1. Let's indicate the numbers of the nodes on the diagram and take the 3rd node as the reference node, the potential of which is equal to 0 (Figure 1.80).

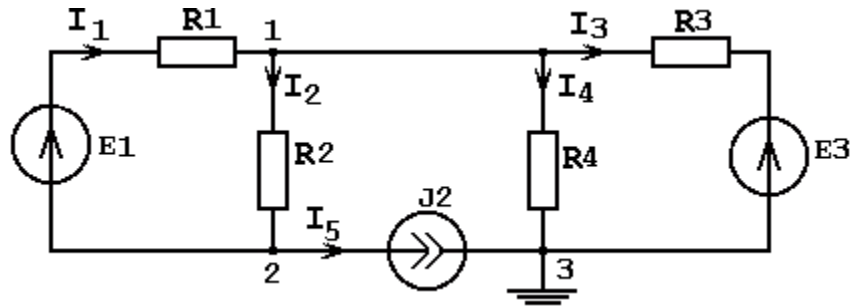


Figure1.80

2. Number of equations $N = ny - 1 - n_{EMF} = 3 - 1 - 0 = 2$.

3. Make a system of equations

$$\begin{cases} G_{11}\varphi_1 - G_{12}\varphi_2 = \sum_1 EG + \sum_1 J \\ -G_{21}\varphi_1 + G_{22}\varphi_2 = \sum_2 EG + \sum_1 J \end{cases}$$

4. Determine the quantities necessary to solve the system of equations

$$G_{11} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{100} + \frac{1}{300} + \frac{1}{150} + \frac{1}{250} = 0.024 \text{ CM},$$

$$G_{12} = G_{21} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{100} + \frac{1}{300} = 0.013 \text{ CM},$$

$$G_{22} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{100} + \frac{1}{300} = 0.013 \text{ CM},$$

$$\sum_1 EG = E_1 \cdot \frac{1}{R_1} + E_3 \cdot \frac{1}{R_3} = 10 \cdot \frac{1}{100} + 15 \cdot \frac{1}{150} = 0.2 \text{ A},$$

$$\sum_1 J = 0,$$

$$\sum_2 EG = -E_1 \cdot \frac{1}{R_1} = -10 \cdot \frac{1}{100} = -0.1 \text{ A},$$

$$\sum_2 J = -J_2 = -0.1 \text{ A}.$$

5. Solving a System of Equations

$$\begin{cases} 0.024 \cdot \varphi_1 - 0.013 \cdot \varphi_2 = 0.2 \\ -0.013 \cdot \varphi_1 + 0.013 \cdot \varphi_2 = 0.2 \end{cases} \text{ and find } \begin{cases} \varphi_1 = 0 \text{ B,} \\ \varphi_2 = -15 \text{ B.} \end{cases}$$

6. Choose conditionally positive directions of currents in the branches.

7. Applying Ohm's law for a section of the circuit, we find

$$I_1 = \frac{\varphi_2 - \varphi_1 + E_1}{R_1} = -0.05 \text{ A,}$$

$$I_2 = \frac{\varphi_1 - \varphi_2}{R_2} = 0.05 \text{ A,}$$

$$I_3 = \frac{\varphi_1 - \varphi_3 - E_3}{R_3} = -0.1 \text{ A,}$$

$$I_4 = \frac{\varphi_1 - \varphi_3}{R_4} = \frac{0 - 0}{250} = 0 \text{ A.}$$

8. Current in branches with a current source

$$I_5 = I_2 = 0.1 \text{ A.}$$

9. Let's check the fulfillment of the first Kirchhoff's law for node 2

$$-I_1 - I_5 + I_2 = 0$$

$$-(-0.05) - 0.1 + 0.05 = 0$$

10. To check the correctness of the calculations, let's determine the balance of capacities.

10.1. Power generated by energy sources:

$$P_{\text{ист}} = E_1 \cdot I_1 - E_3 \cdot I_3 + U_2 \cdot I_2 = 10 \cdot (-0.05) - 15 \cdot (-0.099) + 15 \cdot 0.1 = 2.5 \text{ Вт.}$$

Here, U_2 is the voltage at the current source J_2 (Figure 1.80)

$$U_2 = I_2 R_2 - I_4 R_4 = 0.05 \cdot 300 - 0 \cdot 250 = 15 \text{ B.}$$

10.2. Power Consumed by Passive Circuit Elements

$$\begin{aligned} P_{\text{пс}} &= I_1^2 \cdot R_1 + I_2^2 \cdot R_2 + I_3^2 \cdot R_3 + I_4^2 \cdot R_4 = \\ &= (-0.05)^2 \cdot 100 + (0.05)^2 \cdot 300 + (-0.1)^2 \cdot 150 + 0^2 \cdot 250 = 2.5 \text{ Вт.} \end{aligned}$$

Since $R_{\text{ист}} = R_{\text{пс}} = 2.5 \text{ W}$, the power balance condition is met in the circuit.

4. Calculation of Sine Current Electrical Circuits

Study questions:

1. Calculation of currents and voltages in idealized elements.
2. Calculation of currents and voltages in series connection of elements.
3. Calculation of currents and voltages in parallel connection of elements.

Task to prepare for the lesson

1. Study:

1. Nikulin V.I. Theory of Electrical Circuits. - Moscow: RIOR, 2016, pp. 51-57.
2. Bakalov V.P., Vorobienko P.P., Kruk B.I. Theory of Electrical Circuits.- Moscow: Radio and Communication, 1998, pp. 73-82.
3. Shebes M. R. Zadachnik po teorii lineynykh elektricheskikh tsepey [Task book on the theory of linear electric circuits]. - Moscow: Vysshaya shkola, 1982. - pp. 47-51.

2. Answer the questions:

1. Write down the expression for complex amplitude and effective current if instantaneous current is $i = 2\sin(\omega t - 1450)\text{mA}$.
2. Generate a Vector Diagram for a Harmonic Current $i = 2\sin(\omega t - 1450)\text{mA}$.
3. Write an expression of Ohm's law in a complex form for a section of the circuit with a resistive element and draw a vector diagram of current and voltage.
4. Write an expression of Ohm's law in complex form for a section of the circuit with an inductive element and depict a vector diagram of current and voltage.
5. Write the expression of Ohm's law in complex form for a section of the circuit with a capacitive element and depict a vector diagram of current and voltage.

3. Analyze the solution of the following tasks:

No2.24, 2.31 (Shebes M. R. Task book on the theory of linear electric circuits, Moscow: Vysshaya shkola, 1982. - pp. 66-67, 70)

During the practical lesson, complete the tasks:

Task No1. Determine the instantaneous current in the inductive element L (Table 2.4), construct vector and temporal diagrams of current and voltage, if the voltage on the element is specified according to the variant (Table 2.4) u .

Task No2. For the capacitive element C and instantaneous current specified according to the variant (Table 2.4), i determine complex amplitudes and active currents and voltages. Construct vector and time diagrams of current and voltage.

Task No3. The circuit elements R and L (or C) (Table 2.5) are connected in series and are under the influence of instantaneous current i (or voltage u). Determine the applied instantaneous voltage to the circuit, instantaneous voltages on the circuit elements. Construct vector diagrams of current and voltages.

Task No4. The elements of the circuit R, C (or L) (Table 2.6) are connected in parallel and are under the influence of instantaneous voltage u (or current i). Determine instantaneous currents in the circuit and in its elements. Construct a vector diagram of currents and voltages.

Table 2.4

Variant №	L, Gn	Instantaneous Voltage U			S, μ F	Instantaneous Current I		
		Um, B	ψ , hail	ω , rad/s		Im , A	ψ ,deg	ω , rad/s
0	0.1	20	-30	103	0.10	2.82	30	105
1	0.2	10	45	103	0.04	2.5	-25	106
2	0.5	30	-20	104	0.05	1.2	100	107
3	0.15	40	110	102	0.07	3.2	-35	108
4	0.8	15	-75	105	0.01	4.0	70	109
5	0.05	20	195	105	0.02	5.0	-60	104
6	0.04	35	-15	104	0.05	5.5	35	105
7	0.3	60	210	103	0.07	6.5	-70	104
8	0.6	75	-35	102	0.09	4.0	120	105
9	0.65	45	60	103	0.01	3.0	-40	106
10	0.7	25	-70	105	0.03	6.0	175	107
11	0.75	75	40	104	0.04	7.5	-80	108
12	0.9	90	-130	103	0.08	4.5	135	109
13	0.3	20	145	103	0.06	3.5	-45	106
14	0.2	25	-200	104	0.08	2.2	10	107
15	0.25	40	140	102	0.05	4.2	-95	108
16	0.9	25	-175	105	0.02	5.0	80	109
17	0.03	30	95	105	0.07	6.0	-160	104
18	0.09	45	-115	104	0.03	1.5	305	105
19	0.6	30	10	103	0.05	4.5	-170	104
20	0.4	15	-135	102	0.03	9.0	20	105
21	0.85	35	160	103	0.04	5.0	-140	106
22	0.5	15	-170	105	0.08	6.0	75	107
23	0.7	70	60	104	0.03	3.5	-100	108
24	0.3	10	-30	103	0.05	4.5	125	109
25	0.6	20	65	103	0.08	3.5	-125	106
26	0.7	40	-120	104	0.03	4.2	70	107
27	0.1	70	170	102	0.08	3.6	-30	108
28	0.5	75	-75	105	0.04	7.0	80	109
29	0.25	28	19	105	0.09	1.0	-90	104
30	0.03	50	-145	104	0.04	7.5	135	105

31	0.35	70	230	103	0.03	2.5	-130	104
32	0.65	85	-305	102	0.01	4.3	320	105
33	0.5	95	60	103	0.08	3.8	-160	106
34	0.3	85	-150	105	0.07	6.5	105	107
35	0.7	75	400	104	0.04	4.5	-280	108
36	0.45	30	-10	103	0.09	1.5	30	109
36	0.36	26	14	103	0.05	2.5	-405	106
38	0.29	25	-260	104	0.08	6.2	100	107
39	0.75	49	340	102	0.04	4.8	-905	108
40	0.03	95	60	104	0.04	7.5	135	105
41	0.35	85	-150	103	0.03	6.5	105	104
42	0.65	75	400	102	0.01	4.5	-280	105
43	0.5	30	-10	103	0.08	1.5	30	106
44	0.3	26	14	105	0.07	2.5	-405	107
45	0.7	25	-260	104	0.04	6.2	100	108

Table 2.5

Variant №	R, Ω	L, Gn	S, μF	Instantaneous Voltage U			Instantaneous Current I		
				Um, B	ψ, hail	ω, rad/s	Im, mA	ψ, Hail	ω, rad/s
0	40	0.03	-	-	-	-	100	30	103
1	20	-	0.1	20	-45	105	-	-	-
2	400	0.04	-	-	-	-	10	-25	104
3	60	-	0.2	30	50	105	-	-	-
4	70	0.05	-	-	-	-	20	45	104
5	100	-	0.02	40	120	106	-	-	-
6	120	0.6	-	-	-	-	30	-120	103
7	15	-	0.04	45	-30	107	-	-	-
8	500	0.07	-	-	-	-	40	60	104
9	3	-	0.2	60	70	106	-	-	-
10	900	0.08	-	-	-	-	15	-75	104
11	4	-	0.02	70	-20	107	-	-	-
12	2	0.01	-	-	-	-	25	80	104
13	30	-	0.3	30	-50	105	-	-	-
14	600	0.03	-	-	-	-	20	-65	104
15	80	-	0.4	40	60	105	-	-	-
16	90	0.03	-	-	-	-	10	145	104
17	200	-	0.06	25	150	106	-	-	-
18	130	0.7	-	-	-	-	45	-140	103
19	45	-	0.09	95	-300	107	-	-	-
20	700	0.04	-	-	-	-	20	160	104
21	6	-	0.3	20	50	106	-	-	-
22	400	0.05	-	-	-	-	75	-175	104
23	5	-	0.04	65	-200	107	-	-	-
24	8	0.03	-	-	-	-	24	35	104
25	30	-	0.1	15	25	105	-	-	-
26	35	0.02	-	-	-	-	10	25	104
27	200	-	0.04	80	240	106	-	-	-
28	240	0.66	-	-	-	-	60	-20	103
29	30	-	0.08	85	-60	107	-	-	-

30	250	0.04	-	-	-	-	80	130	104
31	7	-	0.4	40	40	106	-	-	-
32	600	0.07	-	-	-	-	35	-95	104
33	5	-	0.03	40	-300	107	-	-	-
34	6	0.03	-	-	-	-	85	40	104
35	40	-	0.9	70	-120	105	-	-	-
36	200	0.08	-	-	-	-	80	-165	104
37	30	-	0.3	30	70	105	-	-	-
38	60	0.04	-	-	-	-	50	115	104
39	300	-	0.04	75	250	106	-	-	-
40	150	0.3	-	-	-	-	55	-100	103
41	4	-	0.02	70	-300	107	-	-	-
42	2	0.01	-	-	-	-	20	160	104
43	30	-	0.3	30	50	106	-	-	-
44	600	0.03	-	-	-	-	75	-175	104
45	80	-	0.4	40	-200	107	-	-	-

Table 2.6

Variant №	R, Om	L, Gn	S, μF	Instantaneous Voltage U			Instantaneous Current I		
				Um, B	ψ, hail	ω, rad/s	Im, mA	ψ, hail	ω, rad/s
0	100	-	0.1	100	-30	105	-	-	-
1	200	-	0.2	-	-	-	2	30	105
2	400	0.05	-	200	30	104	-	-	-
3	10	-	0.02	-	-	-	4	-45	5·106
4	250	0.2	-	30	-60	103	-	-	-
5	40	-	0.05	-	-	-	6	160	8·105
6	450	0.03	-	20	120	104	-	-	-
7	400	-	0.01	-	-	-	5	-60	3·105
8	50	0.8	-	10	-50	102	-	-	-
9	200	-	0.03	-	-	-	3	245	2·105
10	500	0.02	-	50	145	104	-	-	-
11	300	-	0.04	-	-	-	7	-35	105
12	150	0.02	-	150	-35	105	-	-	-
13	250	-	0.25	-	-	-	5	300	105
14	450	0.07	-	300	300	104	-	-	-
15	30	-	0.03	-	-	-	6	-145	5·106
16	350	0.25	-	70	-40	103	-	-	-
17	70	-	0.02	-	-	-	9	170	8·105
18	250	0.04	-	25	125	104	-	-	-
19	500	-	0.03	-	-	-	5	-60	3·105
20	70	0.6	-	40	-70	102	-	-	-
21	250	-	0.06	-	-	-	6	145	2·105
22	600	0.09	-	70	245	104	-	-	-
23	200	-	0.07	-	-	-	9	-135	105
24	350	0.1	-	37	-65	103	-	-	-
25	35	-	0.04	-	-	-	7	10	8·105
26	750	0.02	-	28	125	104	-	-	-
27	540	-	0.02	-	-	-	6	-260	3·105
28	80	0.75	-	15	-150	102	-	-	-
29	280	-	0.05	-	-	-	5	345	2·105
30	900	0.07	-	40	175	104	-	-	-

31	500	-	0.08	-	-	-	7	-335	105
32	450	0.04	-	170	-305	105	-	-	-
33	290	-	0.22	-	-	-	8	310	105
34	400	0.02	-	200	200	104	-	-	-
35	70	-	0.04	-	-	-	5	-345	5·106
36	150	0.55	-	30	-400	103	-	-	-
37	90	-	0.03	-	-	-	3	270	8·105
38	240	0.07	-	85	25	104	-	-	-
39	300	-	0.07	-	-	-	6	-160	3·105
40	85	0.65	-	90	-190	102	-	-	-
41	250	-	0.05	-	-	-	7	145	2·105
42	600	0.09	-	70	205	104	-	-	-
43	200	-	0.08	-	-	-	8	-135	105
44	350	0.1	-	37	-165	103	-	-	-
45	35	-	0.03	-	-	-	9	10	8·105
46	750	0.02	-	28	105	104	-	-	-

Example of completing tasks (option No 0)

Task No1. Determine the instantaneous current in the inductive element $L=0.1$ H (Table 2.4), construct vector and time diagrams of current and voltage, if the voltage on the inductive element $u = 20 \sin(10^3 t - 30^\circ)$ B.

Solution

1. Determine the complex amplitude of stress $\underline{U}_m = U_m e^{j\psi_u} = 20e^{-j30^\circ}$ B.

2. Determine the complex impedance of an inductive element

$$\underline{Z} = j\omega L = j \cdot 10^3 \cdot 0.1 = j \cdot 100 = 100e^{j90^\circ} \text{ Ом.}$$

3. According to Ohm's law, we find the complex amplitude of current in an

$$\text{inductive element } \underline{I}_m = \frac{\underline{U}_m}{\underline{Z}_1} = \frac{20e^{-j30^\circ}}{100e^{j90^\circ}} = 0.2e^{-j120^\circ} \text{ A.}$$

4. Define instantaneous current $i = I_m \sin(\omega t + \psi) = 0.2 \sin(10^3 t - 120^\circ)$ A.

5. Build a vector diagram.

5.1. Choosing Scale Multipliers $m_U = 5 \text{ B/cm}$, $m_I = 0.1 \text{ A/cm}$.

5.2. Determining the length of the vectors corresponding to the amplitudes of voltage

$$\text{and current } \ell_U = \frac{U_m}{m_U} = \frac{20}{5} = 4 \text{ cm}, \quad \ell_I = \frac{I_m}{m_I} = \frac{0.2}{0.1} = 2 \text{ cm.}$$

5.3. Construct stress vectors $\underline{U}_m$ и тока $\underline{I}_m$ on a complex plane, taking into account the initial phases (Figure 2.5).

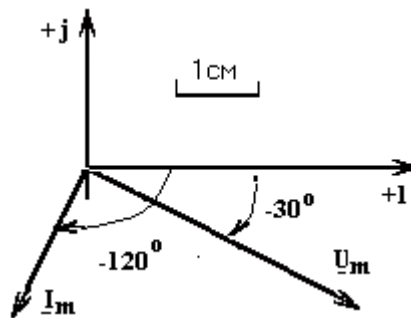


Figure 2.5

6. Construct time diagrams of current and voltage (Figure 2.6). Examples and recommendations on the method of constructing time diagrams are presented in practical lesson No2.1

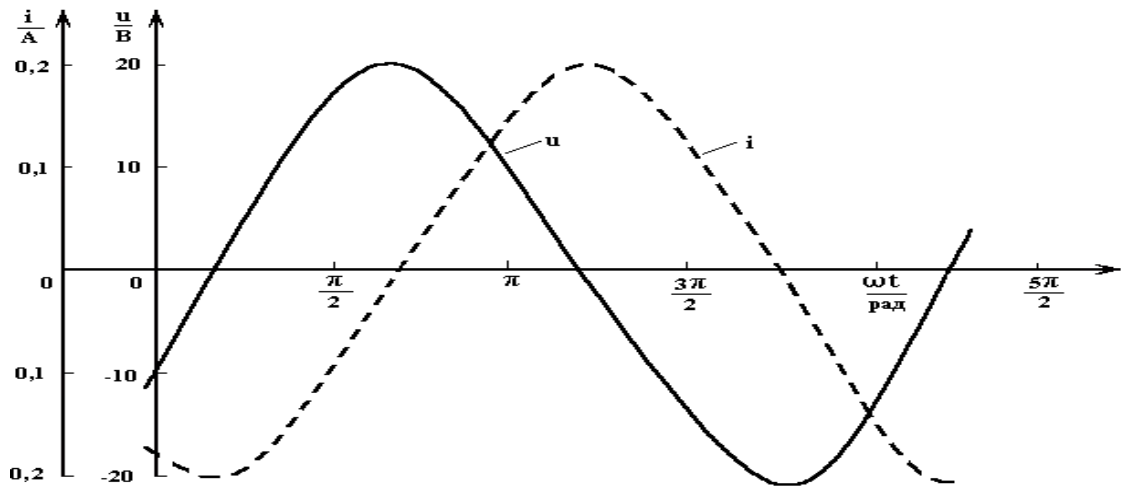


Figure 2.6

Task No2. For a given capacitive element $C = 0.1 \mu\text{F}$ and instantaneous current $i = 2.82 \sin(10^5 t + 30^\circ) \text{ A}$, determine complex amplitudes and effective current and voltage. Construct vector and time diagrams of current and voltage.

Solution

1. Determine the complex amplitude of current $\underline{I}_m = I_m e^{j\psi_i} = 2.82 e^{j30^\circ} \text{ A}$.

2. Determine the Complex Resistance of a Capacitive Element

$$\underline{Z} = \frac{1}{j\omega C} = \frac{1}{j \cdot 10^5 \cdot 0.1 \cdot 10^{-6}} = -j \cdot 100 = 100 \cdot e^{-j90^\circ} \text{ Ohm}.$$

3. According to Ohm's law, we find the complex amplitude of stress

$$\underline{U}_m = \underline{I}_m \cdot \underline{Z} = 2.82 \cdot e^{j30^\circ} \cdot 100 \cdot e^{-j90^\circ} = 282 \cdot e^{-j60^\circ} \text{ B}.$$

4. Complex effective current and voltage are determined by expressions

$$\underline{I} = \frac{\underline{I}_m}{\sqrt{2}} = \frac{2.82 \cdot e^{j30^\circ}}{1.41} = 2 \cdot e^{j30^\circ} \text{ A},$$

$$\underline{U} = \frac{\underline{U}_m}{\sqrt{2}} = \frac{282 \cdot e^{-j60^\circ}}{141} = 200 \cdot e^{-j60^\circ} \text{ B}.$$

5. Instantaneous Voltage on Capacitive Cell

$$u = U_m \sin(\omega t + \psi_u) = 282 \sin(10^5 t - 60^\circ) \text{ B}.$$

6. Construct a vector diagram of complex stresses $\underline{U}$ и тока $\underline{I}$ (Figure 2.7).

6.1. Scale Multipliers $m_U = 50 \text{ B/cm}$, $m_I = 1 \text{ A/cm}$.

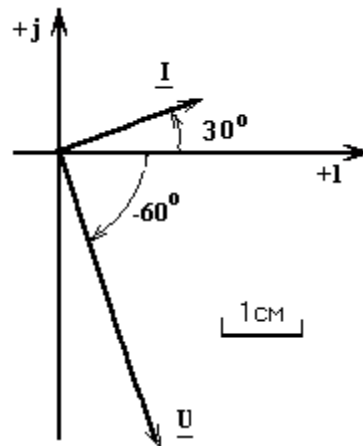


Figure 2.7

7. Constructing Temporal Diagrams of Current and Voltage (Figure 2.8)

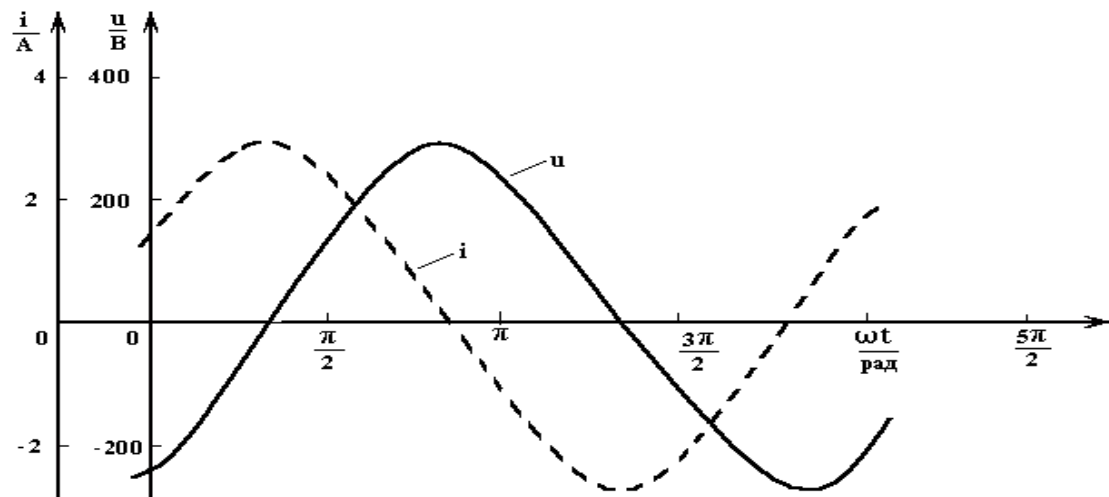


Figure 2.8

Task No3. The elements of the circuit $R = 40 \text{ Ohm}$, $L = 0.03 \text{ H}$ (Table 2.5) are connected in series and are under the influence of current $i = 100\sin(103t+300)$ mA. Determine the applied voltage to the circuit, the voltages on the circuit elements. Build vector diagrams of current and voltages.

Solution

1. Draw a circuit diagram (Figure 2.9)

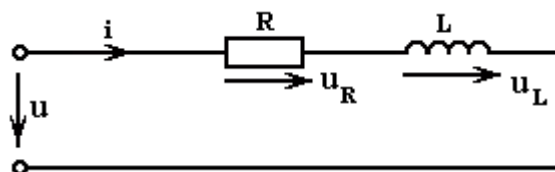


Figure 2.9

2. Determine the complex amplitude of current in the circuit

$$\underline{I}_m = I_m \cdot e^{j\psi_i} = 100e^{j30^0} \text{ mA.}$$

3. According to Ohm's law, we find the complex amplitude of stress on the resistive element

$$\underline{U}_{mR} = \underline{I}_m \cdot R = 10^2 \cdot 10^{-3} \cdot e^{j30^0} \cdot 40 = 4.0 \cdot e^{j30^0} = 4\cos 30^0 + j \cdot 4 \cdot \sin 30^0 = 3.46 + j \cdot 2 \text{ B.}$$

4. According to Ohm's law, we find the complex amplitude of stress on the

$$\begin{aligned} \text{inductive element} \quad \underline{U}_{mL} &= \underline{I}_m \cdot j\omega L = 10^2 \cdot 10^{-3} e^{j30^0} \cdot j \cdot 10^3 \cdot 0.03 = 3e^{j120^0} = \\ &= 3\cos 120^0 + j \cdot 3\sin 120^0 = -1.5 + j \cdot 2.6 \text{ B.} \end{aligned}$$

5. According to Kirchhoff's 2nd law, we determine the complex amplitude of the applied stress

$$\begin{aligned} \underline{U}_m &= \underline{U}_{mR} + \underline{U}_{mL} = 3.46 + j \cdot 2 - 1.5 + j \cdot 2.6 = 1.96 + j \cdot 4.6 = \\ &= \sqrt{1.96^2 + 4.6^2} \cdot e^{j\arctg \frac{4.6}{1.96}} = 5 \cdot e^{j66.9^0} \text{ B.} \end{aligned}$$

6. Instantaneous Stresses on Circuit Elements

$$u_R = U_{mR} \sin(\omega t + \psi_{u_R}) = 4 \sin(10^3 t + 30^0) \text{ B,}$$

$$u_L = U_{mL} \sin(\omega t + \psi_{u_L}) = 3 \sin(10^3 t + 120^0) \text{ B.}$$

7. Instantaneous voltage applied to the circuit

$$u_R = U_m \sin(\omega t + \psi_u) = 5 \sin(10^3 t + 66.9^0) \text{ B.}$$

8. Build a vector diagram of currents and voltages (Figure 2.10).

8.1. Scale Multipliers $m_I = 20 \text{ mA/cm}$, $m_U = 1 \text{ B/cm}$.

8.2. Vector Chart

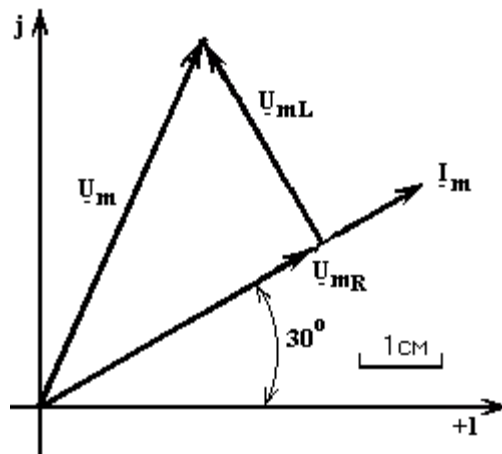


Figure 2.10

Task No4. The elements of the circuit $R = 100 \text{ Ohm}$, $C = 0.1 \text{ } \mu\text{F}$ (Table 2.6) are connected in parallel and are under the influence of voltage $u = 100 \sin(10^5 t - 30^\circ) \text{ B}$. Determine the currents in the circuit and in its elements. Build a vector diagram of currents and voltages.

Solution

1. Draw a circuit diagram (Figure 2.11)

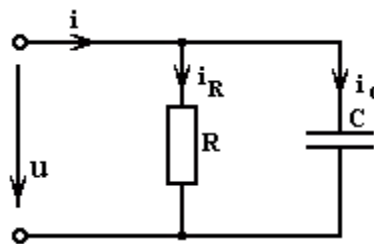


Figure 2.11

2. Determine the complex amplitude of the applied voltage

$$\underline{U}_m = U_m \cdot e^{j\psi_u} = 100e^{-j30^\circ} \text{ B.}$$

3. According to Ohm's law, we find the current in the resistive element

$$\underline{I}_{mR} = \frac{\underline{U}_m}{R} = \frac{100e^{-j30^\circ}}{100} = 1e^{-j30^\circ} = 1 \cdot \cos 30^\circ - j \cdot 1 \cdot \sin 30^\circ = 0.866 - j \cdot 0.5 \text{ A} = 1e^{-j30^\circ} \text{ A.}$$

4. According to Ohm's law, we find the current in the capacitive element

$$\begin{aligned} \underline{I}_{mC} &= \frac{\underline{U}_m}{\frac{1}{j\omega C}} = \underline{U}_m \cdot j\omega C = 100e^{-j30^\circ} \cdot e^{+j90^\circ} \cdot 10^5 \cdot 0.1 \cdot 10^{-6} = 1e^{j60^\circ} = \\ &= 1 \cdot \cos 60^\circ + j \sin 60^\circ = 0.5 + j \cdot 0.866 \text{ A} = 1e^{j60^\circ} \text{ A.} \end{aligned}$$

5. According to Kirchhoff's law 1, we determine the complex amplitude of current in a circuit

$$\underline{I}_m = \underline{I}_{mR} + \underline{I}_{mL} = 0.866 - j \cdot 0.5 + 0.5 + j \cdot 0.866 = 1.366 + j \cdot 0.366 = 1.414 e^{j16^\circ} \text{ A.}$$

6. Instantaneous currents in the circuit:

$$i_R = I_{mR} \sin(\omega t + \psi_{iR}) = 1 \sin(10^5 t - 30^\circ) \text{ A,}$$

$$i_C = I_{mC} \sin(\omega t + \psi_{iC}) = 1 \sin(10^5 t + 60^\circ) \text{ A,}$$

$$i = I_m \sin(\omega t + \psi_i) = 1.414 \sin(10^5 t + 15^\circ) \text{ A.}$$

7. Build a vector diagram of current and voltages (Figure 2.12).

7.1. Scale Multipliers $m_U = 20 \text{ B/cm}$, $m_I = 0.25 \text{ A/cm}$.

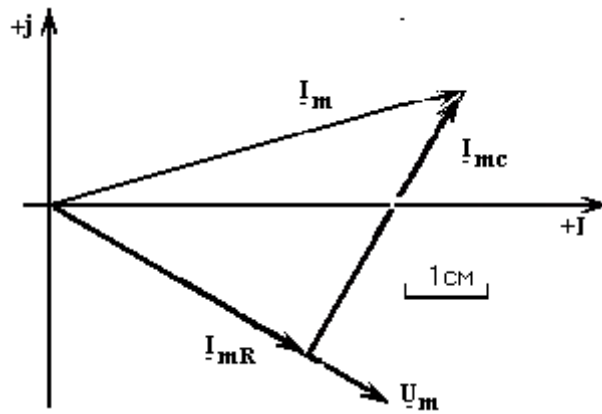


Figure 2.12

5. Calculation of three-phase circuits

Study questions:

1. Calculation of currents and voltages in a three-phase circuit, connection of receiver phases according to the "star" scheme.
2. Calculation of currents and voltages in a three-phase circuit, connection of receiver phases according to the "triangle" scheme.

Task to prepare for the lesson

1. Study:

1. Volynsky B.A., Zeyn E.N., Shaternikov V.E. Electrical engineering.- Moscow: Energoatomizdat, 1987, pp. 124-150.
2. Shebes M. R. Zadachnik po teorii lineynykh elektricheskikh tsepey [Task book on the theory of linear electric circuits]. - Moscow: Vysshaya shkola, 1982. - pp. 54-55.

2. Answer the questions:

1. Write down the expression for the instantaneous EMF of a three-phase circuit.
2. Write down the expression for complex amplitudes and operating EMF of a three-phase circuit.
3. To construct a vector diagram for complex amplitudes and operating EMF of a three-phase circuit.
4. What are the Relationships Between Line and Phase Voltages in a Symmetrical Three-Phase Circuit?
5. How to determine the current in a neutral wire in a three-phase circuit when connecting the phases of the receiver according to the "star" scheme?
6. How to determine the neutral bias voltage of a three-phase circuit when connecting the phases of the receiver according to the "star" scheme?
7. What are the relations between linear and phase currents in a symmetrical three-phase circuit when connecting the phases of the successor according to the "triangle" scheme?

3. Analyze the solution of the following tasks:

No2.74 (Shebes M. R. Task book on the theory of linear electric circuits, Moscow: Vysshaya shkola, 1982. - pp. 88 - 89)

During the practical lesson, complete the tasks:

Task No1. An asymmetrical receiver is connected to a symmetrical three-phase line with a voltage of L (Table 3), the phases of which are connected by a star to a neutral wire. Complex resistances of the phases of the receiver Z_a, Z_B, Z are given according to the variant (Table 3). Calculate the currents in the phases of the receiver, in the line wires and in the neutral wire. Construct vector diagrams of currents and voltages. Calculate the power consumed by the three-phase receiver.

Task No2. A symmetrical three-phase line with a voltage of L (Table 3) is connected to an asymmetrical receiver, the phases of which are connected by a star without a neutral wire. Complex resistances of the phases of the receiver Z_a, Z_B, Z_c are given according to the variant (Table 3). Calculate the currents in the phases of the receiver and in the line wires. Calculate the currents in the phases of the receiver and in the line wires in case of a short circuit of one of the phases of the receiver. Construct vector diagrams of currents and voltages. Calculate the power consumed by a three-phase receiver.

Task No3. A symmetrical three-phase line with a voltage L (Table 3) is connected to an asymmetrical receiver, the phases of which are connected by a triangle. Complex resistances of the receiver phases Z_a, Z_B, Z are given according to the variant (Table 3). Calculate the currents in the phases of the receiver, in the line wires. Calculate the currents in the phases of the receiver, in the line wires in case of a break in one of the line wires (Table 3). Construct vector diagrams of currents and voltages. Calculate the power consumed by the three-phase receiver.

Table 3 - Initial data for the design of three-phase circuits

Option No	U _I , V	<u>Z_a</u> , Om	<u>Z_B</u> , Ω	<u>Z_c</u> , Ohm	Option No	Broken line wire
0	220	10	-j20	j30	0	A
1	360	j10	15	-j20	1	In
2	120	10-j10	j15	20	2	S
3	150	20	20-j60	40+j30	3	A
4	170	j60	10+j2	20-j40	4	In
5	225	15-j20	10	-j25	5	S
6	300	20+j50	24-j50	10+j10	6	A
7	100	20	j25	-j10	7	In
8	110	25-j60	30+j9	45-j50	8	S
9	125	150	j80	-j40	9	A
10	220	-j25	20	45+j40	10	In
11	360	10+j30	15-j35	20+j80	11	S
12	120	20+j50	24-j50	10+j10	12	A
13	150	10	-j20	j30	13	In
14	170	j10	15	-j20	14	S
15	225	10-j10	j15	20	15	A
16	300	20-j25	30-j60	30+j30	16	In
17	100	15-j90	j10	-j25	17	S
18	110	20+j80	29-j50	60+j10	18	A
19	125	j20	-j25	12-j10	19	In
20	220	25-j60	8+j40	45-j50	20	S
21	360	10-j50	j80	-j40	21	A
22	120	30-j25	20	45-j40	22	In
23	150	80+j30	15-j35	40+j80	23	S
24	170	10+j70	15-j20	80+j30	24	A
25	225	-j10	15+j8	-j20	25	In
26	300	10-j10	j15	20-j20	26	S
27	100	20+j7	20-j60	20+j30	27	A
28	110	90+j60	10+j2	20-j40	28	In
29	125	50-j20	10+j8	-j25	29	S

30	220	20+j30	20-j50	20+j10	30	A
31	360	20-j45	j25	10-j10	31	In
32	120	25-j60	30+j6	35-j50	32	S
33	150	15-j60	j80	50-j40	33	A
34	170	-j25	20+j8	45+j40	34	In
35	225	10+j40	15-j35	20+j80	35	S
36	300	10+j60	8-j20	j30	36	A
37	100	25-j10	15+j5	40-j20	37	In
38	110	10-j10	8+j15	20-j6	38	S
39	125	20	20-j60	40+j30	39	A
40	220	j60	10+j7	20-j40	40	In
41	300	10+j20	15-j25	20+j60	41	S
42	220	25+j50	30-j50	20+j10	42	A
43	120	25-j50	-j20	25+j50	43	In
44	150	10+j20	15-j25	10-j20	44	S
45	200	10-j10	10+j20	15-j25	45	A

3.1. Calculation of a three-phase circuit connection according to the "star with neutral wire" scheme

A diagram of a three-phase circuit of a "star with neutral wire" connection is shown in Figure 3.1

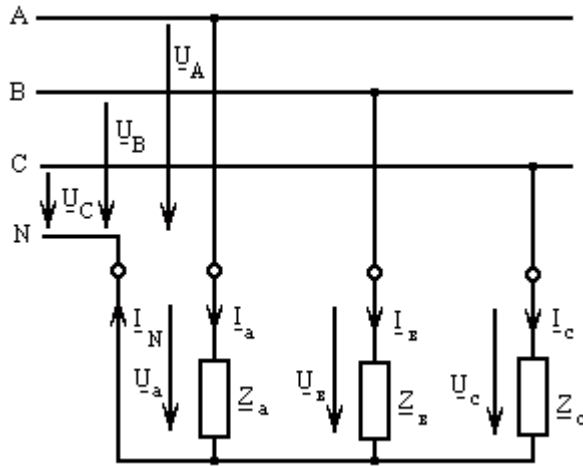


Figure 3.1 - Connecting the phases of the receiver according to the "star to neutral wire" scheme

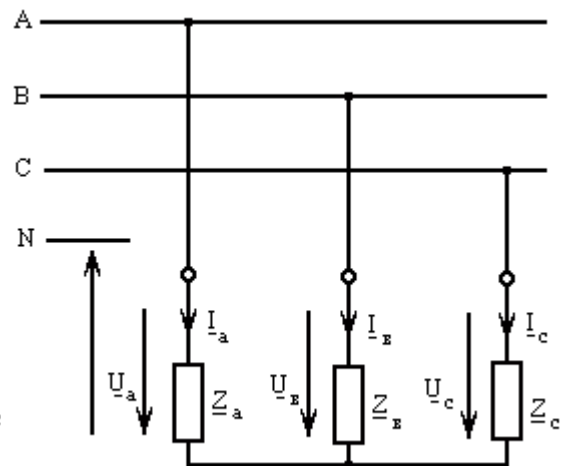


Figure 3.2 - Star-to-neutral receiver phase connection

1. We determine complex voltages at the phases of a symmetrical three-phase source (synchronous generator)

$$\underline{U}_A = \frac{U_\pi}{\sqrt{3}} e^{j^0} = \frac{220}{1.73} e^{j^0} = 127 e^{j^0} \text{ B,}$$

$$\underline{U}_B = \frac{U_\pi}{\sqrt{3}} e^{-j120^0} = \frac{220}{1.73} (\cos 120^0 - j \sin 120^0) = -63.5 - j110 \text{ B,}$$

$$\underline{U}_C = \frac{U_\pi}{\sqrt{3}} e^{j120^0} = \frac{220}{1.73} (\cos 120^0 + j \sin 120^0) = -63.5 + j110 \text{ B,}$$

2. Determine the complex voltages at the receiver phases. Since the resistance of the connecting wires (linear and neutral) is zero,

$$\underline{U}_A = \underline{U}_a = 127 \text{ B, } \underline{U}_B = \underline{U}_b = 127 e^{-j120^0} \text{ B, } \underline{U}_C = \underline{U}_c = 127 e^{j120^0} \text{ B.}$$

3. Determine the complex currents in the receiver phases using Ohm's law for

a section of the circuit
$$\underline{I}_a = \frac{\underline{U}_a}{\underline{Z}_a} = \frac{127e^{j0}}{10} = 12.7e^{j0} = 12.7 \text{ A}$$

$$\underline{I}_b = \frac{\underline{U}_b}{\underline{Z}_b} = \frac{127e^{-j120^\circ}}{20e^{-j90^\circ}} = 6.35e^{-j30^\circ} = 5.5 - j3.175 \text{ A.}$$

$$\underline{I}_c = \frac{\underline{U}_c}{\underline{Z}_c} = \frac{127e^{j120^\circ}}{30e^{j90^\circ}} = 4.23e^{j30^\circ} = 3.667 + j2.117 \text{ A.}$$

4. The complex current in a neutral wire can be determined using Kirchhoff's first law:

$$\underline{I}_N = \underline{I}_a + \underline{I}_b + \underline{I}_c = 12.7 + 5.5 - j3.175 + 3.667 + j2.117 = 21.868 - j1.058 = 21.894e^{-j2.8^\circ} \text{ A.}$$

5. Complex interphase (linear) voltages at the receiver can be determined using Kirchhoff's second law

$$\underline{U}_{ab} = \underline{U}_a - \underline{U}_b = 127 + 63.509 + j110 = 190.5 + j110 = 220e^{j30^\circ} \text{ B.}$$

$$\underline{U}_{bc} = \underline{U}_b - \underline{U}_c = -63.509 - j110 + 63.509 - j110 = -j220 = 220e^{-j90^\circ} \text{ B.}$$

$$\underline{U}_{ca} = \underline{U}_c - \underline{U}_a = -63.509 + j110 - 127 = -190.5 + j110 = 220e^{j150^\circ} \text{ B.}$$

6. A vector diagram of currents and voltages is shown in Figure 3.3

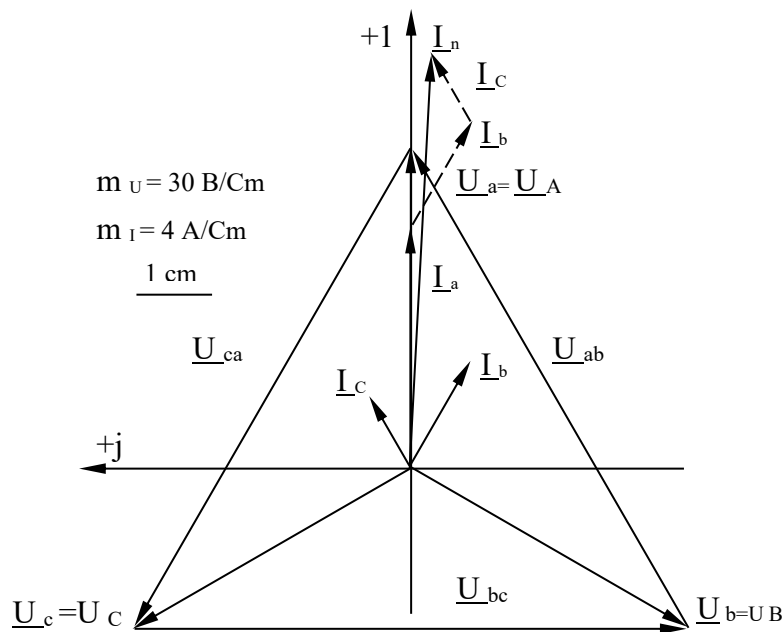


Figure 3.3

7. Let's calculate the complex power consumed by a three-phase receiver

$$\underline{S} = \underline{U}_a^* \underline{I}_a + \underline{U}_b^* \underline{I}_b + \underline{U}_c^* \underline{I}_c = 127 \cdot 12.7 + 127e^{-j120^\circ} \cdot 6.351e^{-j30^\circ} + 127e^{j120^\circ} \cdot 4.234e^{-j30^\circ} = 1613 - j269 \text{ BA.}$$

3.2. Calculation of a three-phase connection circuit according to the scheme "star at a neutral wire break"

1. Determining complex voltages in the phases of a symmetrical three-phase circuit

$$\underline{U}_A = \frac{U_{\text{л}}}{\sqrt{3}} e^{j0} = \frac{220}{1.73} e^{j0} = 127e^{j0} \text{ B,}$$

$$\underline{U}_B = \frac{U_{\text{л}}}{\sqrt{3}} e^{-j120^\circ} = \frac{220}{1.73} e^{-j120^\circ} = 127e^{-j120^\circ} \text{ B,}$$

$$\underline{U}_C = \frac{U_{\text{л}}}{\sqrt{3}} e^{j120^\circ} = \frac{220}{1.73} e^{j120^\circ} = 127e^{j120^\circ} \text{ B.}$$

2. Determining the complex conductivities of the receiver phases

$$\underline{Y}_a = \frac{1}{\underline{Z}_a} = \frac{1}{10} = 0.1 \text{ CM,} \quad \underline{Y}_b = \frac{1}{\underline{Z}_b} = \frac{1}{-j20} = 0.05e^{j90^\circ} = j0.05 \text{ CM,}$$

$$\underline{Y}_c = \frac{1}{\underline{Z}_c} = \frac{1}{j30} = 0.033e^{-j90^\circ} = -j0.033 \text{ CM.}$$

3. Determine the neutral displacement voltage (voltage between neutral points of the network and the receiver)

$$\underline{U}_{nN} = \frac{\underline{U}_A \cdot \underline{Y}_a + \underline{U}_B \cdot \underline{Y}_b + \underline{U}_C \cdot \underline{Y}_c}{\underline{Y}_a + \underline{Y}_b + \underline{Y}_c} = \frac{127e^{j0} \cdot 0.1 + 127e^{-j120^\circ} \cdot 0.05e^{j90^\circ} + 127e^{j120^\circ}}{0.1 + j0.05 - j0.033} = 211.057 - j45.761 = 215.96e^{-j12.23^\circ} \text{ B.}$$

4. Determining complex voltages at the receiver phases

$$\underline{U}_a = \underline{U}_A - \underline{U}_{nN} = 127 - 211.057 + j45.761 = -84.04 + j45.76 = 95.69e^{j151^\circ} \text{ B}$$

$$\underline{U}_b = \underline{U}_B - \underline{U}_{nN} = -63.509 - j110 - 211.057 + j45.761 = -274.565 - j64.239 = 281.98e^{-j167^\circ} \text{ B}$$

$$\underline{U}_c = \underline{U}_C - \underline{U}_{nN} = -63.509 + j110 - 211.057 + j45.761 = -274.565 + j155.76 = 315.67e^{j150^\circ} \text{ B.}$$

5. Calculating complex currents in receiver phases using Ohm's law

$$\underline{I}_a = \underline{U}_a \underline{Y}_a = 95.69e^{j151^\circ} \cdot 0.1 = 9.569e^{j151^\circ} \text{ A},$$

$$\underline{I}_b = \underline{U}_b \underline{Y}_b = 281.98e^{-j167^\circ} \cdot 0.05e^{j90^\circ} = 14.1e^{-j77^\circ} \text{ A},$$

$$\underline{I}_c = \underline{U}_c \underline{Y}_c = 315.67e^{j150^\circ} \cdot 0.33 \cdot e^{-j90^\circ} = 10.5e^{j60^\circ} \text{ A}.$$

6. Using Kirchhoff's second law, let's determine the phase-to-phase (linear) voltages at the receiver

$$\underline{U}_{ab} = \underline{U}_a - \underline{U}_b = -84.04 + j45.76 + 274.565 - j64.239 = 190.526 + j110 = 220e^{j30^\circ} \text{ B}$$

$$\underline{U}_{bc} = \underline{U}_b - \underline{U}_c = -274.565 - j64.239 + 274.565 - j155.761 = -j220 = 220e^{-j90^\circ} \text{ B}$$

$$\underline{U}_{ca} = \underline{U}_c - \underline{U}_a = -274.565 + j155.761 + 84.04 - j45.761 = -190.526 + j110 = 220e^{j150^\circ} \text{ B}.$$

7. Based on the results of current and voltage calculations, we build vector diagrams of currents and voltages (Figure 3.4)

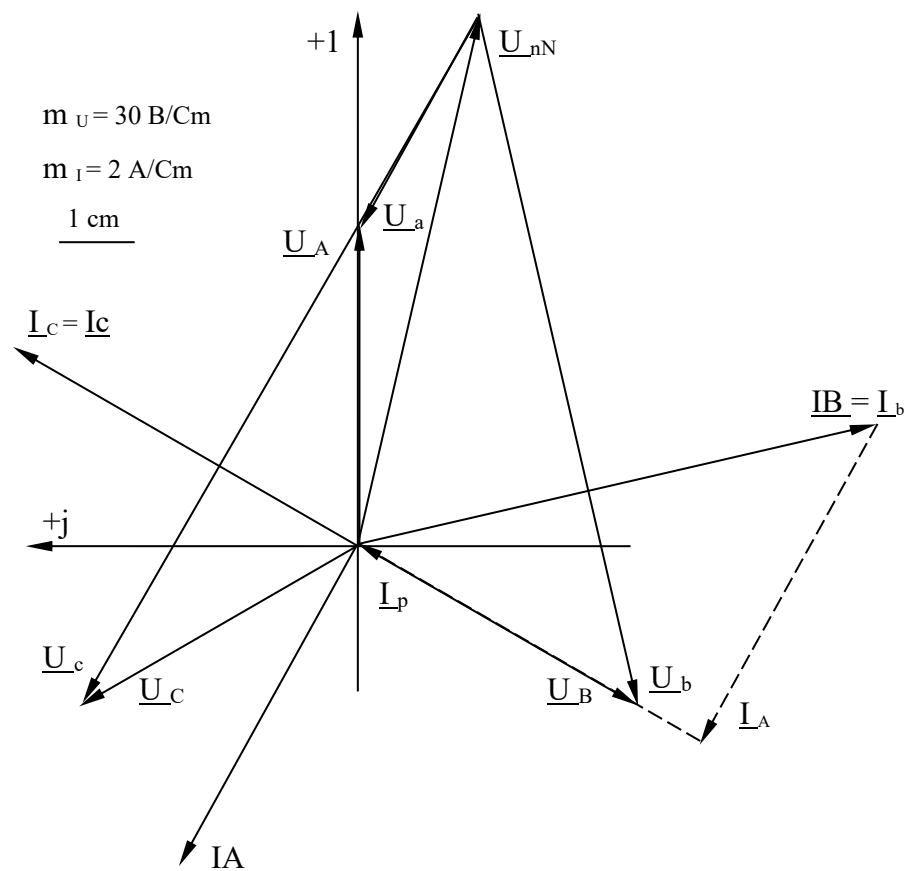


Figure 3.4

8. Let's calculate the power consumed by a three-phase receiver

$$\underline{S} = \underline{U}_a \underline{I}_a^* + \underline{U}_b \underline{I}_b^* + \underline{U}_c \underline{I}_c^* = 95.691e^{j151^0} \cdot 9.569e^{-j151^0} + 281.98e^{-j167^0} \cdot 14.1e^{j76.8^0} + 315.67e^{-j150^0} \cdot 10.522e^{-j60^0} = 915.676 - j654.054 \text{ BA}$$

3.3. Calculation of a three-phase connection circuit according to the "star without neutral wire" scheme in case of a short circuit of phase "a" of the receiver

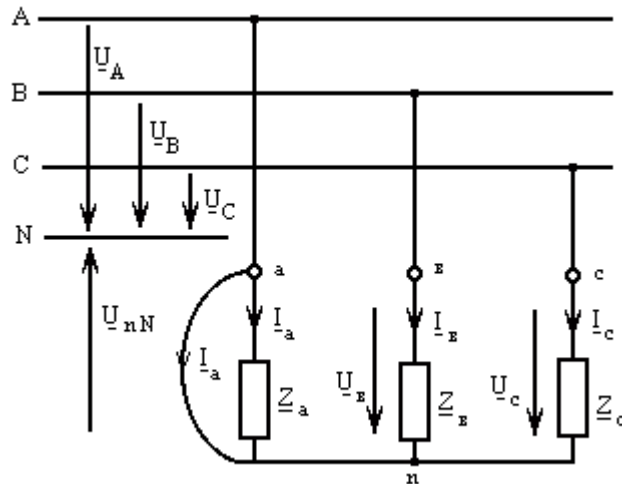


Figure 3.5 - Connection of the phases of the receiver according to the scheme "star without neutral wire" and the short circuit of the phase "a" of the receiver

1. Determining complex voltages in the phases of a symmetrical three-phase circuit

$$\underline{U}_A = \frac{U_{\pi}}{\sqrt{3}} e^{j^0} \quad \underline{U}_B = \frac{U_{\pi}}{\sqrt{3}} e^{-j120^0} \quad \underline{U}_C = \frac{U_{\pi}}{\sqrt{3}} e^{j120^0}$$

2. The offset voltage is determined by the value of the complex voltage of the network phase to which the shorted phase of the receiver is connected. In the case under consideration

$$\underline{U}_{nN} = \underline{U}_A = 127e^{j^0} = 127 \text{ B.}$$

3. Determining complex voltages at the receiver phases

$$\underline{U}_a = \underline{U}_A - \underline{U}_{nN} = 127 - 127 = 0 \text{ B}$$

$$\underline{U}_b = \underline{U}_B - \underline{U}_{nN} = -63.509 - j110 - 127 = -190.526 - j110 = 220e^{-j150^0} \text{ B}$$

$$\underline{U}_c = \underline{U}_C - \underline{U}_{nN} = -63.509 + j110 - 127 = -190.526 + j110 = 220e^{j150^0} \text{ B}$$

4. Complex currents in phases, calculated using Ohm's law

$$\underline{I}_a = \frac{\underline{U}_a}{\underline{Z}_a} = \frac{0}{10} = 0 \text{ A}, \quad \underline{I}_b = \frac{\underline{U}_b}{\underline{Z}_b} = \frac{220e^{-j150^\circ}}{-j20} = 11e^{-j60^\circ} = 5.5 - j9.526 \text{ A}$$

$$\underline{I}_c = \frac{\underline{U}_c}{\underline{Z}_c} = \frac{220e^{j150^\circ}}{j30} = 7.333e^{j60^\circ} = 3.667 + j6.351 \text{ A}.$$

5. Complex currents in the line wire "A" are determined using Kirchhoff's first law

$$\underline{I}_A = -\underline{I}_b - \underline{I}_c = -5.5 + j9.526 - 3.667 - j6.351 = -9.167 + j3.175 = 9.7e^{j161^\circ} \text{ A}$$

Complex currents in line wires B and C are equal to phase currents, i.e.

$$\underline{I}_B = \underline{I}_b = 11e^{-j60^\circ} \text{ A}, \quad \underline{I}_C = \underline{I}_c = 7.333e^{j60^\circ} \text{ A}$$

6. Interphase (linear) voltages at the receiver are determined using Kirchhoff's second law

$$\underline{U}_{ab} = \underline{U}_a - \underline{U}_b = 0 + 190.526 + j110 = 220e^{j30^\circ} \text{ B}$$

$$\underline{U}_{bc} = \underline{U}_b - \underline{U}_c = -190.525 - j110 + 190.526 - j110 = -j220 = 220e^{j90^\circ} \text{ B}$$

$$\underline{U}_{ca} = \underline{U}_c - \underline{U}_a = -190.526 + j110 - 0 = 220e^{j150^\circ} \text{ B}.$$

7. A vector diagram of currents and voltages is shown in Figure 3.6

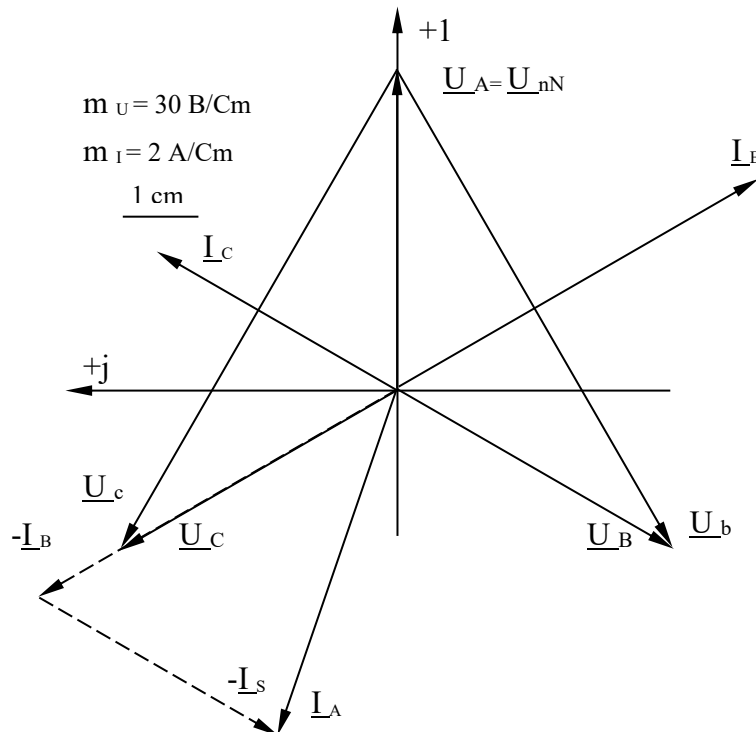


Figure 3.6

8. Let's calculate the power consumed by a three-phase receiver:

$$\underline{S} = \underline{U}_a^* \underline{I}_a + \underline{U}_b^* \underline{I}_b + \underline{U}_c^* \underline{I}_c = 220e^{-j150^\circ} 11e^{-j60^\circ} + 220e^{j150^\circ} \cdot 7.333e^{j60^\circ} = -j806.667 \text{ BA}$$

3.4. Calculation of the three-phase circuit of the receiver phase connection according to the "triangle" scheme

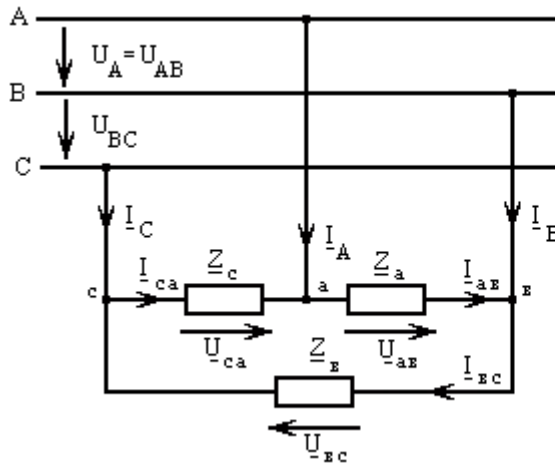


Figure 3.7 - Connection of receiver phases according to the "triangle" scheme

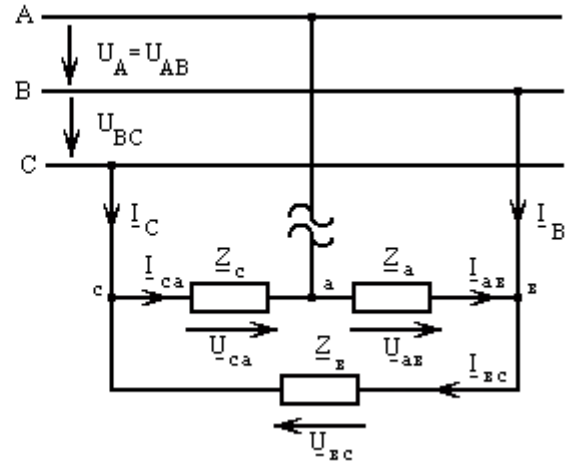


Figure 3.8 - Connection of the receiver phases according to the "triangle" scheme and the break of the line wire "A"

1. We determine the complex linear voltages of a symmetrical three-phase circuit

$$\underline{U}_{AB} = U_{\pi} e^{j^0} = 220 e^{j^0} = 220 \text{ B,}$$

$$\underline{U}_{BC} = U_{\pi} e^{j120^0} = 220 e^{-j120^0} = -110 - j190.526 \text{ B}$$

$$\underline{U}_{CA} = U_{\pi} e^{j120^0} = 220 e^{j120^0} = -110 + j190.526 \text{ B.}$$

2. The complex stresses at the receiver phases, provided that the resistances of the connecting (line) wires are zero, will be determined by the corresponding complex line stresses:

$$\underline{U}_{ab} = \underline{U}_{AB} = 220 \text{ B, } \underline{U}_{bc} = \underline{U}_{BC} = 220 e^{-j120^0} \text{ B, } \underline{U}_{cb} = \underline{U}_{CA} = 220 e^{j120^0} \text{ B.}$$

3. Complex currents in the receiver phases are determined using Ohm's law:

$$\underline{I}_{ab} = \frac{\underline{U}_{ab}}{\underline{Z}_a} = \frac{220 e^{j^0}}{10} = 22 e^{j^0} \text{ A} = 22 \text{ A}$$

$$\underline{I}_{bc} = \frac{\underline{U}_{bc}}{\underline{Z}_b} = \frac{220 e^{-j120^0}}{-j20} = 11 e^{-j30^0} = 9.526 - j5.5 \text{ A}$$

$$\underline{I}_{ca} = \frac{\underline{U}_{ca}}{\underline{Z}_c} = \frac{220 e^{j120^0}}{j30} = 7.33 e^{j30^0} = 6.351 + j3.667 \text{ A}$$

4. Complex currents in line wires can be determined using Kirchhoff's first law

$$\underline{I}_A = \underline{I}_{ab} - \underline{I}_{ca} = 22 - 6.351 - j3.667 = 15.649 - j3.667 = 16.073e^{-j13^0} \text{ A}$$

$$\underline{I}_B = \underline{I}_{bc} - \underline{I}_{ab} = 9.526 - j5.5 - 22 = -12.474 - j5.5 = 13.632e^{-j156^0} \text{ A}$$

$$\underline{I}_C = \underline{I}_{ca} - \underline{I}_{bc} = 6.351 + j3.667 - 9.526 + j5.5 = -3.175 + j9.167 = 9.7e^{j109^0} \text{ A.}$$

5. Based on the results of the calculations, we build a vector diagram of currents and voltages (Figure 3.9).

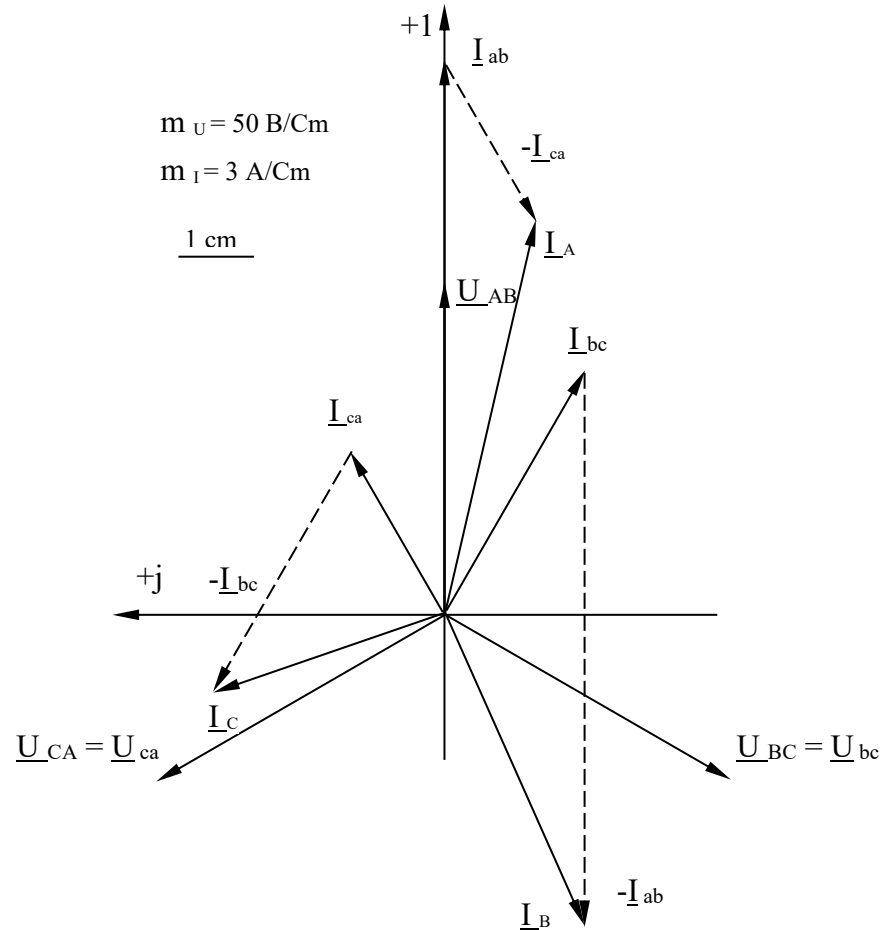


Figure 3.9

6. Calculating the Complex Power Consumed by a Three-Phase Receiver

$$\underline{S} = \underline{U}_{ab}^* \underline{I}_{ab} + \underline{U}_{bc}^* \underline{I}_{bc} + \underline{U}_{ca}^* \underline{I}_{ca} = 220.22 + 220e^{-j120^0} \cdot 11e^{j30^0} + 220e^{j120^0} \cdot 7.33e^{-j30^0} = 4840 - j806.667 \text{ BA.}$$

3.5. Calculation of the three-phase circuit of the receiver phase connection according to the "triangle" scheme in case of a break in the line wire "A"

1. Draw a circuit diagram when a line wire is broken (Figure 2.8). Conditionally positive directions of currents in phases are indicated as in the diagram Figure 2.7.

From the analysis of the diagram (Figure 2.8) it follows that the complex voltage at the "B" phase "B" of the receiver $\underline{Z}_b$ is equal to the phase voltage. $\underline{U}_{bc} = 220e^{-j120^\circ}$ B.
 $\underline{U}_{bc} = 220e^{-j120^\circ}$ B.

2. Using Ohm's law, calculate the currents in the phases of the receiver

$$\underline{I}_{ab} = -\frac{\underline{U}_{bc}}{\underline{Z}_a + \underline{Z}_c} = -\frac{220e^{-j120^\circ}}{10 + j30} = 6.957e^{-j11.6^\circ} = 6.816 - j1.395 \text{ A}$$

$$\underline{I}_{bc} = \frac{\underline{U}_{bc}}{\underline{Z}_b} = \frac{220e^{-j120^\circ}}{-j20} = 11e^{-j30^\circ} = 9.526 - j5.5 \text{ A}$$

$$\underline{I}_{ca} = \frac{-\underline{U}_{bc}}{\underline{Z}_a + \underline{Z}_c} = -\frac{220e^{-j120^\circ}}{10 + j30} = 6.957e^{-j11.6^\circ} = 6.816 - j1.395 \text{ A}.$$

3. Complex currents in line wires are determined by Kirchhoff's first law

$$\underline{I}_A = \underline{I}_{ab} - \underline{I}_{ca} = 0$$

$$\underline{I}_B = \underline{I}_{bc} - \underline{I}_{ab} = 9.526 - j5.5 - 6.816 + j1.395 = 2.711 - j4.105 = 4.919e^{-j56.5^\circ} \text{ A}.$$

$$\underline{I}_C = \underline{I}_{ca} - \underline{I}_{bc} = 6.816 - j1.395 - 9.526 + j5.5 = -2.711 + j4.105 = 4.919e^{j123^\circ} \text{ A}.$$

4. Complex voltages at the phases of the receiver "a" and "c" are determined according to Ohm's law

$$\underline{U}_{ab} = \underline{I}_{ab} \cdot \underline{Z}_a = 6.957e^{-j11.6^\circ} \cdot 10 = 69e^{-j11.6^\circ} = 68.158 - j13.947 \text{ B}$$

$$\underline{U}_{ca} = \underline{I}_{ca} \cdot \underline{Z}_c = 6.957e^{-j11.6^\circ} \cdot 30e^{j90^\circ} = 208.71e^{j78.4^\circ} = 41.842 + j204.473 \text{ B}.$$

5. Comprehensive power consumed by the receiver

$$\underline{S} = |\underline{I}_{ab}|^2 (\underline{Z}_a + \underline{Z}_c) + |\underline{I}_{bc}|^2 \underline{Z}_b = 6.957^2 (10 + j30) + 11^2 (-j20) = 484 - j968 \text{ BA} .$$

6. Gross power consumed by the receiver

$$S = |\underline{S}| = \sqrt{P^2 + Q^2} = \sqrt{484^2 + 968^2} = 1082 \text{ BA}.$$

7. Build a vector diagram of currents and voltages based on the results of calculations (Figure 3.10)

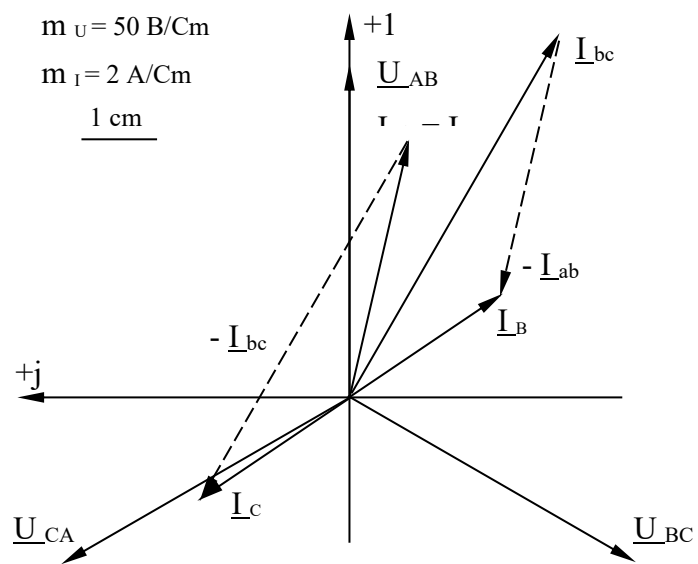


Figure 3.10

6. Calculation of transient processes using the classical method

Study questions:

1. Calculation of transient currents, voltages in the simplest RC (RL) circuit under zero initial conditions.
2. Calculation of transient currents and voltages in the simplest RC (RL) circuit under non-zero initial conditions.
3. Calculation of transient currents and voltages in a complex RC (RL) circuit.

Task to prepare for the lesson

1. Study:

1. Nikulin V.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. - Moscow: RIOR, 2016, pp. 102-108.
2. Bakalov V.P., Vorobienko P.P., Kruk B.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. Moscow, Radio i svyaz Publ., 1998, pp. 102-105.
3. Shebes M. R. Zadachnik po teorii lineynykh elektricheskikh tsepey [Task book on the theory of linear electric circuits]. - Moscow: Vysshaya shkola, 1982. - pp. 172-174.
4. Piskunov N.I. Differential and integral calculus for higher educational institutions.- Moscow: Nauka, 1985, part 2, pp.17-21, 31.

2. Answer the questions:

1. What is meant by switching in an electrical circuit.
2. Formulate the 1st law of commutation. Prove it.
3. Formulate the 2nd law of commutation. Prove it.
4. For the specified circuits (Figure 4.1-4.3), determine the initial conditions based on the switching laws.

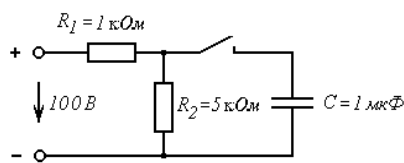


Figure 4.1

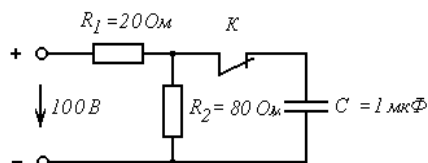


Figure 4.2

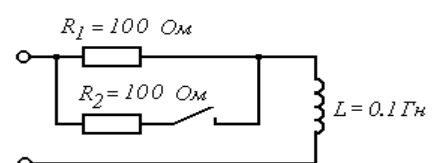


Figure 4.3

5. Write down a first-order linear differential equation.
6. Which linear differential equation is called inhomogeneous? Give examples. Explain the algorithm for solving this equation.
7. What is the general solution of a linear differential equation?
8. What is the partial solution of a linear differential equation? How is it determined?
9. Write down the solution of the differential equation $\frac{dy}{dx} + ax = b$.
10. For the circuit (Figure 4.3), make a differential equation. What laws of the theory of electric circuits are used in this case?
11. Name the stages of the algorithm of the classical method of calculating transient currents and voltages in an electrical circuit.

3. Analyze the solution of the following tasks:

No 6.4, 6.10 (Shebes M. R. Task book on the theory of linear electric circuits. Moscow: Vysshaya shkola, 1982. - pp. 177, 180-181)

During the practical lesson, complete the tasks:

Task No1. In the specified electrical circuit according to the variant (Table 4.1), calculate and plot the transition current $i(t)$ and the voltage on the reactive element $u(t)$ using the classical method.

Task No2. In the specified electrical circuit (Table 4.2), calculate and plot the transient current $i(t)$ and voltage on the reactive element $u(t)$.

Task No3. In the given variant of the complex electric circuit (Table 4.3), calculate and plot the transient currents $i(t)$

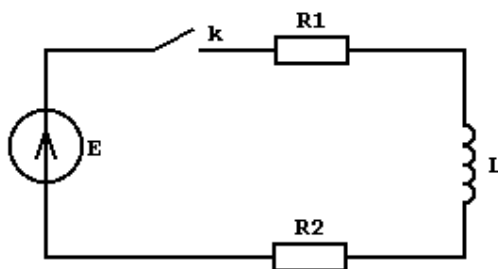


Figure 4.4

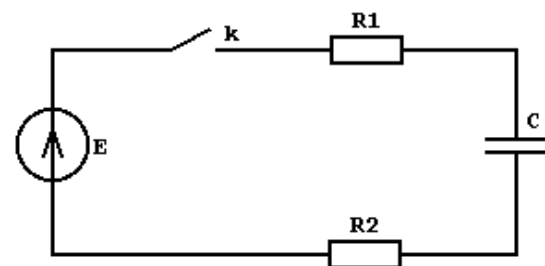


Figure 4.5

Table 4.1

Option №	Scheme Figure No	R1, kOm	R2, kOm	L, mGn	S, μF	E, In	J, mA
0	4.4	1	1	20	-	20	-
1	4.5	10	50	-	0.20	40	-
2	4.6	50	20	-	0.50	-	0.5
3	4.7	20	30	50	-	-	0.1
4	4.8	18	20	80	-	25	-
5	4.9	10	25	-	0.02	30	-
6	4.10	15	10	10	-	-	0.2
7	4.11	20	30	-	0.25	-	0.4
8	4.12	25	40	-	0.05	-	0.5
9	4.13	40	70	40	-	15	-
10	4.14	20	10	25	-	35	-
11	4.15	10	20	-	0.01	40	-
12	4.16	15	25	60	-	45	-
13	4.17	40	30	30	-	25	-
14	4.5	20	40	-	0.10	30	-
15	4.6	50	60	-	0.30	-	0.3
16	4.7	60	40	30	-	-	0.2
17	4.8	48	30	35	-	45	-
18	4.9	50	45	-	0.22	70	-
19	4.10	25	40	15	-	-	0.6
20	4.11	80	30	-	0.20	-	0.5
21	4.12	25	50	-	0.02	-	0.7
22	4.13	40	80	20	-	25	-
23	4.14	25	50	25	-	55	-
24	4.15	30	40	-	0.03	20	-
25	4.16	15	45	65	-	40	-
26	4.17	30	50	35	-	25	-
27	4.11	70	30	-	0.20	-	0.7
28	4.12	35	40	-	0.04	-	0.3
29	4.13	40	20	45	-	10	-
30	4.14	25	15	20	-	30	-

31	4.15	15	30	-	0.06	45	-
32	4.16	10	20	65	-	40	-
33	4.17	40	20	20	-	35	-
34	4.5	60	40	-	0.12	30	-
35	4.6	55	30	-	0.20	-	0.1
36	4.7	90	40	10	-	-	0.2
37	4.8	40	70	35	-	40	-
38	4.9	50	55	-	0.24	70	-
39	4.10	25	70	18	-	-	0.6
40	4.14	30	20	20	-	35	-
41	4.15	20	10	-	0.01	40	-
42	4.16	25	15	30	-	45	-
43	4.17	35	20	10	-	25	-
44	4.5	25	30	-	0.10	30	-
45	4.6	30	40	-	0.30	-	0.5
46	4.7	20	20	33	-	-	0.4

Table 4.2

Option №	Scheme Fig. №	R1, kOm	R2, kOm	L, mGn	S, pF	E, In	J, mA
0	4.18	0.2	0.2	-	2	20	-
1	4.19	10	50	10	-	40	-
2	4.20	50	20	-	0.50	30	-
3	4.21	20	30	50	-	35	-
4	4.22	18	20	-	5	-	0.1
5	4.23	10	25	-	0.02	-	0.2
6	4.24	15	10	10	-	25	-
7	4.25	20	30	-	0.25	35	-
8	4.26	25	40	12	-	40	-
9	4.27	40	70	-	3	15	-
10	4.28	20	10	-	0.25	35	-
11	4.29	10	20	-	0.01	-	0.3
12	4.30	15	25	-	0.3	45	-
13	4.31	40	30	30	-	25	-

14	4.22	20	40	-	5	-	0.1
15	4.23	50	60	-	0.02	-	0.2
16	4.24	60	40	10	-	25	-
17	4.25	48	30	-	0.25	35	-
18	4.26	50	45	12	-	40	-
19	4.27	25	40	-	3	15	-
20	4.28	80	30	-	0.25	35	-
21	4.29	25	50	-	0.01	-	0.3
22	4.30	40	80	-	0.7	45	-
23	4.31	25	50	30	-	25	-
24	4.19	30	40	10	-	40	-
25	4.20	15	45	-	0.50	30	-
26	4.21	30	50	50	-	35	-
27	4.22	70	30	-	5	-	0.1
28	4.23	35	40	-	0.02	-	0.2
29	4.24	40	20	10	-	25	-
30	4.25	25	15	-	0.25	35	-
31	4.26	15	30	12	-	40	-
32	4.27	10	20	-	3	15	-
33	4.28	40	20	-	0.25	35	-
34	4.29	60	40	-	0.01	-	0.3
35	4.30	55	30	-	0.4	45	-
36	4.31	90	40	30	-	25	-
37	4.21	40	70	50	-	35	-
38	4.22	50	55	-	5	-	0.1
39	4.23	25	70	-	0.02	-	0.2
40	4.28	80	30	-	0.25	35	-
41	4.29	25	50	-	0.01	-	0.3
42	4.30	40	80	-	0.7	45	-
43	4.31	25	50	30	-	25	-
44	4.19	30	40	10	-	40	-
45	4.20	15	45	-	0.50	30	-
46	4.21	30	50	50	-	35	-

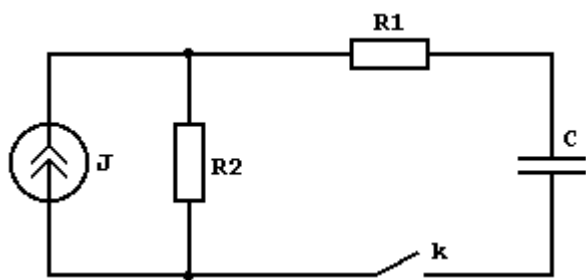


Figure 4.6

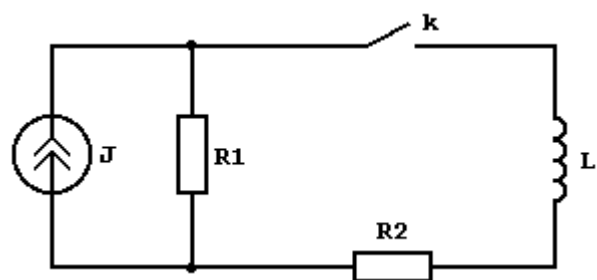


Figure 4.7

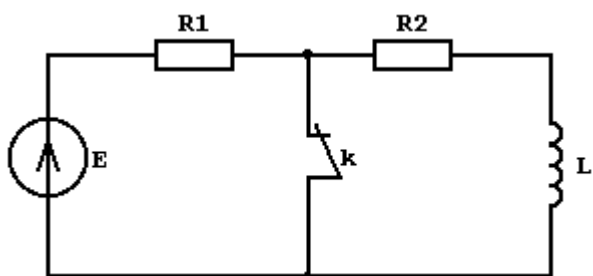


Figure 4.8

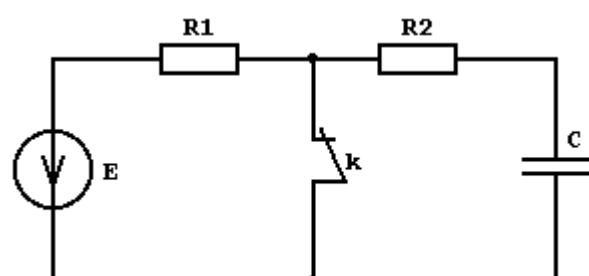


Figure 4.9

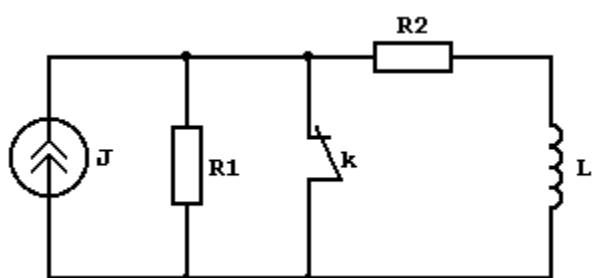


Figure 4.10

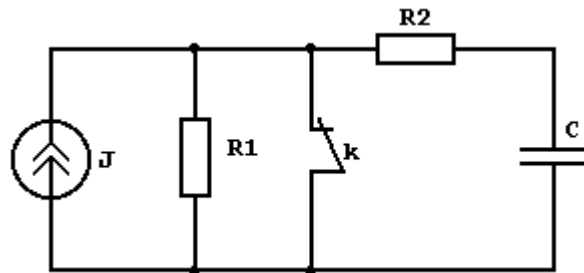


Figure 4.11

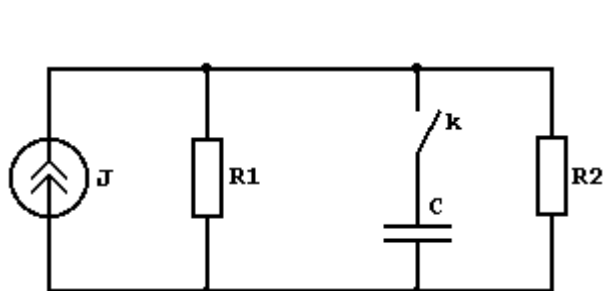


Figure 4.12

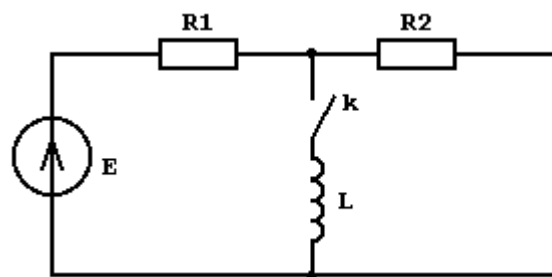


Figure 4.13

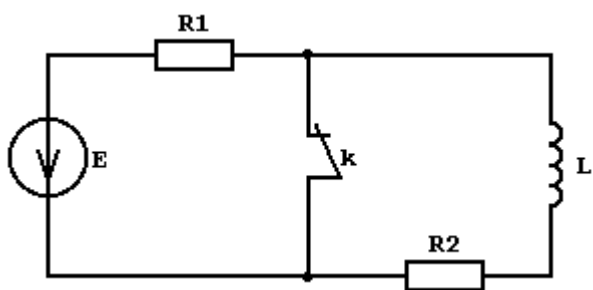


Figure 4.14

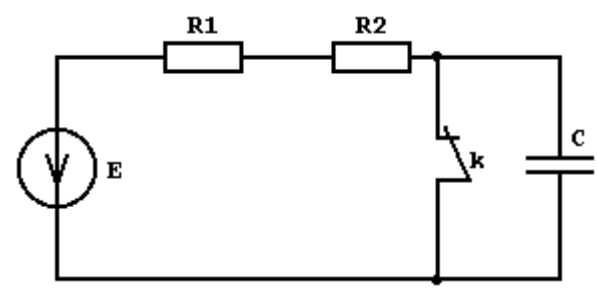


Figure 4.15

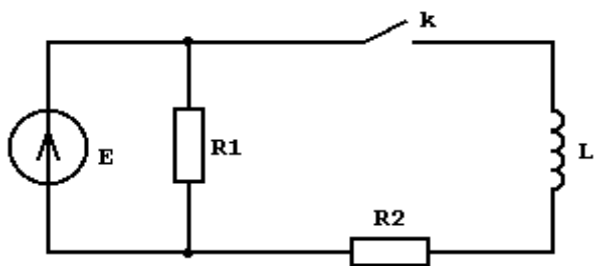


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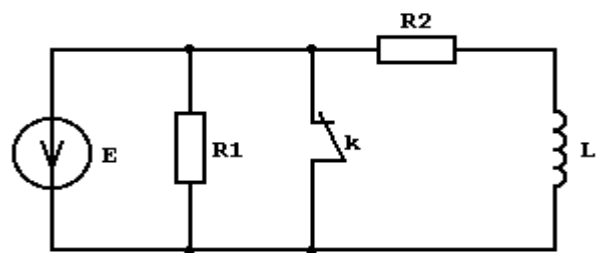


Figure 4.17

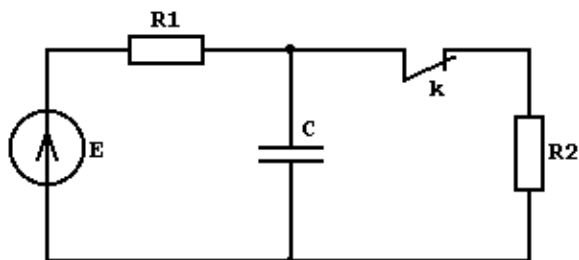


Figure 4.18

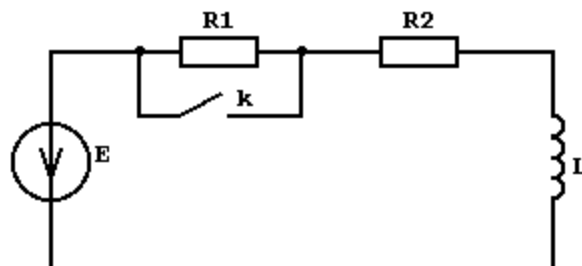


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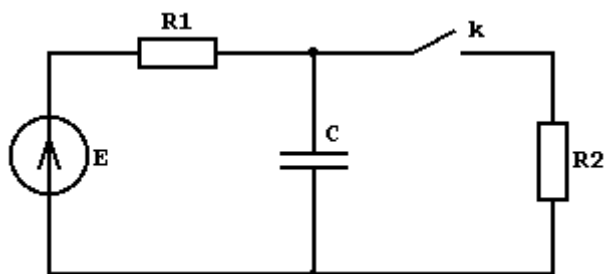


Figure 4.20

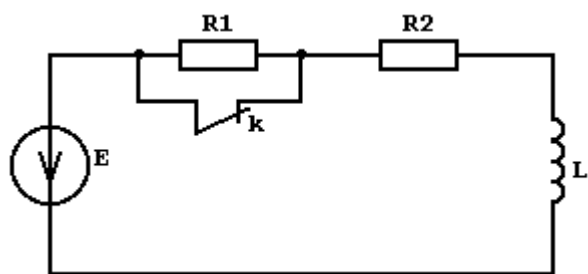


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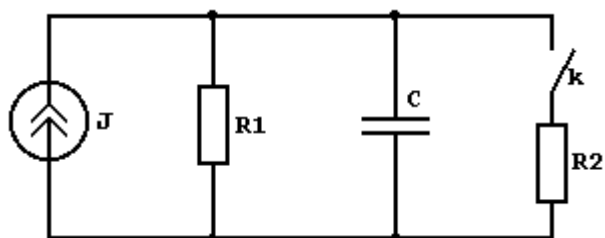


Figure 4.22

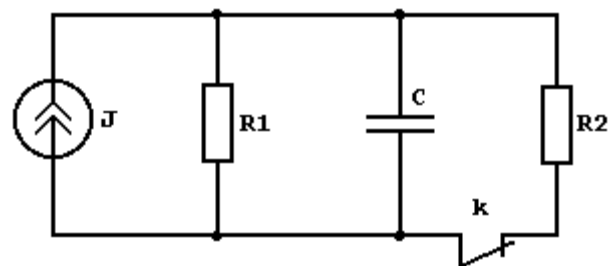


Figure 4.23

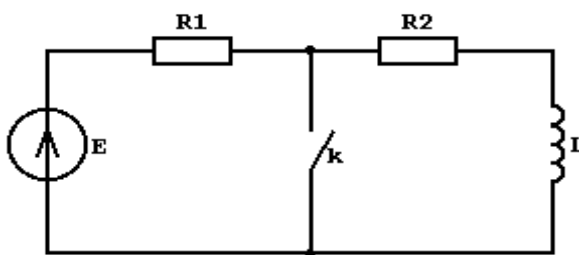


Figure 4.24

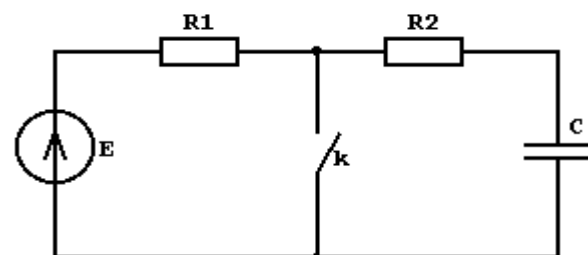


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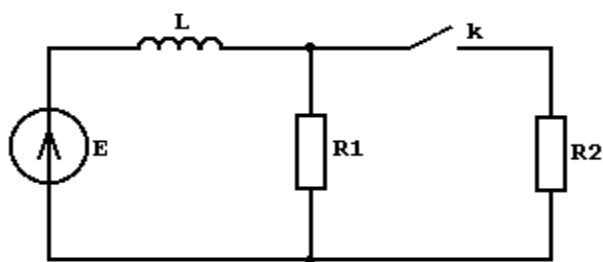


Figure 4.26

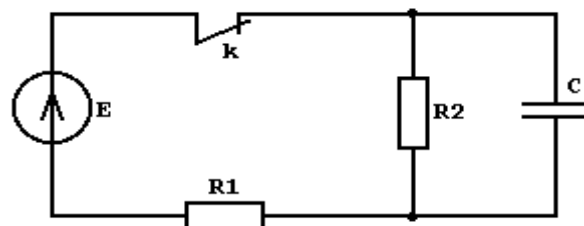


Figure 4.27

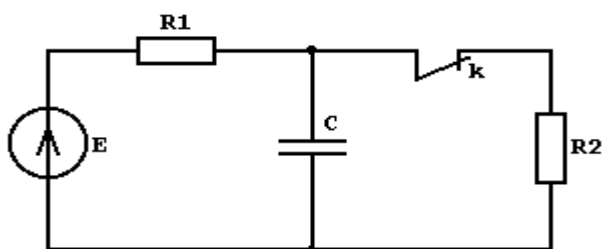


Figure 4.28

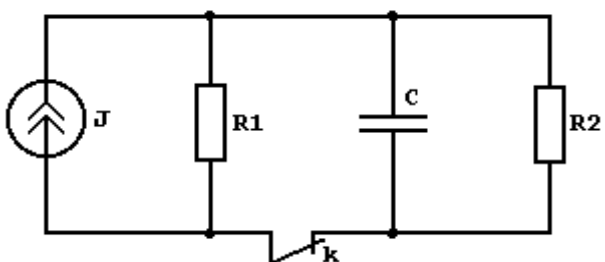


Figure 4.29

Table 4.3

Option №	Scheme Figure No	R1, kOm	R2, kOm	R3, kOm	L, mGn	S, μ F	E, In	J, mA
0	4.32	2	2	2	30	-	20	-
1	4.33	100	50	50	-	0.01	25	-
2	4.34	150	200	200	250	-	30	-
3	4.35	200	300	300	-	0.02	35	-
4	4.36	180	230	230	300	-	-	0.10
5	4.37	160	250	250	-	0.05	40	-
6	4.38	130	150	150	100	-	-	0.20
7	4.39	120	200	200	-	0.03	-	0.25
8	4.40	220	190	190	-	0.04	-	0.30
9	4.41	240	170	170	150	-	50	-
10	4.42	200	210	210	300	-	-	0.10
11	4.43	110	200	200	-	0.10	-	0.20
12	4.42	150	200	200	400	-	-	0.35
13	4.37	200	300	300	-	0.08	60	-
14	4.32	180	230	230	200	-	20	-
15	4.33	160	250	250	-	0.01	25	-
16	4.34	130	150	150	250	-	30	-
17	4.35	120	200	200	-	0.02	35	-

18	4.36	220	190	190	300	-	-	0.10
19	4.37	240	170	170	-	0.05	40	-
20	4.38	200	210	210	100	-	-	0.20
21	4.39	110	200	200	-	0.03	-	0.25
22	4.40	120	200	200	-	0.04	-	0.30
23	4.41	160	250	250	150	-	50	-
24	4.42	150	200	200	200	-	-	0.20
25	4.43	200	300	300	-	0.10	-	0.20
26	4.42	180	230	230	400	-	-	0.35
27	4.37	160	250	250	-	0.08	60	-
28	4.33	130	150	150	-	0.01	25	-
29	4.34	120	200	200	250	-	30	-
30	4.35	220	190	190	-	0.02	35	-
31	4.36	240	170	170	300	-	-	0.10
32	4.37	200	210	210	-	0.05	40	-
33	4.38	110	200	200	100	-	-	0.20
34	4.39	150	200	200	-	0.03	-	0.25
35	4.40	200	300	300	-	0.04	-	0.30
36	4.41	180	230	230	150	-	50	-
37	4.42	160	250	250	100	-	-	0.30
38	4.43	130	150	150	-	0.10	-	0.20
39	4.33	120	200	200	-	0.01	25	-
40	4.42	100	210	240	-	0.04	40	-
41	4.43	210	200	240	-	0.15	-	0.20
42	4.42	350	250	240	200	-	-	0.35
43	4.37	400	350	350	-	0.06	65	-
44	4.32	280	250	250	400	-	25	-
45	4.33	360	280	280	-	0.02	20	-
46	4.34	430	180	180	450	-	35	-

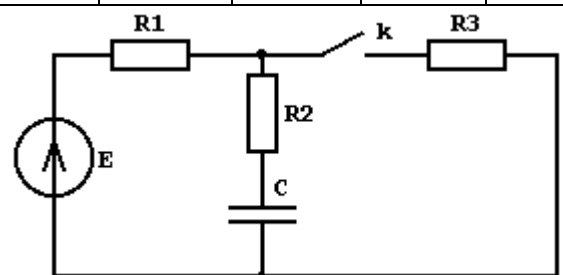
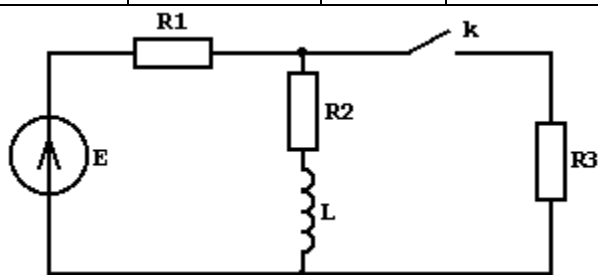


Figure 4.32

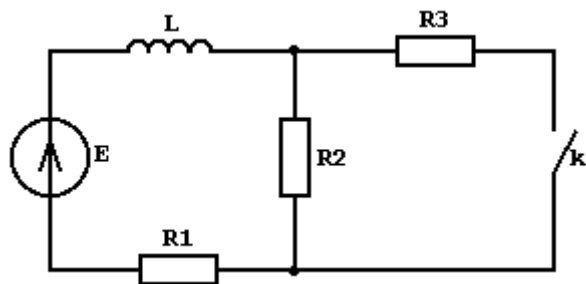


Figure 4.33

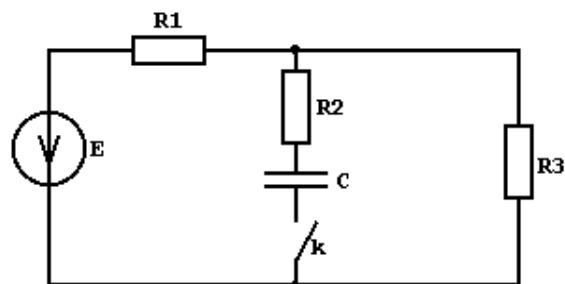


Figure 4.34

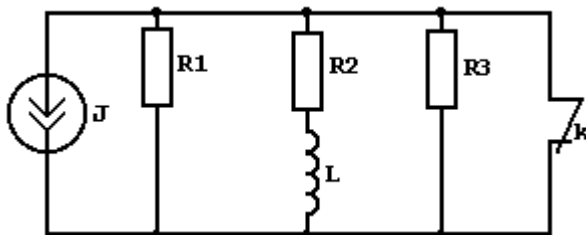


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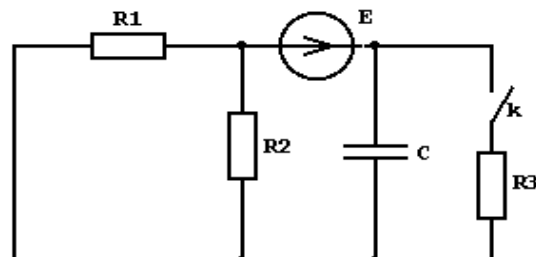


Figure 4.36

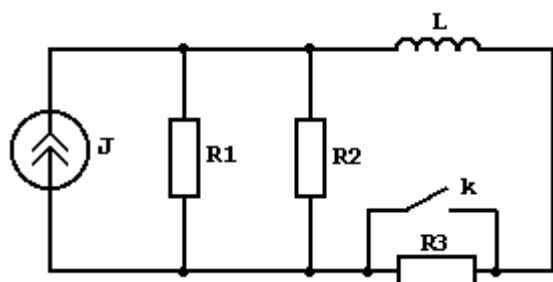


Figure 4.37

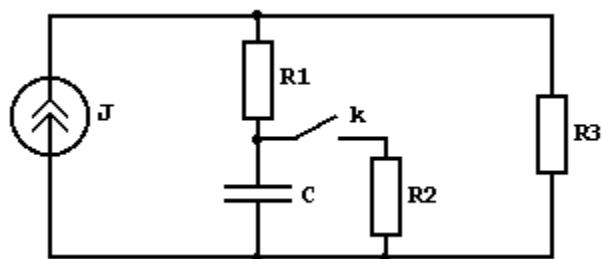


Figure 4.38

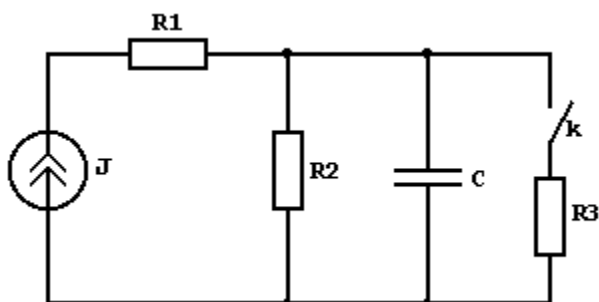


Figure 4.39

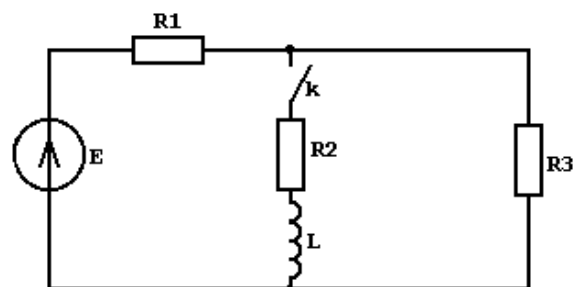


Figure 4.40

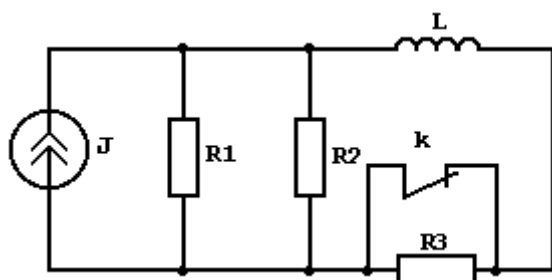


Figure 4.41

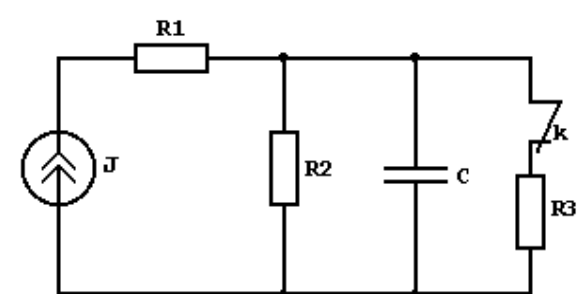


Figure 4.42



Figure 4.43



Example of completing tasks (option No0)

Task 1. In a given electrical circuit (see Figure 4.4), calculate and plot the transient current $i(t)$ and the voltage on the inductive element $u(t)$ if $R_1=1\text{k}\Omega$, $R_2=1\text{k}\Omega$, $L=30\text{ mH}$, $E=20\text{ V}$ (see Table 4.1).

Solution

1. In a given electrical circuit (see Figure 4.4) there is only one inductive element, in the magnetic field of which energy can be stored, so the first switching law is used to determine the initial conditions, according to which

$$i_L(+0) = i_L(-0) = 0.$$

2. For the circuit (Figure 4.46), after closing the key "k", write down the equation according to Kirchhoff's law 2: $u_R + u_L = E$ or $(R_1 + R_2) \cdot i + L \frac{di}{dt} = E$ (1)

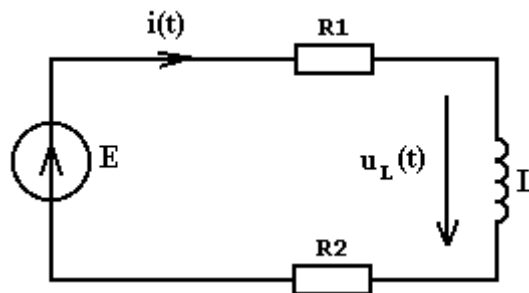


Figure 4.46

3. Transient current $i(t) = i_{sv}(t) + i_{st}(t)$

4. Find the $i_{st}(t)$ from equation (1) for $\frac{di}{dt} = 0$

$$i_{yct}(t) = \frac{E}{R_1 + R_2} = \frac{20}{(1+1) \cdot 10^3} = 10^{-2} \text{ A}.$$

5. Find $i_{sv}(t) = A \cdot e^{st}$,

where s is the root of the characteristic equation $R + sL = 0$;

$$s = -\frac{R}{L} = -\frac{2 \cdot 10^3}{20 \cdot 10^{-3}} = -1 \cdot 10^5 \text{ P-1},$$

A is constant, determined from the initial conditions

$$i(0) = i_{sv}(0) + i_{st}(0), \quad 0 = A \cdot e^{s \cdot 0} + \frac{E}{R}, \quad A = -\frac{E}{R}.$$

$$\text{Therefore } i_{\text{CB}}(t) = -\frac{E}{R} e^{-\frac{R}{L} \cdot t} = -\frac{E}{R} e^{-\frac{t}{\frac{L}{R}}} = -\frac{E}{R} e^{-\frac{t}{\tau}} = -10^{-2} \cdot e^{-10^5 t}, \text{ A,}$$

where $\frac{L}{R} = \tau$ is the time constant of the chain.

6. Transient current in the circuit

$$i(t) = i_{\text{yCT}}(t) + i_{\text{CB}}(t) = \frac{E}{R} - \frac{E}{R} e^{-\frac{t}{\tau}} = \frac{E}{R} \left(1 - e^{-\frac{t}{\tau}} \right) = 10^{-2} \left(1 - e^{-10^5 t} \right) \text{ A.}$$

7. Inductive Element Voltage

$$u(t) = u_L(t) = L \frac{di}{dt} = L \frac{d}{dt} \left(\frac{E}{R} - \frac{E}{R} e^{-\frac{R}{L} t} \right) = -L \left(\frac{R}{L} \cdot \frac{E}{R} e^{-\frac{R}{L} t} \right) = E \cdot e^{-\frac{R}{L} t} = 20 e^{-10^5 t} \text{ B.}$$

8. To plot $i(t)$ and $u(t)$, we will perform calculations and present the results in Table 4.4

Table 4.4 Resource requirements by component

$t \times 10^{-5}, \text{ c}$	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
t/τ	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$e^{-t/\tau}$	1	0.61	0.37	0.22	0.14	0.08	0.05	0.03	0.018	0.011	0.007
$1 - e^{-t/\tau}$	0	0.39	0.63	0.78	0.87	0.92	0.95	0.97	0.98	0.989	0.993
$i(t), \text{ mA}$	0	3.9	6.3	7.8	8.7	9.2	9.5	9.7	9.8	9.89	9.93
$u(t), \text{ B}$	20	12	7.4	4.5	2.7	1.6	1	0.6	0.36	0.22	0.14

9. Plotting $i(t)$ and $u(t)$ charts

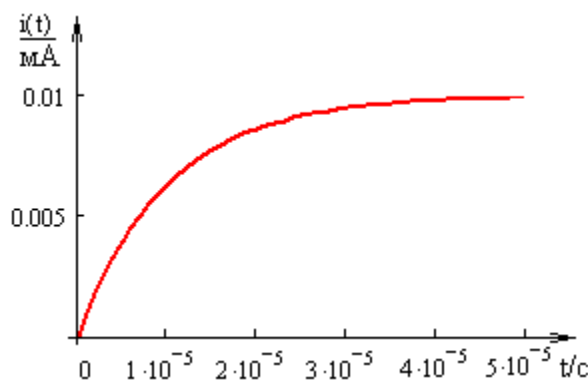


Figure 4.47

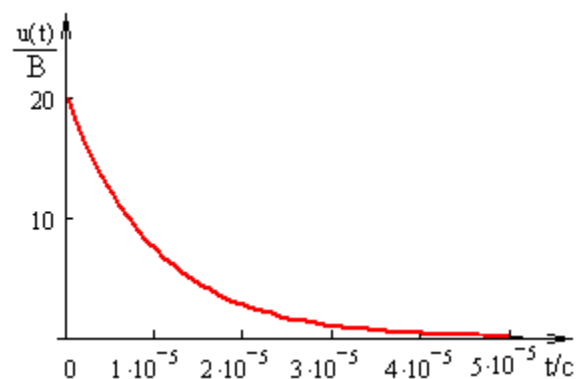


Figure 4.48

10. Let us determine the duration of the transient process $t_{per} = 3 \div 4 \tau = 3 \cdot 10^{-5} \div 4 \cdot 10^{-5}$, s.

Task 2. In an electrical circuit (see Figure 4.18), calculate and plot the transient current $i(t)$ and the voltage on the reactive element $u(t)$ if $R_1 = 0.2 \text{ k}\Omega$, $R_2 = 0.2 \text{ k}\Omega$, $C = 20 \text{ pF}$, $E = 20 \text{ V}$ (see Table 4.2).

Solution

1. In a given electrical circuit (see Figure 4.18) there is only one capacitive element in which energy can be stored, so the second switching law is used to determine the initial conditions, according to which $u_c(+0) = u_c(-0) = B$

$$u_c(0) = \frac{E \cdot R_2}{R_1 + R_2} = \frac{E \cdot 200}{400} = \frac{E}{2} = \frac{20}{2} = 10 \text{ V}.$$

2. Construct an equation for stresses according to Kirchhoff's second law after switching in a circuit (Figure 4.9) $u_{R1} + u_c = E$ or $R_1 i + u_c = E$, $R_1 C \frac{du_c}{dt} + u_c = E$

(2)

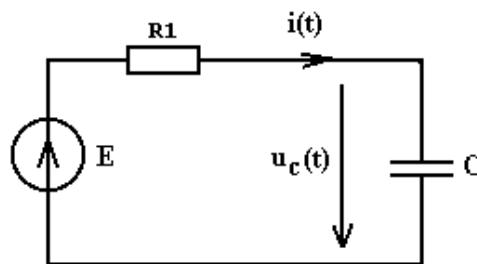


Figure 4.49

3. The transient voltage is defined as $u_c(t) = u_c^{CB} + u_c^{yCT}$.

4. u_c^{yCT} From equation (2) we find at $\frac{du_c}{dt} = 0$, i.e. $u_c^{yCT} = E = 20 \text{ V}$.

5. $u_c^{CB}(t) = Ae^{st}$ - general solution of a homogeneous linear equation

$$R_1 C \frac{du_c}{dt} + u_c = 0$$

To determine the root s , let us make a characteristic equation $R_1 C \cdot s + 1 = 0$

$$\text{Hence } s = -\frac{1}{R_1 C} = -\frac{1}{200 \cdot 2 \cdot 10^{-12}} = -\frac{1}{4 \cdot 10^{-10}} = -25 \cdot 10^8 \text{ s}^{-1}.$$

The constant A is found from the equation taking into account the initial conditions $u_c(0) = u_c^{yct}(0) + u_c^{cb}(0)$, $\frac{E}{2} = E + Ae^{s \cdot 0}$, $A = -\frac{E}{2} = -10$ B, hence

$$u_c^{cb}(t) = -\frac{E}{2} e^{-\frac{t}{R_1 C}} = -\frac{E}{2} e^{-\frac{t}{\tau}} = -10 e^{-\frac{t}{4 \cdot 10^{-10}}} = -10 \cdot e^{-25 \cdot 10^8 t} \text{ B.}$$

Here $\tau = R_1 C = 4 \cdot 10^{-10}$ c, is τ the time constant of the chain.

6. Transient voltage

$$u_c(t) = u_c^{yct} + u_c^{cb} = E - \frac{E}{2} \cdot e^{-\frac{t}{R_1 C}} = E \left(1 - 0.5 \cdot e^{-\frac{t}{R_1 C}} \right) = 20 \left(1 - 0.5 \cdot e^{-25 \cdot 10^8 t} \right) \text{ B.}$$

7. Transient Current

$$i(t) = C \frac{du_c}{dt} = C \frac{d}{dt} \left(E - \frac{E}{2} \cdot e^{-\frac{t}{R_1 C}} \right) = -C \cdot \frac{E}{2} \cdot \left(-\frac{1}{R_1 C} \right) \cdot e^{-\frac{t}{R_1 C}} = \frac{1}{2} \cdot \frac{E}{R_1} \cdot e^{-\frac{t}{R_1 C}} =$$

$$= \frac{20}{2 \cdot 200} e^{-25 \cdot 10^8 \cdot t} = 0.05 e^{-25 \cdot 10^8 t} \text{ A.}$$

8. To build graphs $i(t)$ and $u(t)$, we will perform calculations and present the results in Table 4.5

Table 4.5 Resource requirements

$t \times 10^{-10},$ c	0	2	4	6	8	10	12	14	16	18	20
t/τ	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$e^{-t/\tau}$	1	0.61	0.37	0.22	0.14	0.08	0.05	0.03	0.018	0.011	0.007
$i(t), \text{mA}$	0.05	0.03	0.018	0.011	0.007	0.004	0.0025	0.002	0.001	0.0005	0.0003
$u(t), \text{B}$	10	14	16	17.8	18.6	19.2	19.5	19.7	19.8	19.89	19.9

9. Build Charts $u_c(t)$ and $i(t)$

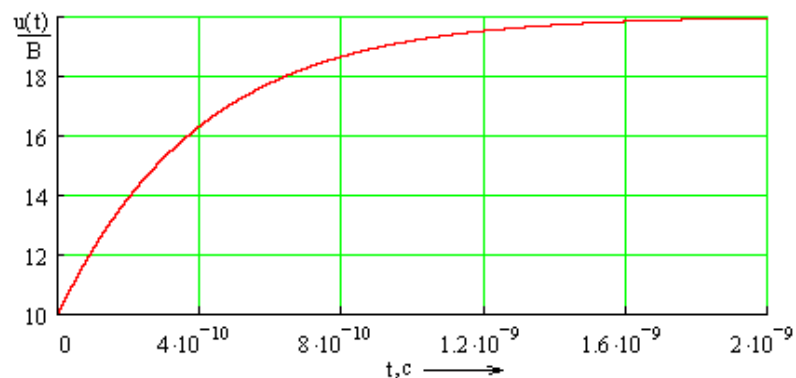


Figure 4.50

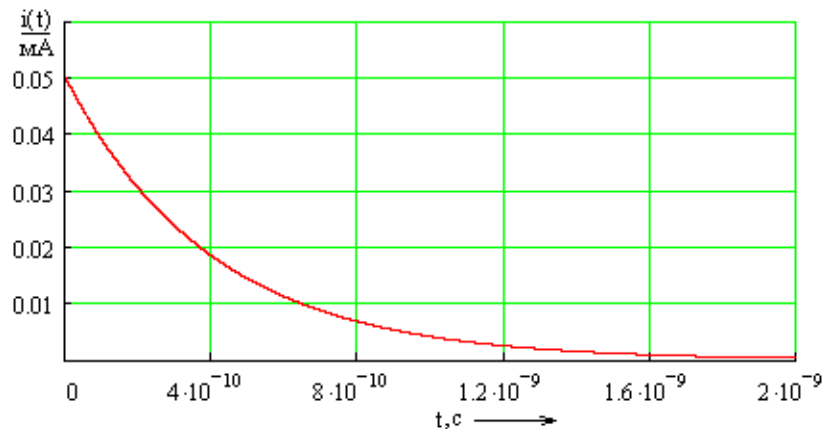


Figure 4.51

8. Finding the duration (practical) of the transition process

$$T \approx 4\tau = 16 \cdot 10^{-10} \text{ s.}$$

Task 3. In an electrical circuit (see Figure 4.32), calculate and plot transient currents if $R_1=2\text{k}\Omega$, $R_2=2\text{k}\Omega$, $R_3=2\text{k}\Omega$, $L=30 \text{ mH}$, $E=20 \text{ V}$ (see Table 4.3).

Solution

The first solution

1. Let's determine the initial conditions

$$i_2(t) = i_2(0) = \frac{E}{R_1 + R_2} = \frac{20}{4 \cdot 10^3} = 5 \cdot 10^{-3} \text{ A.}$$

2. The circuit after switching can be converted to a view (Figures 4.52, 4.53):

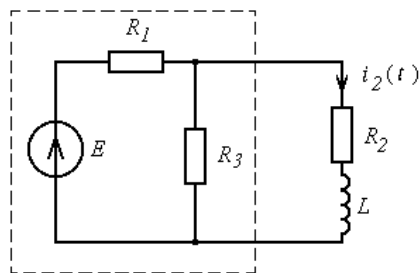


Figure 4.52

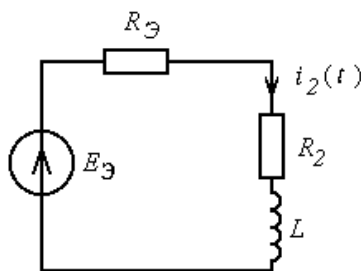


Figure 4.53

$$E_9 = U^{xx} = \frac{E \cdot R_3}{R_1 + R_3} = 10 \text{ V}$$

$$R_9 = \frac{R_1 \cdot R_3}{R_1 + R_3} = 1 \text{ k}\Omega$$

3. For the resulting diagram (Figure 4.53), write down the differential

$$\text{equation } L \frac{di_2}{dt} + (R_9 + R_2)i_2 = E_9 \quad (3)$$

4. Find the transient current $i_2(t) = i_{2\text{cb}}(t) + i_{2\text{ycr}}(t)$

5. The steady-state current is determined from equation (3) at $\frac{di_2}{dt} = 0$

$$i_{2ycT}(t) = \frac{E_3}{R_3 + R_2} = \frac{10}{10^3 + 2 \cdot 10^3} = 3,3 \cdot 10^{-3} \text{ A}$$

6. Free current $i_{2cB}(t) = A \cdot e^{st}$,

where s is the root of the characteristic equation $sL + (R_3 + R_2) = 0$

$$s = -\frac{R_3 + R_2}{L} = -\frac{3 \cdot 10^3}{30 \cdot 10^{-3}} = -10^5 \text{ c}^{-1},$$

The constant A is determined taking into account the initial conditions

$$i_2(0) = i_{2ycT}(0) + i_{2cB}(0), \text{ , } \frac{E}{R_1 + R_2} = \frac{E_3}{R_3 + R_2} + A \cdot e^{s \cdot 0}.$$

$$A = \frac{E}{R_1 + R_2} - \frac{E_3}{R_3 + R_2} = 5 \cdot 10^{-3} - 3,3 \cdot 10^{-3} = 1,7 \cdot 10^{-3} \text{ A}$$

Therefore $i_{2cB}(t) = A \cdot e^{st} = 1,7e^{-10^5 t} \text{ mA}.$

7. Transient current $i_2(t) = i_{2ycT}(t) + i_{2cB}(t) = 3,3 \cdot 10^{-3} + 1,7 \cdot 10^{-3} e^{-10^5 t} \text{ A}.$

8. Stress in the section with elements R_2, L

$$\begin{aligned} u(t) &= R_2 \cdot i_2(t) + L \frac{di_2(t)}{dt} = 2 \cdot 10^3 \left(3,3 \cdot 10^{-3} + 1,7 \cdot 10^{-3} e^{-10^5 t} \right) + 30 \cdot 10^{-3} \left(-1,7 \cdot 10^2 e^{-10^5 t} \right) = \\ &= 6,6 + 3,4 \cdot e^{-10^5 t} - 5,1 \cdot e^{-10^5 t} = 6,6 - 1,7 \cdot e^{-10^5 t} \text{ B.} \end{aligned}$$

9. Since the voltage in the section with the elements R_2, L is equal to the voltage in the element R_3 (the sections are connected to each other in parallel, see Figure 4.52), then according to Ohm's law, we find the current

$$i_3 = \frac{u(t)}{R_3} = 3,3 \cdot 10^{-3} - 0,85 \cdot 10^{-3} \cdot e^{-10^5 t} \text{ A.}$$

10. Current $i_1 = i_2 + i_3 = 6,6 \cdot 10^{-3} + 0,85 \cdot 10^{-3} \cdot e^{-10^5 t} \text{ A.}$

11. To build graphs, let's perform calculations and present the results in Table 4.6

12. Let's plot currents and voltages (Figures 4.54-4.55)

Table 4.6 Resource requirements by component

$t \times 10^{-5},$ c	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
t/τ	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$e^{-t/\tau}$	1	0.61	0.37	0.22	0.14	0.08	0.05	0.03	0.018	0.011	0.007
$i_1(t),$ mA	7.5	7.17	6.97	6.85	6.779	6.74	6.71	6.69	6.68	6.676	6.672
$i_2(t),$ mA	5	4.34	3.95	3.71	3.559	3.47	3.42	3.38	3.36	3.352	3.345
$i_3(t),$ mA	2.5	2.83	3.02	3.15	3.220	3.27	3.29	3.31	3.32	3.324	3.328
$u(t),$ B	5	5.66	6.05	6.29	6.44	6.53	6.58	6.62	6.64	6.648	6.655

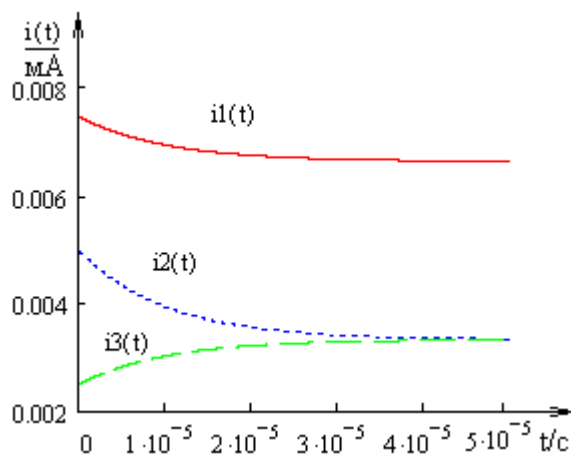


Figure 4.54

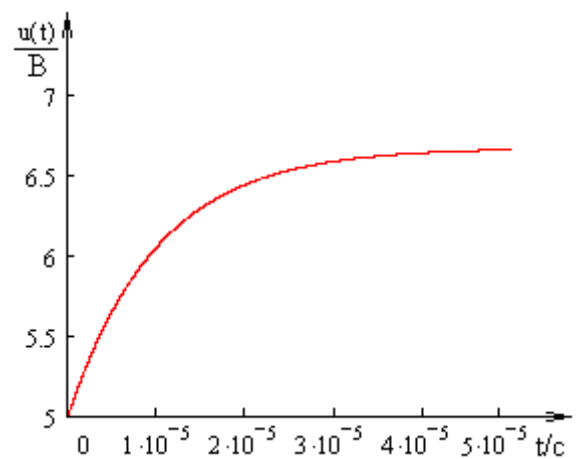


Figure 4.55

The second solution

1. Initial conditions $i_2(0) = \frac{20}{4 \cdot 10^{-3}} = 5 \cdot 10^{-3} \text{ A}.$

2. Using Kirchhoff's laws 1 and 2, we will make a system of equations for the chain (Figure 4.56)

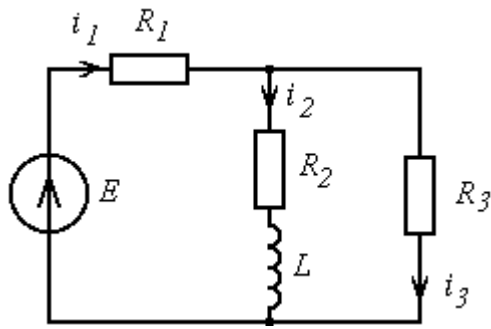


Figure 4.56

$$i_1 = i_2 + i_3 \quad (4)$$

$$R_1 i_1 + i_2 R_2 + L \frac{di_2}{dt} = E \quad (5)$$

$$R_1 i_1 + i_3 R_3 = E \quad (6)$$

From (4) $i_3 = i_1 - i_2$ we substitute in (6) $R_1 i_1 + (i_1 - i_2) R_3 = E$, from here

$$i_1 = \frac{E + i_2 R_3}{R_1 + R_3}, \text{ then from (5) } R_1 \cdot \frac{E}{R_1 + R_3} + \frac{i_2 R_3 R_1}{R_1 R_3} + i_2 R_2 + L \frac{di_2}{dt} = E \quad \text{or}$$

$$L \frac{di}{dt} + \frac{R_3 \cdot R_1 + R_2 R_1 + R_3 R_2}{R_1 + R_3} i_2 = \frac{E(R_1 + R_3) - R_1 E}{R_1 + R_3}$$

$$\text{Let's denote } R_e = \frac{R_3 \cdot R_1 + R_2 R_1 + R_3 R_2}{R_1 + R_3}, \quad E_e = \frac{E(R_1 + R_3) - R_1 E}{R_1 + R_3} = \frac{E(R_3)}{R_1 + R_3}$$

$$R_9 = \frac{(2 \cdot 10^3 \cdot 2 \cdot 10^3 + 2 \cdot 10^3 \cdot 2 \cdot 10^3 + 2 \cdot 10^3 \cdot 2 \cdot 10^3)}{4 \cdot 10^3} = 3 \cdot 10^3 \text{ Ohm,}$$

$$E_9 = \frac{E \cdot R_3}{R_1 + R_3} = \frac{20 \cdot 2 \cdot 10^3}{4 \cdot 10^3} = 10 \text{ B.}$$

3. Taking into account the notations, the differential equation will take the form

$$L \frac{di_2}{dt} + R_9 i_2 = E_9$$

4. Transient current $i_2(t) = i_{2\text{ycr}}(t) + i_{2\text{cb}}(t)$

5. Steady-state current $i_{2\text{ycr}}(t) = \frac{E_9}{R_9} = \frac{10}{3 \cdot 10^3} = 3,3 \cdot 10^{-3} \text{ A.}$

6. Free current $i_{2\text{cb}}(t) = A \cdot e^{s \cdot t}$. Here $s = -\frac{R_9}{L} = \frac{3 \cdot 10^3}{30 \cdot 10^{-3}} = -10^5 \text{ c}^{-1}$.

A is the constant, determined taking into account the initial conditions from the equation

$$i_2(0) = i_{2\text{ycr}}(0) + i_{2\text{cb}}(0) \quad \text{or} \quad \frac{E}{R_1 + R_2} = A \cdot e^{s \cdot 0} + \frac{E_9}{R_9},$$

$$\text{hence } A = 5 \cdot 10^{-3} - 3,3 \cdot 10^{-3} = 1,7 \cdot 10^{-3},$$

Consequently $i_{2CB}(t) = 1.7 \cdot 10^{-3} \cdot e^{-10^5 t}$ A.

7. Transient current $i_2(t) = 3.3 \cdot 10^{-3} + 1.7 \cdot 10^{-3} \cdot e^{-10^5 t}$ A.

8. Current $i_1(t) = \frac{E + i_2 R_3}{R_1 + R_3} = \frac{20 + 6.6 + 3.4 \cdot e^{-10^5 t}}{4 \cdot 10^{-3}} = 6.6 \cdot 10^{-3} + 0.85 \cdot 10^{-3} \cdot e^{-10^5 t}$ A

9. Current $i_3(t) = i_1(t) - i_2(t) = 3.3 \cdot 10^{-3} - 0.85 \cdot 10^{-3} \cdot e^{-10^5 t}$ A.

10. Voltage $u(t) = i_3(t) \cdot R_3 = 6.6 - 1.7 \cdot e^{-10^5 t}$ V.

Currents and voltages have the same values as in the 1st way solution.

7. Calculation of transient processes by the operator method

Study questions:

1. Calculation of transient currents, voltages in the simplest RC (RL) circuit under zero initial conditions.
2. Calculation of transient currents and voltages in the simplest RC (RL) circuit under non-zero initial conditions.
3. Calculation of transient currents and voltages in a complex RC (RL) circuit.

Assignment for students to prepare for the lesson

1. Study:

1. Nikulin V.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. - Moscow: RIOR, 2016, pp. 109-114.
2. Bakalov V.P., Vorobienko P.P., Kruk B.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. Moscow, Radio i svyaz Publ., 1998, pp. 102-105.
3. Shebes M. R. Zadachnik po teorii lineynykh elektricheskikh tsepey [Task book on the theory of linear electric circuits]. - Moscow: Vysshaya shkola, 1982. - pp. 202-207.
4. Piskunov N.I. Differential and integral calculus for higher educational institutions. - Moscow: Nauka, 1985, part 2, pp. 400-410.

2. Answer the questions:

1. Formulate the 1st and 2nd laws of commutation.

2. Draw the substitution schemes of an idealized inductive element under zero initial conditions.
3. Draw a substitution scheme for an idealized inductive element under non-zero initial conditions.
4. Draw a scheme for replacing an idealized capacitive element under zero initial conditions.
5. Draw a replacement scheme for an idealized capacitive element under non-zero initial conditions.
6. Using the direct Laplace transform, define the image $F(s)$ for unit function $1(t)$ (Heaviside function).
7. List the main properties of Laplace transformations.
8. For the specified circuits (Figures 4.57-4.59), determine the initial conditions on the basis of the switching laws and draw up operator substitution schemes:

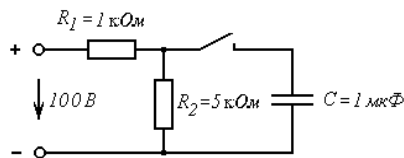


Figure 4.57

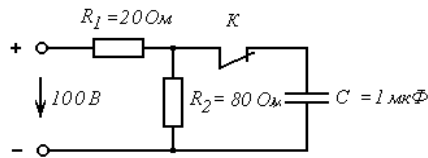


Figure 4.58

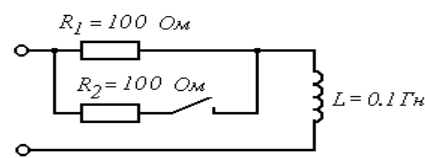


Figure 4.59

9. Write the expression for Ohm's law in operator form under zero and non-zero initial conditions for a circuit containing R, L, C elements connected in series.
10. Name the stages of the algorithm of the operator method for calculating transient processes in an electrical circuit.

3. Analyze the solution of the following tasks:

No 7.1, 7.10 (Shebes M. R. Task book on the theory of linear electric circuits. Moscow: Vysshaya shkola, 1982. - pp. 207-209, 213-215)

During the practical lesson, complete the tasks:

Task No1. In the specified electrical circuit (see Table 4.1), calculate and plot the transient currents $i(t)$ and voltage $u(t)$ on the reactive element using the operator method.

Task No2. In the specified electrical circuit (see Table 4.2), calculate and plot the transient currents $i(t)$ and voltage $u(t)$ on the reactive element using the operator method.

Task No3. In the given according to the variant of a complex electric circuit (see Table 4.3), calculate by the operator method and plot the transient currents $i(t)$.

Table 4.7 - Table of Laplace transformations

№ p/n	F(s)	f(t), (t > 0)
1	1	$\delta(t)$
2	$\frac{1}{s}$	1
3	$\frac{A}{s}$	A
4	$\frac{1}{s+a}$	e^{-at}
5	$\frac{s}{s+a}$	$\delta(t) - ae^{-at}$
6	$\frac{1}{s(s+a)}$	$\frac{1}{a}(1 - e^{-at})$
7	$\frac{1}{(s+a)(s+b)}$	$\frac{1}{b-a}(e^{-at} - e^{-bt})$
8	$\frac{s}{(s+a)(s+b)}$	$\frac{1}{a-b}(ae^{-at} - be^{-bt})$
9	$\frac{1}{(s+a)^2}$	te^{-at}
10	$\frac{s}{(s+a)^2}$	$e^{-at}(1 - at)$
11	$\frac{1}{s(s+a)^2}$	$\frac{1}{a^2}(1 - e^{-at} - ate^{-at})$
12	$\frac{1}{s(s+a)(s+b)}$	$\frac{1}{ab(a-b)}[a - b + be^{-at} - ae^{-bt}]$
13	$\frac{1}{s^2 + a^2}$	$\frac{1}{a}\sin at$
14	$\frac{s}{s^2 + a^2}$	$\cos at$
15	$\frac{1}{s(s^2 + a^2)}$	$\frac{1}{a^2}(1 - \cos at)$

16	$\frac{1}{(s+b)^2 + a^2}$	$\frac{1}{a} e^{-bt} \sin at$
17	$\frac{s}{(s+b)^2 + a^2}$	$e^{-bt} \left(\cos at - \frac{b}{a} \sin at \right)$
18	$\frac{1}{s((s+b)^2 + a^2)}$	$\frac{1}{a^2 + b^2} \left[1 - e^{-bt} \left(\cos at + \frac{b}{a} \sin at \right) \right]$

Example of completing tasks (option No0)

Task 1. In the given electrical circuit (see Figure 4.4), calculate and plot the transient current $i(t)$ and voltage $u(t)$ on the inductive element using the operator method if $R_1=1\text{k}\Omega$, $R_2=1\text{k}\Omega$, $L=20\text{ mH}$ (see Table 4.1).

Solution

1. Determine the initial conditions according to the first law of commutation

(See Figure 4.4) $i_L(0) = 0$

2. Draw up an operator substitution scheme (Figure 4.60), provided that the key "k" is closed and $i_L(0) = 0$

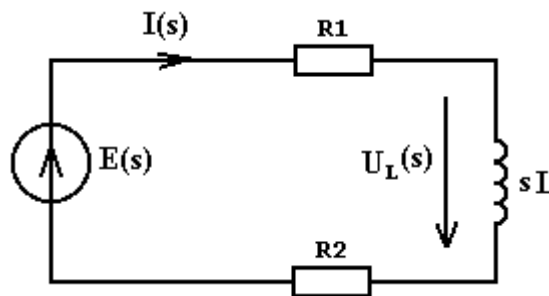


Figure 4.60

3. According to Ohm's law, in the operator form for the circuit (Figure 4.60) we find

$$I(s) = \frac{E(s)}{Z(s)} = \frac{\frac{E}{s}}{(R_1 + R_2 + sL)} = \frac{20}{s(1000 + 1000 + 0.02s)} = \frac{20}{s(0.02s + 2000)}$$

4. Convert the expression for the operator current $I(s)$ into a form convenient for the Laplace tabular conversion (see Table 4.7, item 6).

$$I(s) = \frac{20}{s(0.02s + 2000)} = \frac{20}{0.02s(s + 10^5)} = \frac{1000}{s(s + 10^5)}$$

5. Using the Laplace transform table (see Table 4.7, item 6), using the linearity property of the Laplace transformation, we find the transient current

$$i(t) = \frac{1000}{10^5} \left(1 - e^{-10^5 t} \right) = 10^{-2} \left(1 - e^{-10^5 t} \right) \text{ A.}$$

6. The transient voltage is determined using Kirchhoff's second law for the circuit (Figure 4.61)

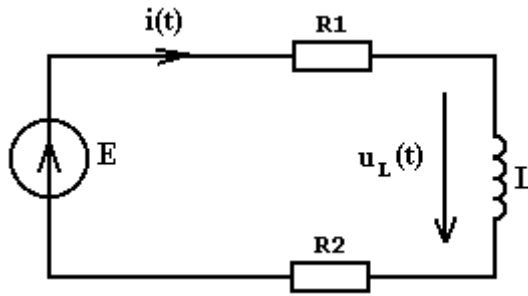


Figure 4.61

$$u_L(t) = u(t) = E - (R_1 + R_2)i(t) = 20 - 2000 \cdot 10^{-2} \left(1 - e^{-10^5 t}\right) = 20e^{-10^5 t} \text{ B.}$$

7. To build graphs $i(t)$ and $u(t)$, we will perform calculations, and the results will be presented in Table 4.8

Table 4.8 Resource requirements by component

$t \times 10^{-5},$ c	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
t/τ	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$e^{-t/\tau}$	1	0.61	0.37	0.22	0.14	0.08	0.05	0.03	0.018	0.011	0.007
$1 - e^{-t/\tau}$	0	0.39	0.63	0.78	0.87	0.92	0.95	0.97	0.98	0.989	0.993
$i(t),$ mA	0	3.9	6.3	7.8	8.7	9.2	9.5	9.7	9.8	9.89	9.93
$u(t), \text{ B}$	20	12	7.4	4.5	2.7	1.6	1	0.6	0.36	0.22	0.14

9. Plotting $i(t)$ and $u(t)$ charts

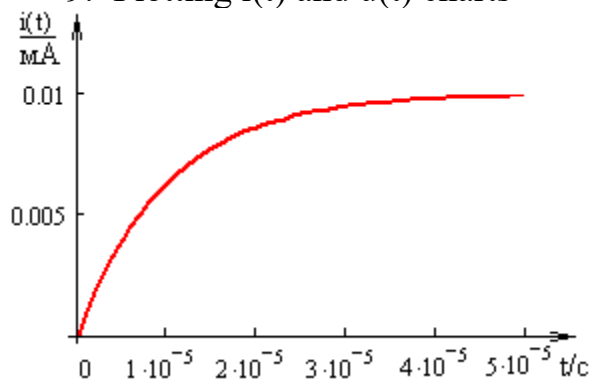


Figure 4.62

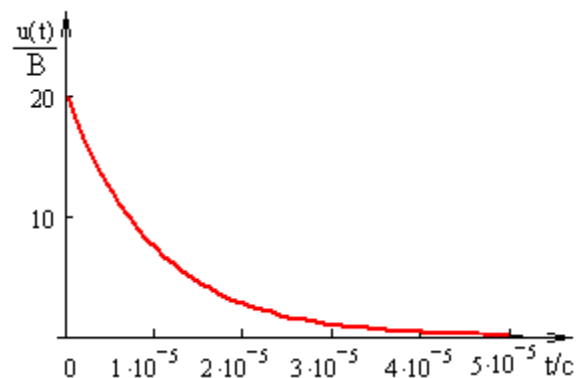


Figure 4.63

Task 2. In an electric circuit (see Figure 4.18), calculate and plot the transient currents $i(t)$ and voltage on the reactive element $u(t)$ using the operator method if $R_1=0.2\text{k}\Omega$, $R_2=0.2\text{k}\Omega$, $C=20\text{ pF}$, $E=20\text{ V}$ (see Table 4.2).

Solution

1. Determine the initial conditions according to the second law of commutation

$$u_c(0) = \frac{ER_1}{R_1 + R_2} = 10\text{ B.}$$

2. Draw up an operator substitution scheme (Figure 4.64), provided that the key "k" in the electrical circuit (see Figure 4.18) is open

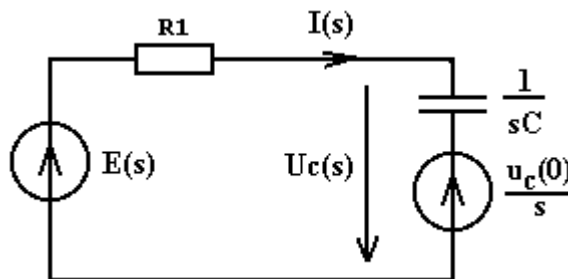


Figure 4.64

3. According to Ohm's law, we find
$$I(s) = \frac{E(s) - \frac{u_c(0)}{s}}{Z(s)} = \frac{\frac{E}{s} - \frac{u_c(0)}{s}}{\left(R_1 + \frac{1}{sC}\right)}$$

4. Convert the expression for the operator current $I(s)$ into a form convenient for the tabular Laplace transformation (see Table 4.7, item 4).

$$I(s) = \frac{\frac{E}{s} - \frac{u_c(0)}{s}}{\left(R_1 + \frac{1}{sC}\right)} = \frac{E - u_c(0)}{\frac{sRC + 1}{C}} = \frac{E - u_c(0)}{R\left(s + \frac{1}{RC}\right)} = \frac{1}{200} \cdot \frac{10}{s + 25 \cdot 10^8}$$

5. Using the Laplace transform table (see Table 4.7, item 4), using the linearity property of the Laplace transformation, we find the transient current

$$i(t) = 0.05e^{-25 \cdot 10^8 t} \text{ A.}$$

6. The transient voltage is determined using Kirchhoff's second law for the circuit (Figure 4.65)

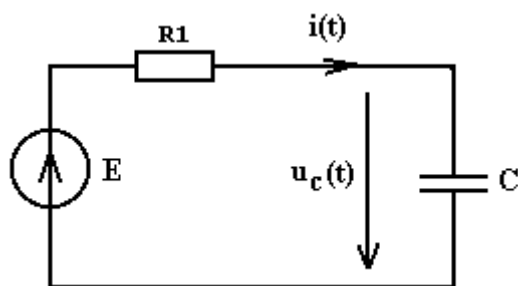


Figure 4.65

$$u_c(t) = u(t) = E - R_1 i(t) = 20 - 200 \cdot 0.05 \left(e^{-25 \cdot 10^8 t} \right) = 20 - 10 e^{-25 \cdot 10^8 t} \text{ B.}$$

7. To build graphs $i(t)$ and $u(t)$, we will perform calculations, and the results will be presented in Table 4.9

Table 4.9 Resource requirements by component

$t \cdot 10^{-10}, \text{ c}$	0	2	4	6	8	10	12	14	16	18	20
t/τ	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$e^{-t/\tau}$	1	0.61	0.37	0.22	0.14	0.08	0.05	0.03	0.018	0.011	0.007
$i(t), \text{ mA}$	0.05	0.03	0.018	0.011	0.007	0.004	0.0025	0.002	0.001	0.0005	0.0003
$u(t), \text{ B}$	10	14	16	17.8	18.6	19.2	19.5	19.7	19.8	19.89	19.95

8. Plotting the Graphs of $u(t)$ and $i(t)$

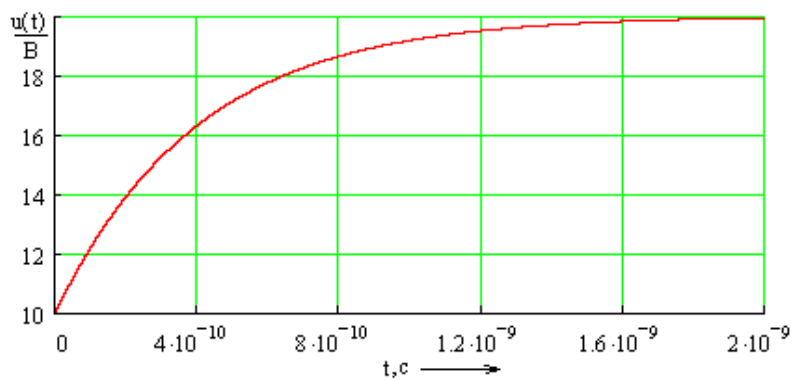


Figure 4.66

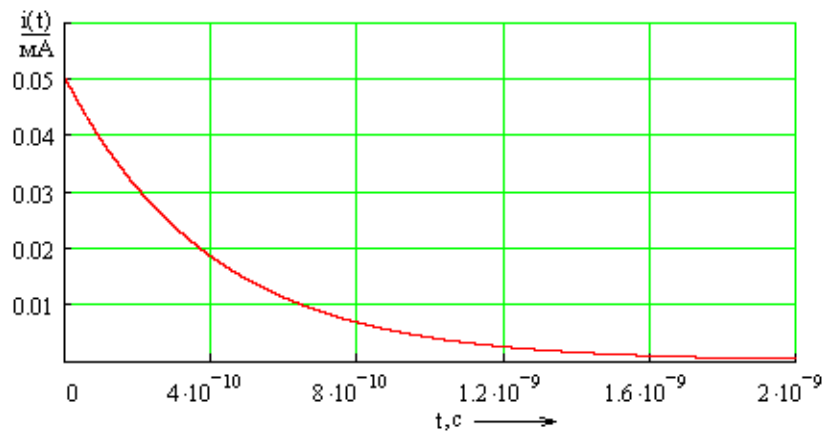


Figure 4.67

Task 3. In an electric circuit (see Figure 4.32), calculate and plot transient currents using the operator method if $R_1=2\text{k}\Omega$, $R_2=2\text{k}\Omega$, $R_3=2\text{k}\Omega$, $L=30\text{ mH}$, $E=20\text{ V}$ (see Table 4.3).

Solution

1. Determine the initial conditions according to the first switching law for the circuit

(see Figure 4.32) $i_L(0) = \frac{E}{R_2 + R_1} = 0.005\text{ A}.$

2. Draw up an operator substitution scheme (Figure 4.68), provided that the key "k" in the electrical circuit (see Figure 4.32) is closed

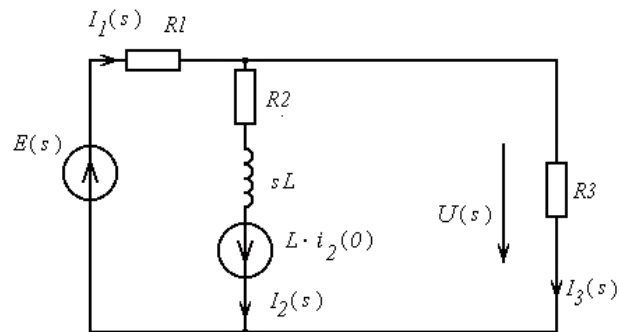


Figure 4.68

3. Using the two-node method, we will determine the operator voltage

$$U(s) = \frac{E(s)Y_1(s) - L i_2(0)Y_2(s)}{Y_1(s) + Y_2(s) + Y_3(s)} = \frac{\frac{20}{s} \cdot 0.0005 - 30 \cdot 10^{-3} \cdot 0.005 \cdot \frac{1}{2000 + s30 \cdot 10^{-3}}}{0.0005 + \frac{1}{2000 + s30 \cdot 10^{-3}} + 0.0005} = \frac{s \cdot 15 \cdot 10^{-5} + 20}{3 \cdot 10^{-5} s(s + 10^5)}$$

Here $E(s) = \frac{20}{s}$, $Y_1(s) = \frac{1}{R_1} = 0.0005 C_M$, $Y_3(s) = \frac{1}{R_3} = 0.0005 C_M$,

$$Y_2(s) = \frac{1}{R_2 + sL} = \frac{1}{2000 + s30 \cdot 10^{-3}} C_M.$$

4. Convert the expression for the operator voltage $U(s)$ into a form convenient for the Laplace table transformation (see Table 4.7, p.4 and p.6).

$$U(s) = \frac{s \cdot 15 \cdot 10^{-5} + 20}{3 \cdot 10^{-5} s(s + 10^5)} = 5 \cdot \frac{1}{s + 10^5} + \frac{20 \cdot 10^5}{3} \cdot \frac{1}{s(s + 10^5)}$$

5. Using the Laplace transform table (see Table 4.7, clauses 4 and 6), using the linearity property of the Laplace transformation, we find the transient voltage

$$u(t) = 5e^{-10^5 t} + \frac{20 \cdot 10^5}{3} \cdot \frac{1}{10^5} (1 - e^{-10^5 t}) = 6.66 - 1.67e^{-10^5 t} B.$$

6. Determine the transient currents

$$i_3(t) = \frac{u(t)}{R_3} = 3.33 \cdot 10^{-3} - 0.85 \cdot 10^{-3} e^{-10^5 t} A.$$

$$i_1(t) = \frac{E - u(t)}{R_1} = 6.6 \cdot 10^{-3} + 0.85 \cdot 10^{-3} e^{-10^5 t} A.$$

$$i_2(t) = i_1(t) - i_3(t) = 3.3 \cdot 10^{-3} + 1.7 \cdot 10^{-3} e^{-10^5 t} A.$$

7. We build graphs of transient currents and voltages

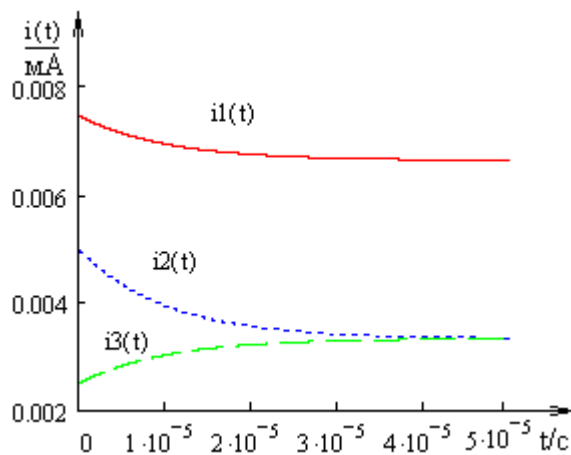


Figure 4.69

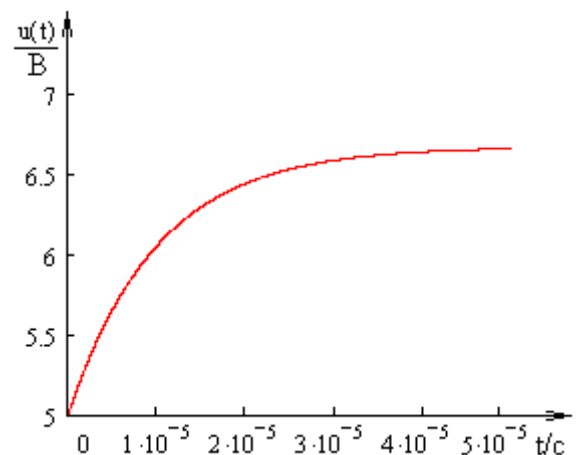


Figure 4.70

8. Calculation of four-pole parameters

Study questions:

1. Calculation of A-parameters of a given four-pole.
2. Calculation of the Y-parameters of a given four-pole.
3. Calculation of the Z-parameters of a given four-pole.

Task to prepare for the lesson

1. Study:

1. Nikulin V.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. Moscow, RIOR Publ., 2013, pp. 109-114.
2. Bakalov V.P., Vorobienko P.P., Kruk B.I. Teoriya elektricheskikh tsepey [Theory of electric circuits]. Moscow, Radio i svyaz Publ., 1998, pp. 241-260.
3. Shebes M. R. Zadachnik po teorii lineynykh elektricheskikh tsepey [Task book on the theory of linear electric circuits]. - Moscow: Vysshaya shkola, 1982. - pp. 303-312.

2. Answer the questions:

1. What is called a four-pole?
2. Give examples of four-pole communication equipment.
3. Name the main forms of the four-pole equation systems.
4. Write down the equation of the four-pole in the form of A-parameters.
5. Why are these parameters called primary?
6. How can the parameters A_{11} and A_{21} be determined?
7. How can the parameters A_{12} and A_{22} be determined?
8. Draw a diagram of the cascade connection of two four-poles and write down the matrix equation for determining the primary parameters of a composite four-pole.
9. Draw a diagram of the serial connection of two four-poles and write down the matrix equation for determining the primary parameters of a composite four-pole.

10. Draw a diagram of a parallel connection of two four-poles and write down the matrix equation for determining the primary parameters of a composite four-pole.
11. Explain the algorithm for multiplying two matrices.
12. Explain the algorithm for adding two matrices.

3. Analyze the solution of the following tasks:

No 11.1, 11.13 (Shebes M. R. Task book on the theory of linear electric circuits. Moscow: Vysshaya shkola, 1982. - pp. 321-322, 324-325)

During the practical lesson, complete the tasks:

Task No1. Two identical four-poles (Table 5.1) are connected in a cascade. Determine A - the parameters of a composite four-pole.

Task No2. Two identical four-poles (Table 5.1) are connected in parallel. Determine Y- and A - the parameters of a composite four-pole.

Task No3. Two identical four-poles (Table 5.1) are connected in series. Determine Z- and A - the parameters of a composite four-pole.

Task No4. Two identical four-poles (Table 5.1) are connected in series - in parallel. Determine H- and A - parameters of a composite four-pole.

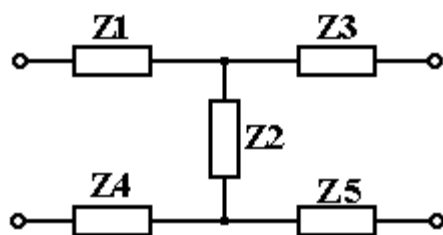


Fig. 5.1

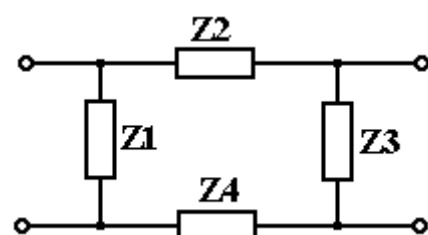


Fig. 5.2

Table 5.1

№ variant	Fig.No	$\underline{Z}_1$, Om	$\underline{Z}_2$, Om	$\underline{Z}_3$, Om	$\underline{Z}_4$, Om	$\underline{Z}_5$, Om	EG, In	$\underline{Z}_G$, Om	$\underline{Z}_H$, Om
0	1	10	j10	5	0	0	10	10	20
1	2	10	j5	10	0	-	12	20	10
2	1	0	-j10	10	0	0	15	25	50
3	2	10	0	10	-j4	-	20	15	16
4	1	5	-j5	0	0	0	10	5	20
5	1	0	j4	0	j4	4	25	6	12
6	1	-j2	2	-j4	0	0	30	8	16
7	2	j5	5	10	j5	-	20	10	20
8	1	10	j10	-j10	0	0	10	20	10
9	1	5	-j10	5	j5	j5	20	10	30
10	2	10	-j20	10	20	-	25	20	40
11	2	10	j5	10	5	-	12	20	10
12	1	j3	-j10	10	0	0	15	25	50
13	2	10	0	8	-j4	-	20	15	16
14	1	8	-j5	5	0	0	10	5	20
15	1	0	j4	3	j4	4	25	6	12
16	1	-j2	4	-j4	0	0	30	8	16
17	2	j5	5	5	j5	-	20	10	20
18	1	7	j10	j10	0	0	10	20	10
19	1	0	-j10	5	j5	j5	20	10	30
20	2	10	-j20	10	0	-	25	20	40
21	2	10	j5	10	10	-	12	20	10
22	1	0	-j9	10	3	0	15	25	50
23	2	6	0	10	-j4	-	20	15	16
24	1	5	-j5	9	0	0	10	5	20
25	1	3	j4	0	j4	4	25	6	12
26	1	j2	9	-j4	0	0	30	8	16
27	2	j5	3	9	j5	-	20	10	20
28	1	10	10	j10	0	0	10	20	10
29	1	5	j10	5	-j5	j5	20	10	30
30	2	10	-j20	0	20	-	25	20	40

31	2	10	j5	12	0	-	12	20	10
32	1	3	-j10	10	0	0	15	25	50
33	2	4	0	10	-j4	-	20	15	16
34	1	6	-j5	0	0	0	10	5	20
35	1	0	j4	8	j4	4	25	6	12
36	1	-j2	2	j4	0	0	30	8	16
37	2	j5	15	10	j5	-	20	10	20
38	1	10	j20	j10	0	0	10	20	10
39	1	5	-j10	5	-j5	j5	20	10	30
40	2	20	j25	10	20	-	25	20	40
41	2	10	j15	j10	0	-	12	20	10
42	1	0	-j10	j20	0	0	15	25	50
43	2	10	0	j10	-j6	-	20	15	16
44	1	15	-j19	0	0	0	10	15	20
45	1	10	j4	0	J8	4	25	6	12
46	1	-j2	3	-j6	0	0	30	8	16
47	2	j5	5	10	j5	-	20	10	20

Example of completing tasks (option No 0)

Task No 1. Two identical four-poles (Table 5.1, option No0) are connected in a cascade.

Calculate the A-parameters of the composite four-pole.

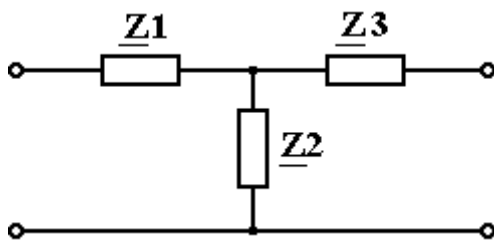


Fig.5.3

$$\underline{Z}_1 = 10 \text{ OM},$$

$$\underline{Z}_2 = j10 \text{ OM},$$

$$\underline{Z}_3 = 5 \text{ OM}.$$

Solution

1. A system of equations of a four-pole in the form A:

$$\underline{U}_1 = \underline{A}_{11} \underline{U}_2 + \underline{A}_{12} \underline{I}_2$$

$$\underline{I}_1 = \underline{A}_{21} \underline{U}_2 + \underline{A}_{22} \underline{I}_2$$

2. Calculation of parameters at $\underline{I}_2 = 0$ (idle mode relative to output clamps).

2.1. Four-pole diagram in idle mode (Fig.5.4)

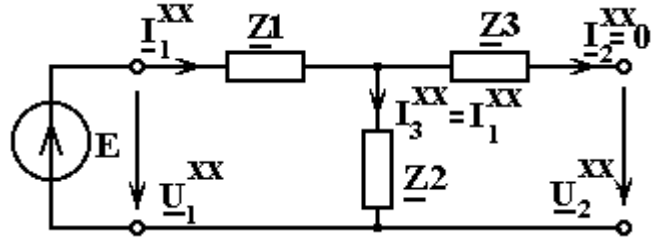


Fig.5.4

2.2. System of equations for idle mode

$$\underline{U}_1^{xx} = \underline{A}_{11} \underline{U}_2^{xx}$$

$$\underline{I}_1^{xx} = \underline{A}_{21} \underline{U}_2^{xx}$$

2.3. Currents and voltages in the circuit (Fig. 5.4)

$$\underline{U}_1^{xx} = \underline{I}_1^{xx} (\underline{Z}_1 + \underline{Z}_2)$$

$$\underline{U}_2^{xx} = \underline{I}_1^{xx} \underline{Z}_2$$

2.4. Primary Parameters $\underline{A}_{11}, \underline{A}_{21}$

$$\underline{A}_{11} = \frac{\underline{U}_1^{xx}}{\underline{U}_2^{xx}} = \frac{\underline{I}_1^{xx} (\underline{Z}_1 + \underline{Z}_2)}{\underline{I}_1^{xx} \underline{Z}_2} = 1 + \frac{\underline{Z}_1}{\underline{Z}_2} = 1 + \frac{10}{j10} = 1 - j2$$

$$\underline{A}_{21} = \frac{\underline{I}_1^{xx}}{\underline{U}_2^{xx}} = \frac{\underline{I}_1^{xx}}{\underline{I}_1^{xx} \underline{Z}_2} = \frac{1}{\underline{Z}_2} = \frac{1}{j10} = -j0.1 \text{ CM.}$$

3. Calculation of primary parameters at $\underline{U}_2 = 0$ (short-circuit mode).

3.1. Diagram of a four-pole in short-circuit mode (Fig. 5.5)

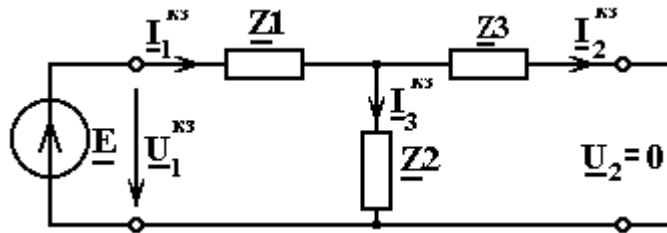


Fig.5.5

3.2. System of equations for the short-circuit mode

$$\underline{U}_1^{k3} = \underline{A}_{12} \underline{I}_2^{k3}$$

$$\underline{I}_1^{k3} = \underline{A}_{22} \underline{I}_2^{k3}$$

3.3. Currents and voltages in a four-pole at a short circuit

$$\underline{U}_1^{k3} = \underline{I}_1^{k3} (\underline{Z}_1 + \frac{\underline{Z}_2 \cdot \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3}) = \underline{I}_1^{k3} \cdot \frac{\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3}$$

$$\underline{I}_2^{K3} = \underline{I}_1^{K3} \cdot \frac{\underline{Z}_2}{\underline{Z}_2 + \underline{Z}_3}$$

3.4. Primary Parameters $\underline{A}_{12}, \underline{A}_{22}$

$$\begin{aligned} \underline{A}_{12} &= \frac{\underline{U}_1^{K3}}{\underline{I}_2^{K3}} = \frac{\underline{I}_1^{K3} (\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3) (\underline{Z}_2 + \underline{Z}_3)}{(\underline{Z}_1 + \underline{Z}_3) \cdot \underline{I}_1^{K3} \cdot \underline{Z}_2} = \frac{\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3}{\underline{Z}_2} = \\ &= \underline{Z}_1 + \underline{Z}_3 + \frac{\underline{Z}_1 \cdot \underline{Z}_3}{\underline{Z}_2} = 10 + 5 + \frac{10 \cdot 5}{j10} = 15 - j5 \text{ Ом}, \end{aligned}$$

$$\underline{A}_{22} = \frac{\underline{I}_1^{K3}}{\underline{I}_2^{K3}} = \frac{\underline{I}_1^{K3} (\underline{Z}_2 + \underline{Z}_3)}{\underline{I}_1^{K3} \cdot \underline{Z}_2} = 1 + \frac{\underline{Z}_3}{\underline{Z}_2} = 1 + \frac{5}{j10} = 1 - j0.5.$$

4. Check:

$$\begin{aligned} \underline{A}_{11} \underline{A}_{22} - \underline{A}_{21} \cdot \underline{A}_{12} &= (1 - j1)(1 - j0.5) - (-j0.1) \cdot (15 - j5) = \\ &= 1 - j1 - j0.5 - 1.5 + j1.5 + 0.5 = 1 \end{aligned}$$

5. Calculation of A - parameters of a composite four-pole.

5.1. Diagram of a composite four-pole (Fig. 5.6)

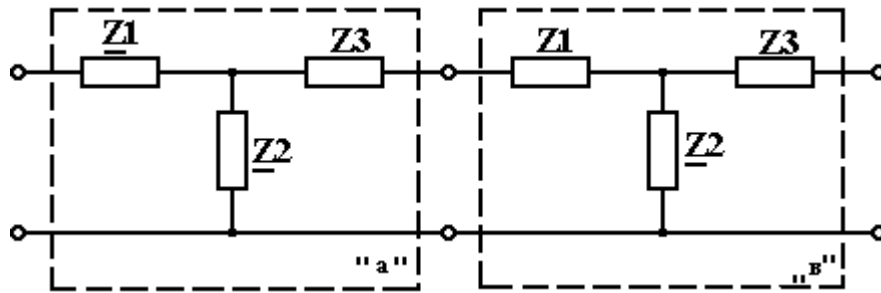


Fig.5.6

5.2. Matrix of a composite four-pole $[\underline{A}] = [\underline{A}_a] \cdot [\underline{A}_b]$

Here is $[\underline{A}_a] = \begin{bmatrix} \underline{A}_{11a} & \underline{A}_{12a} \\ \underline{A}_{21a} & \underline{A}_{22a} \end{bmatrix}$ – the matrix A of the parameters of the four-pole "a"

$$[\underline{A}_b] = \begin{bmatrix} \underline{A}_{11b} & \underline{A}_{12b} \\ \underline{A}_{21b} & \underline{A}_{22b} \end{bmatrix} \text{ – matrix A of the parameters of the four-pole "B"}$$

By problem condition $[\underline{A}_a] = [\underline{A}_b]$

5.3. Elements of matrix A of a composite four-pole

$$\underline{A}_{11} = \underline{A}_{11a} \cdot \underline{A}_{11b} + \underline{A}_{12a} \cdot \underline{A}_{21b} = (1 - j1)(1 - j1) + (15 - j5)(-j0.1) = -0.5 - j3.5,$$

$$\underline{A}_{12} = \underline{A}_{11a} \cdot \underline{A}_{12b} + \underline{A}_{12a} \cdot \underline{A}_{22b} = (1 - j1)(15 - j5) + (15 - j5) \cdot (1 - j0.5) = 22.5 - j32.5 \text{ Ом},$$

$$\underline{A}_{21} = \underline{A}_{21a} \cdot \underline{A}_{11b} + \underline{A}_{22a} \cdot \underline{A}_{21b} = -j0.1 \cdot (1 - j1) + (1 - j0.5)(-j0.1) = -0.5 - j0.2 \text{ See,}$$

$$\underline{A}_{22} = \underline{A}_{21a} \cdot \underline{A}_{21B} + \underline{A}_{22a} \cdot \underline{A}_{22B} = -j0.1(15 - j5) + (1 - j0.5)(1 - j0.5) = 0.25 - j0.5.$$

5.4.

Verification:

$$\underline{A}_{11} \cdot \underline{A}_{22} - \underline{A}_{12} \cdot \underline{A}_{21} = (-0.5 - j3.5)(0.25 - j2.5) - (22.5 - j32.5)(-0.15 - j0.2) = 1$$

Task No 2. Two identical four-poles (Fig. 5.3) are connected in parallel. Calculate the $\underline{Y}$ -, $\underline{A}$ -parameters of a composite four-pole if $Z_1 = 10 \text{ Ohm}$, $Z_2 = j10 \text{ Ohm}$, $Z_3 = 5 \text{ Ohm}$ (Table 5.1, option No 0).

Solution

1. A system of equations of a four-pole in the form of $\underline{Y}$.

$$\underline{I}_1 = \underline{Y}_{11} \underline{U}_1 + \underline{Y}_{12} \underline{U}_2$$

$$\underline{I}_2 = \underline{Y}_{21} \underline{U}_1 + \underline{Y}_{22} \underline{U}_2$$

2. Calculation of primary parameters at $\underline{U}_2 = 0$ (short circuit of output clamps).

2.1. Diagram of a four-pole (Fig. 5.7)

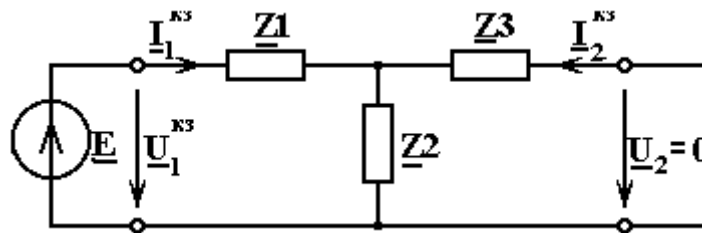


Fig.5.7

2.2. System of Equations for Short Circuit of Output Terminals

$$\underline{I}_1^{K3} = \underline{Y}_{11} \underline{U}_1^{K3}$$

$$\underline{I}_2^{K3} = \underline{Y}_{21} \underline{U}_1^{K3}$$

2.3. Currents and voltages in the circuit

$$\underline{U}_1^{K3} = \underline{I}_1^{K3} \cdot \left(\underline{Z}_1 + \frac{\underline{Z}_2 \cdot \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3} \right) = \underline{I}_1^{K3} \cdot \frac{\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3},$$

$$-\underline{I}_2^{K3} = \underline{I}_1^{K3} \cdot \frac{\underline{Z}_2}{\underline{Z}_2 + \underline{Z}_3}.$$

2.4. Primary Parameters $\underline{Y}_{11}, \underline{Y}_{21}$

$$\begin{aligned} \underline{Y}_{11} &= \frac{\underline{I}_1^{K3}}{\underline{U}_1^{K3}} = \frac{\underline{I}_1^{K3} (\underline{Z}_2 + \underline{Z}_3)}{\underline{I}_1^{K3} (\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3)} = \frac{\underline{Z}_2 + \underline{Z}_3}{\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3} = \\ &= \frac{j10 + 5}{10 \cdot j10 + 10 \cdot 5 + j10 \cdot 5} = 0.07 - j0.01 \text{ CM}, \end{aligned}$$

$$\begin{aligned}\underline{Y}_{21} &= \frac{\underline{I}_2^{K3}}{\underline{U}_1^{K3}} = \frac{-\underline{I}_1^{K3} \cdot \underline{Z}_2 \cdot (\underline{Z}_2 + \underline{Z}_3)}{(\underline{Z}_2 + \underline{Z}_3) \underline{I}_1^{K3} \cdot (\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3)} = \\ &= \frac{-\underline{Z}_2}{\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3} = \frac{-j10}{10 \cdot j10 + 10 \cdot 5 + j10 \cdot 5} = -0.06 - j0.02 \text{ C}_M.\end{aligned}$$

3. Calculation of primary parameters at $\underline{U}_1 = 0$ (short circuit of input clamps).

3.1. Diagram of a four-pole in case of a short circuit of the input terminals (Fig. 5.8)

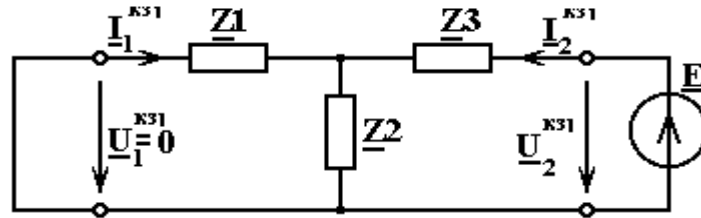


Fig.5.8

3.2. System of equations of a four-pole at a short circuit of input terminals

$$\begin{aligned}\underline{I}_{11}^{K3} &= \underline{Y}_{12} \underline{U}_2^{K31} \\ \underline{I}_2^{K31} &= \underline{Y}_{22} \underline{U}_2^{K31}\end{aligned}$$

3.3. Currents and voltages in the circuit

$$\begin{aligned}\underline{U}_2^{K31} &= \underline{I}_2^{K31} \left(\underline{Z}_3 + \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} \right) = \underline{I}_2^{K31} \cdot \frac{\underline{Z}_3 \underline{Z}_1 + \underline{Z}_3 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2}, \\ -\underline{I}_1^{K31} &= \underline{I}_2^{K31} \cdot \frac{\underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2}.\end{aligned}$$

3.4. Primary Parameters $\underline{Y}_{12}, \underline{Y}_{22}$

$$\begin{aligned}\underline{Y}_{12} &= \frac{\underline{I}_1^{K31}}{\underline{U}_2^{K31}} = \frac{-\underline{I}_2^{K31} \cdot \underline{Z}_2 \cdot (\underline{Z}_1 + \underline{Z}_2)}{(\underline{Z}_1 + \underline{Z}_2) \cdot \underline{I}_2^{K31} (\underline{Z}_3 \underline{Z}_1 + \underline{Z}_3 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_2)} = \\ &= \frac{-\underline{Z}_2}{\underline{Z}_3 \underline{Z}_1 + \underline{Z}_3 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_2} = \frac{-j10}{5 \cdot 10 + 5 \cdot j10 + 10 \cdot j10} = -0.06 - j0.02 \text{ C}_M, \\ \underline{Y}_{22} &= \frac{\underline{I}_2^{K31}}{\underline{U}_2^{K31}} = \frac{\underline{I}_2^{K31} (\underline{Z}_1 + \underline{Z}_2)}{\underline{I}_2^{K31} (\underline{Z}_3 \underline{Z}_1 + \underline{Z}_3 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_2)} = \frac{\underline{Z}_1 + \underline{Z}_2}{\underline{Z}_3 \underline{Z}_1 + \underline{Z}_3 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_2} = \\ &= \frac{10 + j10}{5 \cdot 10 + 5 \cdot j10 + 10 \cdot j10} = 0.08 - j0.04 \text{ C}_M.\end{aligned}$$

4. Check: $\underline{Y}_{12} - \underline{Y}_{21} = -0.06 - j0.02 + 0.06 + j0.02 = 0$

5. Calculation of A-parameters of a composite four-pole.

5.1. Diagram of a composite four-pole (Fig. 5.9)

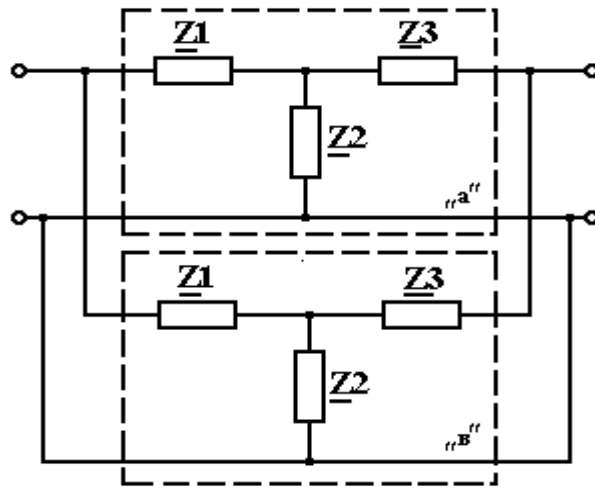


Fig. 5.9

5.2. Matrix of Y-parameters of a composite four-pole $[Y] = [Y_a] + [Y_b]$

Here is $[Y_a]$ – the matrix of Y-parameters of the four-pole "a",

$[Y_b]$ – Matrix of Y-parameters of a four-pole "b"

By problem condition $[Y_a] = [Y_b]$

5.3. Elements of the matrix of a composite four-pole

$$\underline{Y}_{11} = \underline{Y}_{11a} + \underline{Y}_{11b} = 2\underline{Y}_{11a} = 2 \cdot (0.07 - j0.01) = 0.14 - j0.02 \text{ CM},$$

$$\underline{Y}_{12} = \underline{Y}_{12a} + \underline{Y}_{12b} = 2\underline{Y}_{12a} = 2 \cdot (0.06 - j0.02) = -0.12 - j0.04 \text{ CM},$$

$$\underline{Y}_{21} = \underline{Y}_{21a} + \underline{Y}_{21b} = 2\underline{Y}_{21a} = 2(-0.06 - j0.02) = -0.12 - j0.04 \text{ CM},$$

$$\underline{Y}_{22} = \underline{Y}_{22a} + \underline{Y}_{22b} = 2\underline{Y}_{22a} = 2(0.08 - j0.04) = 0.16 - j0.08 \text{ CM}.$$

5.4. The matrix of A-parameters of a composite four-pole can be determined through Y parameters (Table 5.2) [3]

$$[\underline{A}] = \begin{bmatrix} \frac{-\underline{Y}_{22}}{\underline{Y}_{21}} & -1 \\ -\frac{|\underline{Y}|}{\underline{Y}_{21}} & \frac{-\underline{Y}_{11}}{\underline{Y}_{21}} \end{bmatrix}$$

Table 5.2

Defined parameters	Depending on the parameters				
	$\underline{Y}$	$\underline{Z}$	$\underline{H}$	$\underline{F}$	$\underline{A}$

$\underline{\mathbf{Y}}$	$\frac{\underline{Y}_{11} \underline{Y}_{12}}{\underline{Y}_{21} \underline{Y}_{22}}$	$\frac{\underline{Z}_{22} - \underline{Z}_{12}}{ \underline{Z} } \frac{\underline{Z}_{12}}{ \underline{Z} }$ $-\frac{\underline{Z}_{21}}{ \underline{Z} } \frac{\underline{Z}_{11}}{ \underline{Z} }$	$\frac{1}{\underline{H}_{11}} \frac{-\underline{H}_{12}}{\underline{H}_{11}}$ $\frac{\underline{H}_{21}}{\underline{H}_{11}} \frac{ \underline{H} }{\underline{H}_{11}}$	$\frac{ \underline{F} }{\underline{F}_{22}} \frac{\underline{F}_{12}}{\underline{F}_{22}}$ $-\frac{\underline{F}_{21}}{\underline{F}_{22}} \frac{1}{\underline{F}_{22}}$	$\frac{\underline{A}_{22} - \underline{A} }{\underline{A}_{12} \underline{A}_{12}}$ $\frac{-1}{\underline{A}_{12}} \frac{\underline{A}_{11}}{\underline{A}_{12}}$
$\underline{\mathbf{Z}}$	$\frac{\underline{Y}_{22} - \underline{Y}_{12}}{ \underline{Y} } \frac{\underline{Y}_{12}}{ \underline{Y} }$ $-\frac{\underline{Y}_{21}}{ \underline{Y} } \frac{\underline{Y}_{11}}{ \underline{Y} }$	$\underline{Z}_{11} \underline{Z}_{12}$ $\underline{Z}_{21} \underline{Z}_{22}$	$\frac{ \underline{H} }{\underline{H}_{22}} \frac{\underline{H}_{12}}{\underline{H}_{22}}$ $-\frac{\underline{H}_{21}}{\underline{H}_{22}} \frac{1}{\underline{H}_{22}}$	$\frac{1}{\underline{F}_{11}} \frac{-\underline{F}_{12}}{\underline{F}_{11}}$ $\frac{\underline{F}_{21}}{\underline{F}_{11}} \frac{ \underline{F} }{\underline{F}_{11}}$	$\frac{\underline{A}_{11}}{\underline{A}_{21}} \frac{ \underline{A} }{\underline{A}_{21}}$ $\frac{1}{\underline{A}_{21}} \frac{\underline{A}_{22}}{\underline{A}_{21}}$
$\underline{\mathbf{H}}$	$\frac{1}{\underline{Y}_{11}} \frac{-\underline{Y}_{12}}{\underline{Y}_{11}}$ $\frac{\underline{Y}_{21}}{\underline{Y}_{11}} \frac{ \underline{Y} }{\underline{Y}_{11}}$	$\frac{ \underline{Z} }{\underline{Z}_{22}} \frac{\underline{Z}_{12}}{\underline{Z}_{22}}$ $-\frac{\underline{Z}_{21}}{\underline{Z}_{22}} \frac{1}{\underline{Z}_{22}}$	$\underline{H}_{11} \underline{H}_{12}$ $\underline{H}_{21} \underline{H}_{22}$	$\frac{\underline{F}_{22} - \underline{F}_{12}}{ \underline{F} } \frac{\underline{F}_{12}}{ \underline{F} }$ $-\frac{\underline{F}_{21}}{ \underline{F} } \frac{\underline{F}_{11}}{ \underline{F} }$	$\frac{\underline{A}_{12}}{\underline{A}_{22}} \frac{ \underline{A} }{\underline{A}_{22}}$ $\frac{-1}{\underline{A}_{22}} \frac{\underline{A}_{21}}{\underline{A}_{22}}$
$\underline{\mathbf{F}}$	$\frac{ \underline{Y} }{\underline{Y}_{22}} \frac{\underline{Y}_{12}}{\underline{Y}_{22}}$ $-\frac{\underline{Y}_{21}}{\underline{Y}_{22}} \frac{1}{\underline{Y}_{22}}$	$\frac{1}{\underline{Z}_{11}} \frac{-\underline{Z}_{12}}{\underline{Z}_{11}}$ $\frac{\underline{Z}_{21}}{\underline{Z}_{11}} \frac{ \underline{Z} }{\underline{Z}_{11}}$	$\frac{\underline{H}_{22} - \underline{H}_{12}}{ \underline{H} } \frac{\underline{H}_{12}}{ \underline{H} }$ $-\frac{\underline{H}_{22}}{ \underline{H} } \frac{\underline{H}_{11}}{ \underline{H} }$	$\underline{F}_{11} \underline{F}_{12}$ $\underline{F}_{21} \underline{F}_{22}$	$\frac{\underline{A}_{21} - \underline{A} }{\underline{A}_{11} \underline{A}_{11}}$ $\frac{1}{\underline{A}_{11}} \frac{\underline{A}_{12}}{\underline{A}_{11}}$
$\underline{\mathbf{A}}$	$\frac{-\underline{Y}_{22}}{\underline{Y}_{21}} \frac{-1}{\underline{Y}_{21}}$ $\frac{- \underline{Y} }{\underline{Y}_{21}} \frac{-\underline{Y}_{11}}{\underline{Y}_{21}}$	$\frac{\underline{Z}_{11}}{\underline{Z}_{21}} \frac{ \underline{Z} }{\underline{Z}_{21}}$ $\frac{1}{\underline{Z}_{21}} \frac{\underline{Z}_{22}}{\underline{Z}_{21}}$	$\frac{- \underline{H} }{\underline{H}_{21}} \frac{-\underline{H}_{11}}{\underline{H}_{21}}$ $\frac{-\underline{H}_{22}}{\underline{H}_{21}} \frac{-1}{\underline{H}_{21}}$	$\frac{1}{\underline{F}_{21}} \frac{\underline{F}_{22}}{\underline{F}_{21}}$ $\frac{\underline{F}_{11}}{\underline{F}_{21}} \frac{ \underline{F} }{\underline{F}_{21}}$	$\underline{A}_{11} \underline{A}_{12}$ $\underline{A}_{21} \underline{A}_{22}$

In the table $|\underline{Y}| = \underline{Y}_{11}\underline{Y}_{22} - \underline{Y}_{12}\underline{Y}_{21}$, $|\underline{Z}| = \underline{Z}_{11}\underline{Z}_{22} - \underline{Z}_{12}\underline{Z}_{21}$, $|\underline{H}| = \underline{H}_{11}\underline{H}_{22} - \underline{H}_{12}\underline{H}_{21}$,

$$|\underline{F}| = \underline{F}_{11}\underline{F}_{22} - \underline{F}_{12}\underline{F}_{21}, |\underline{A}| = \underline{A}_{11}\underline{A}_{22} - \underline{A}_{12}\underline{A}_{21}$$

5.5. Elements of the matrix $[\underline{\mathbf{A}}]$ of a composite four-pole

$$\underline{A}_{11} = -\frac{\underline{Y}_{22}}{\underline{Y}_{21}} = -\frac{0.16 - j0.08}{-0.2 - j0.04} = 1 - j1,$$

$$\underline{A}_{12} = -\frac{1}{\underline{Y}_{21}} = \frac{-1}{-0.12 - j0.04} = 7.5 - j2.5 \text{ Ом},$$

$$\begin{aligned} \underline{A}_{21} &= -\frac{\underline{Y}_{11}\underline{Y}_{22} - \underline{Y}_{12}\underline{Y}_{21}}{\underline{Y}_{21}} = \\ &= -\frac{(0.14 - j0.02)(0.16 - j0.08) - (0.12 - j0.04)(0.12 - j0.04)}{-0.12 - j0.04} = -j0.2 \text{ См}, \end{aligned}$$

$$\underline{A}_{22} = -\frac{\underline{Y}_{11}}{\underline{Y}_{21}} = -\frac{0.14 - j0.02}{-0.12 - j0.04} = 1 - j0.5.$$

5.6. Verification: $\underline{A}_{11} \underline{A}_{22} - \underline{A}_{21} \cdot \underline{A}_{12} = (1 - j1)(1 - j0.5) - (-j0.2)(7.5 - j2.5) = 1$

Task No 3. Two identical four-poles (Fig. 5.3) (Table 5.1. Option No 0) are connected in series. Calculate the $\underline{Z}$ -and $\underline{A}$ -parameters of a composite four-pole.

Solution

1. A system of equations of a four-pole in the form of $\underline{Z}$

$$\underline{U}_1 = \underline{Z}_{11} \underline{I}_1 + \underline{Z}_{12} \underline{I}_2$$

$$\underline{U}_2 = \underline{Z}_{21} \underline{I}_1 + \underline{Z}_{22} \underline{I}_2$$

2. Calculation of primary parameters at $\underline{I}_1 = 0$ (idle mode relative to input clamps).

2.1. Four-pole diagram (Fig. 5.10)

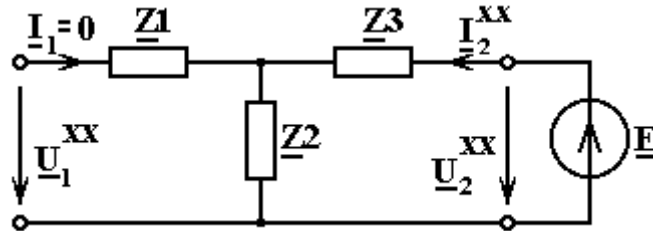


Fig.5.10

2.2. System of equations for the mode under consideration

$$\underline{U}_1^{xx} = \underline{Z}_{12} \underline{I}_2^{xx}$$

$$\underline{U}_2^{xx} = \underline{Z}_{22} \underline{I}_2^{xx}$$

2.3. Currents and voltages in the circuit (Fig. 5.10)

$$\underline{U}_2^{xx} = \underline{I}_2^{xx} (\underline{Z}_3 + \underline{Z}_2)$$

$$\underline{U}_2^{xx} = \underline{Z}_2 \underline{I}_2^{xx}$$

2.4. Primary Parameters $\underline{Z}_{12}, \underline{Z}_{22}$

$$\underline{Z}_{12} = \frac{\underline{U}_1^{xx}}{\underline{I}_2^{xx}} = \frac{\underline{I}_2^{xx} \underline{Z}_2}{\underline{I}_2^{xx}} = \underline{Z}_2 = j10 \text{ OM},$$

$$\underline{Z}_{22} = \frac{\underline{U}_2^{xx}}{\underline{I}_2^{xx}} = \frac{\underline{I}_2^{xx} (\underline{Z}_3 + \underline{Z}_2)}{\underline{I}_2^{xx}} = \underline{Z}_3 + \underline{Z}_2 = 5 + j10 \text{ OM}.$$

3. Calculation of primary parameters at $\underline{I}_2=0$ (idle mode relative to output clamps).

3.1. Calculation diagram of a four-pole (Fig. 5.11)

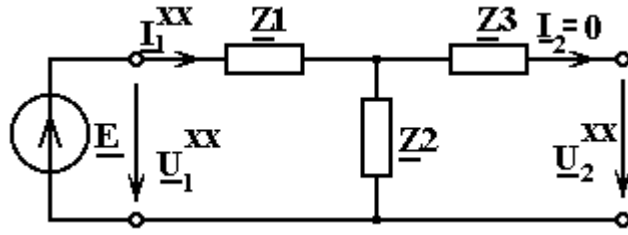


Fig. 5.11

3.2. System of four-pole equations for the mode under consideration

$$\underline{U}_1^{xx} = \underline{Z}_{11} \underline{I}_1^{xx}$$

$$\underline{U}_2^{xx} = \underline{Z}_{21} \underline{I}_1^{xx}$$

3.3. System of four-pole equations for the mode under consideration

$$\underline{U}_1^{xx} = (\underline{Z}_1 + \underline{Z}_2) \underline{I}_1^{xx}$$

$$\underline{U}_2^{xx} = \underline{I}_1^{xx} \cdot \underline{Z}_2$$

3.4. Primary Parameters $\underline{Z}_{11}$ и $\underline{Z}_{21}$:

$$\underline{Z}_{11} = \frac{\underline{U}_1^{xx}}{\underline{I}_1^{xx}} = \frac{\underline{I}_1^{xx} (\underline{Z}_1 + \underline{Z}_2)}{\underline{I}_1^{xx}} = \underline{Z}_1 + \underline{Z}_2 = 10 + j10 \text{ Ом},$$

$$\underline{Z}_{21} = \frac{\underline{U}_2^{xx}}{\underline{I}_1^{xx}} = \frac{\underline{I}_1^{xx} \underline{Z}_2}{\underline{I}_1^{xx}} = \underline{Z}_2 = j10 \text{ Ом}.$$

4. Check: $\underline{Z}_{12} - \underline{Z}_{21} = j10 - j10 = 0$

5. Calculation of A-parameters of a composite four-pole.

5.1. Diagram of a composite four-pole (serial connection, taking into account the regularity of connections) (Fig. 5.12).

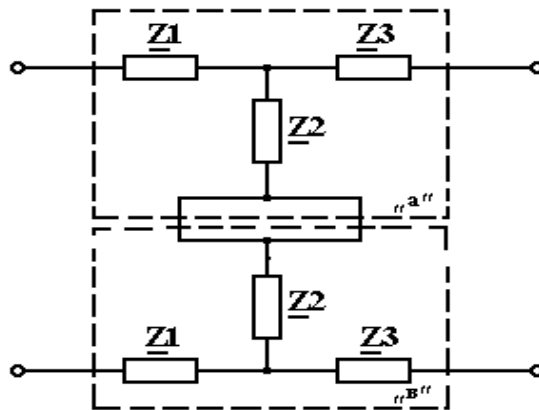


Fig. 5.12

5.2. Matrix of $\underline{Z}$ -parameters of a composite four-pole $[\underline{Z}] = [\underline{Z}_a] + [\underline{Z}_B]$

Here is $[\underline{Z}_a]$ – the matrix of the z-parameters of the four-pole "a",

$[\underline{Z}_B]$ – Z-parameter matrix of the four-pole "B".

According to the condition of the problem $[Z_a] = [Z_b]$.

5.3. Elements of the matrix of a composite four-pole

$$\underline{Z}_{11} = \underline{Z}_{11a} + \underline{Z}_{11b} = 2\underline{Z}_{11a} = 2 \cdot (10 + j10) = 20 + j20 \text{ Ом},$$

$$\underline{Z}_{12} = \underline{Z}_{12a} + \underline{Z}_{12b} = 2\underline{Z}_{12a} = 2(j10) = j20 \text{ Ом},$$

$$\underline{Z}_{21} = \underline{Z}_{21a} + \underline{Z}_{21b} = 2(j10) = j20 \text{ Ом},$$

$$\underline{Z}_{22} = \underline{Z}_{22a} + \underline{Z}_{22b} = 2\underline{Z}_{22a} = 2(5 + j10) = 10 + j20 \text{ Ом}.$$

5.4. The matrix of A-parameters of a composite four-pole can be determined through Z-parameters (Table 5.2) [3].

$$[\underline{A}] = \begin{bmatrix} \frac{\underline{Z}_{11}}{\underline{Z}_{21}} & \frac{|\underline{Z}|}{\underline{Z}_{21}} \\ 1 & \frac{\underline{Z}_{22}}{\underline{Z}_{21}} \end{bmatrix}$$

5.5. Elements of the matrix $[\underline{A}]$ of a composite fourpole

$$\underline{A}_{11} = \frac{\underline{Z}_{11}}{\underline{Z}_{21}} = \frac{20 + j20}{j20} = 1 - j1,$$

$$\underline{A}_{12} = \frac{|\underline{Z}|}{\underline{Z}_{21}} = \frac{\underline{Z}_{11} \cdot \underline{Z}_{22} - \underline{Z}_{12} \cdot \underline{Z}_{21}}{\underline{Z}_{21}} = \frac{(20 + j20) \cdot (10 + j20) - j20 \cdot j20}{j20} = 30 - j10 \text{ Ом},$$

$$\underline{A}_{21} = \frac{1}{\underline{Z}_{21}} = \frac{1}{j20} = -j0.05 \text{ См},$$

$$\underline{A}_{22} = \frac{\underline{Z}_{22}}{\underline{Z}_{21}} = \frac{10 + j20}{j20} = 1 - j0.5.$$

5.6. Verification: $\underline{A}_{11} \cdot \underline{A}_{22} - \underline{A}_{21} \cdot \underline{A}_{12} = (1 - j1) \cdot (1 - j0.5) - (j0.05) \cdot (30 - j10) = 1$

Task No 4. Two identical four-poles (Fig. 5.3) (Table 5.1, option No 0) are connected in series-parallel. Calculate the H- and A-parameters of a composite four-pole.

Solution

1. A system of equations of a four-pole in the form H:

$$\underline{U}_1 = \underline{H}_{11} \underline{I}_1 + \underline{H}_{12} \underline{U}_2$$

$$\underline{I}_2 = \underline{H}_{21} \underline{I}_1 + \underline{H}_{22} \underline{U}_2$$

2. Calculation of H-parameters at $\underline{I}_1 = 0$ (idle mode relative to input clamps).

2.1. Calculation diagram of a four-pole (Fig. 5.13)

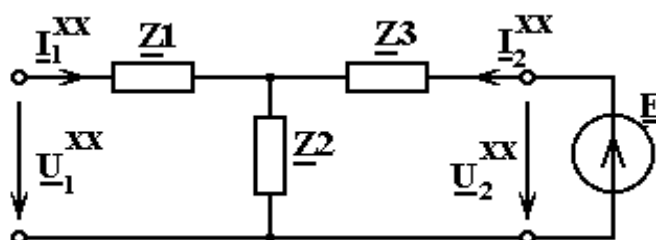


Fig. 5.13

2.2. System of four-pole equations for the mode under consideration

$$\begin{aligned}\underline{U}_1^{xx} &= \underline{H}_{12} \cdot \underline{U}_2^{xx} \\ \underline{I}_2^{xx} &= \underline{H}_{22} \underline{U}_2^{xx}\end{aligned}$$

2.3. Stresses in the circuit (Fig. 5.13). $\underline{U}_2^{xx} = \underline{I}_2^{xx} (\underline{Z}_3 + \underline{Z}_2)$, $\underline{U}_1^{xx} = \underline{I}_2^{xx} \cdot \underline{Z}_2$

2.4. Primary Parameters $\underline{H}_{12}, \underline{H}_{22}$

$$\begin{aligned}\underline{H}_{12} &= \frac{\underline{U}_1^{xx}}{\underline{U}_2^{xx}} = \frac{\underline{I}_2^{xx} \cdot \underline{Z}_2}{\underline{I}_2^{xx} (\underline{Z}_3 + \underline{Z}_2)} = \frac{\underline{Z}_2}{\underline{Z}_3 + \underline{Z}_2} = \frac{j10}{5 + j10} = 0.8 + j0.4, \\ \underline{H}_{22} &= \frac{\underline{I}_2^{xx}}{\underline{U}_2^{xx}} = \frac{\underline{I}_2^{xx}}{\underline{I}_2^{xx} (\underline{Z}_3 + \underline{Z}_2)} = \frac{1}{\underline{Z}_3 + \underline{Z}_2} = \frac{1}{5 + j10} = 0.04 - j0.08 \text{ CM}.\end{aligned}$$

3. Calculation of H parameters at $\underline{U}_2 = 0$ (short-circuit mode relative to output clamps).

3.1. Calculation diagram of a four-pole (Fig. 5.14)

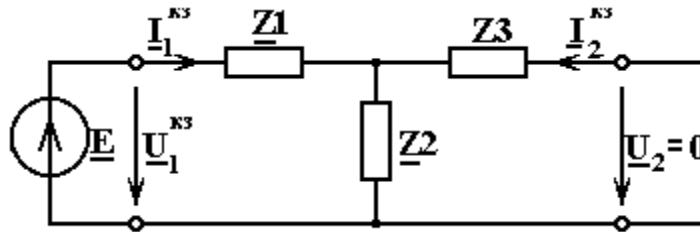


Fig. 5.14

3.2. System of four-pole equations for the mode under consideration

$$\begin{aligned}\underline{U}_1^{K3} &= \underline{H}_{11} \underline{I}_1^{K3} \\ \underline{I}_2^{K3} &= \underline{H}_{21} \underline{I}_1^{K3}\end{aligned}$$

3.3. Currents and voltages in the circuit taking into account the selected conditional positive directions

$$\begin{aligned}\underline{U}_1^{K3} &= \underline{I}_1^{K3} (\underline{Z}_1 + \frac{\underline{Z}_2 \cdot \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3}) = \underline{I}_1^{K3} (\frac{\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3}), \\ -\underline{I}_2^{K3} &= \underline{I}_1^{K3} \cdot \frac{\underline{Z}_2}{\underline{Z}_2 + \underline{Z}_3}.\end{aligned}$$

3.4. Primary Parameters $\underline{H}_{11}, \underline{H}_{21}$

$$\begin{aligned}\underline{H}_{11} &= \frac{\underline{U}_1^{K3}}{\underline{I}_1^{K3}} = \frac{\underline{Z}_1 \underline{Z}_2 + \underline{Z}_1 \underline{Z}_3 + \underline{Z}_2 \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3} = \frac{10 \cdot j10 + 10 \cdot 5 + j10 \cdot 5}{j10 + 5} = 14 + j2 \text{ OM}, \\ \underline{H}_{21} &= \frac{\underline{I}_2^{K3}}{\underline{I}_1^{K3}} = -\frac{\underline{Z}_2}{\underline{Z}_2 + \underline{Z}_3} = -\frac{j10}{j10 + 5} = -0.8 - j0.4.\end{aligned}$$

4. Check: $\underline{H}_{12} + \underline{H}_{21} = 0.8 + j0.4 - 0.8 - j0.4 = 0$

5. Calculation of A-parameters of a composite four-pole.

5.1. Diagram of a composite four-pole (series-parallel connection taking into account the regularity of connections) (Fig. 5.15).

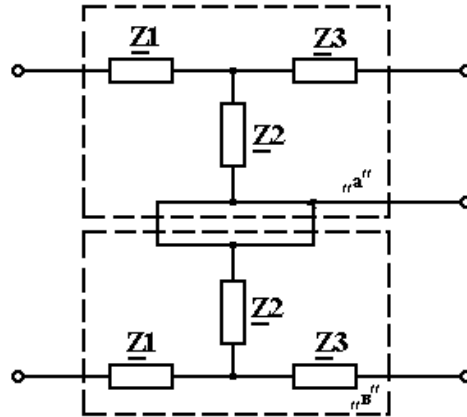


Fig.5.15

5.2. Matrix of H-parameters of a composite four-pole $[\underline{H}] = [\underline{H}_a] + [\underline{H}_b]$

Here $[\underline{H}_a]$ is the matrix of H-parameters of the four-pole "a",

$[\underline{H}_b]$ is the matrix of H-parameters of the four-pole "c".

By problem condition $[\underline{H}_a] = [\underline{H}_b]$.

5.3. Elements of the matrix $[\underline{H}]$ of a composite fourpole

$$\underline{H}_{11} = \underline{H}_{11a} + \underline{H}_{11b} = 2 \cdot \underline{H}_{11a} = 2(14 + j2) = 28 + j4 \text{ Ом},$$

$$\underline{H}_{12} = \underline{H}_{12a} + \underline{H}_{12b} = 2 \cdot \underline{H}_{12a} = 2(0.8 + j0.4) = 1.6 + j0.8,$$

$$\underline{H}_{21} = \underline{H}_{21a} + \underline{H}_{21b} = 2 \cdot \underline{H}_{21a} = 2(-0.8 - j0.4) = -1.6 - j0.8,$$

$$\underline{H}_{22} = \underline{H}_{22a} + \underline{H}_{22b} = 2 \cdot \underline{H}_{22a} = 2(0.04 - j0.08) = 0.08 - j0.16 \text{ См}.$$

5.4. The matrix $\underline{A}$ of -parameters of a composite four-pole can be determined by the known $\underline{H}$ -parameters (Table 5.2) [3]

$$[\underline{A}] = \begin{bmatrix} \frac{-[\underline{H}]}{\underline{H}_{21}} & \frac{-\underline{H}_{11}}{\underline{H}_{21}} \\ \frac{-\underline{H}_{22}}{\underline{H}_{21}} & \frac{-1}{\underline{H}_{21}} \end{bmatrix}$$

5.5. Elements of the matrix [A] - a composite four-pole

$$\underline{A}_{11} = -\frac{|\underline{H}|}{\underline{H}_{21}} = -\frac{\underline{H}_{11}\underline{H}_{22} - \underline{H}_{21}\underline{H}_{12}}{\underline{H}_{21}} = -\frac{(28 + j4)(0.08 - j0.16) - (-1.6 - j0.8)(1.6 + j0.8)}{-1.6 - j0.8} = 2 - j2,$$

$$\underline{A}_{12} = -\frac{\underline{H}_{11}}{\underline{H}_{21}} = -\frac{28 + j4}{-1.6 - j0.8} = 15 - j5 \text{ OM},$$

$$\underline{A}_{21} = -\frac{\underline{H}_{22}}{\underline{H}_{21}} = -\frac{0.08 - j0.16}{-1.6 - j0.8} = -j0.1 \text{ CM},$$

$$\underline{A}_{22} = -\frac{1}{\underline{H}_{21}} = -\frac{1}{-1.6 - j0.8} = 0.5 - j0.25.$$

$$5.6. \text{ Verification: } \underline{A}_{11}\underline{A}_{22} - \underline{A}_{21}\underline{A}_{12} = (2 - j2)(0.5 - j0.25) - (-j0.1)(15 - j5) = 1$$

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MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION
FEDERAL STATE AUTONOMOUS EDUCATIONAL INSTITUTION OF HIGHER
EDUCATION
"NORTH CAUCASUS FEDERAL UNIVERSITY"

Suggestions for Teaching

on the implementation of the term paper
on the discipline "Theory of Electrical and Radio Engineering Circuits"
for students of the field of study / specialty
11.03.02 Infocommunication Technologies and Communication Systems
Profile
"Intelligent Data Processing in Infocommunication
Systems and Networks"

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1 Electrical Circuit Analysis Jobs and Inputs

1.1 Single-phase sine current electrical circuits

Goal:

To calculate currents in branches and voltages on the elements of a given complex linear electric circuit of sinusoidal current using the method of contour currents, the method of nodal potentials, the method of superposition, the method of an equivalent generator. To construct vector and time diagrams of the calculated currents and voltages.

Task 1.1 Calculate instantaneous currents in branches and voltages on the elements of a given linear electric circuit using the contour current method (Table 1). Check the performance of the power balance. Construct vector and time diagrams of the calculated currents and voltages.

Task 1.2 Calculate the complex currents in the branches and voltages on the elements of a given linear electrical circuit using the nodal potential method (Table 1). Check the performance of the power balance.

Task 1.3 Calculate complex currents in branches and voltages on the elements of a given linear electric circuit using the superposition method.

Task 1.4 Calculate complex currents in branches and voltages on the elements of a given linear electrical circuit using an equivalent voltage generator and an equivalent current generator.

The numerical initial data and the scheme of the given variant are determined by a given cipher consisting of 6 digits: AB VG DE,

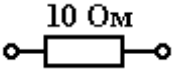
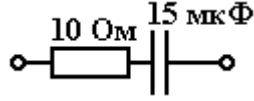
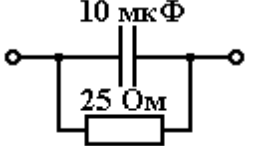
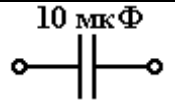
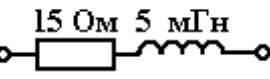
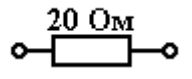
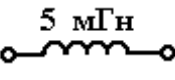
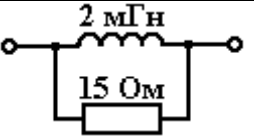
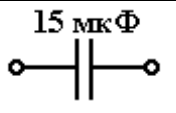
where AB is the number of the drawing of the electrical circuit diagram;

VG - initial data from Table 1;

DE - scheme and parameters of branch resistances from Tables 1 and 2

Table 1- Initial data of energy sources and numbers of element diagrams											
Initial data of energy sources								Z Blueprint Numbers			
№	f, kHz	Em1,B	Ψe1,°	Em2,B	Ψe2,°	Jm, A	Ψ _i ,°	№	Z1	Z2	Z3
01	1.1	10	0	15	30	1.0	0	01	0	1	4
02	1.3	40	30	22	0	0.8	60	02	7	2	6
03	1.5	24	0	40	45	1.4	30	03	2	8	4
04	1.7	36	0	30	0	0.4	30	04	2	0	6
05	1.9	36	45	24	60	1.5	0	05	2	7	3
06	1.2	20	30	46	90	0.6	0	06	7	1	4
07	1.4	24	0	14	30	1.6	45	07	0	2	3
08	1.6	14	60	28	0	1.2	30	08	2	1	3
09	1.8	36	60	30	30	1.3	0	09	2	8	6
10	1.1	30	0	38	45	1.4	60	10	5	0	1
11	1.3	24	30	26	30	1.7	0	11	7	8	5
12	1.2	10	30	42	0	1.0	30	12	4	0	1
13	1.4	15	45	12	90	1.1	0	13	0	8	4
14	1.6	18	90	46	0	0.5	45	14	3	0	2
15	1.5	14	30	24	60	0.9	0	15	2	1	3
16	1.7	28	60	15	0	0.6	45	16	7	2	6
17	1.9	18	0	40	30	1.5	0	17	3	0	2
18	1.8	20	45	26	45	1.7	0	18	0	2	3
19	1.1	30	30	42	0	0.7	90	19	5	1	0
20	1.3	34	60	28	45	1.8	30	20	3	2	0
21	1.5	30	0	48	60	1.1	60	21	1	2	5
22	1.2	22	30	30	0	0.6	0	22	8	0	5
23	1.4	16	0	35	45	2.0	30	23	4	1	2
24	1.6	20	0	14	0	1.2	60	24	6	2	1
25	1.7	32	60	42	30	1.6	0	25	1	0	4
26	1.9	12	0	40	60	0.8	0	26	8	2	3
27	1.8	22	45	15	0	1.4	45	27	2	7	3
28	1.9	32	60	26	0	0.7	30	28	2	0	6
29	1.8	15	90	12	30	0.5	0	29	1	7	4
30	1.7	16	0	22	45	1.3	60	30	5	1	7
31	1.6	22	30	46	0	1.0	90	31	6	7	2
32	1.5	32	45	24	90	1.6	0	32	8	7	4
33	1.4	10	0	28	45	0.6	0	33	4	1	2
34	1.3	30	0	48	60	0.9	30	34	3	2	7
35	1.2	28	60	20	0	1.7	30	35	6	7	2
36	1.1	30	45	35	0	0.8	30	36	1	2	5
37	1.9	34	90	14	45	1.2	0	37	4	2	8
38	1.2	12	30	38	30	1.5	0	38	6	7	8
39	1.8	28	0	22	60	0.7	60	39	8	2	6

40	1.3	18	45	50	0	1.1	30	40	5	7	8
----	-----	----	----	----	---	-----	----	----	---	---	---

Table 2- Diagrams and parameters of passive circuit elements											
Z	Scheme and parameters		Z	Scheme and parameters		Z	Scheme and parameters				
0			3			6					
1			4			7					
2			5			8					

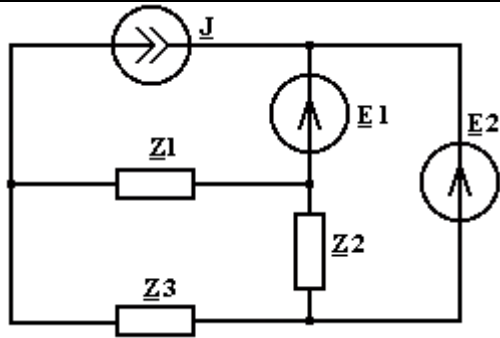


Figure 01

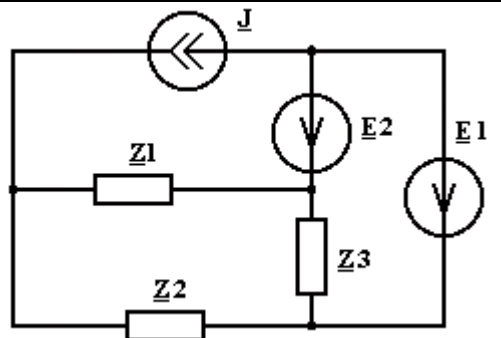


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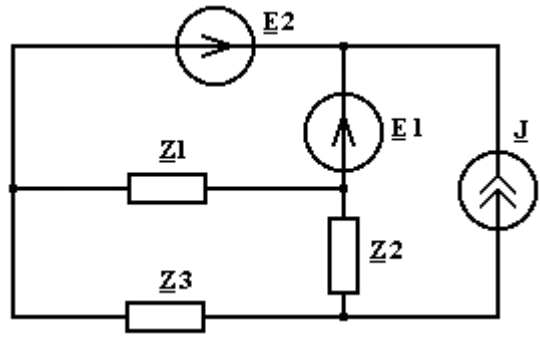


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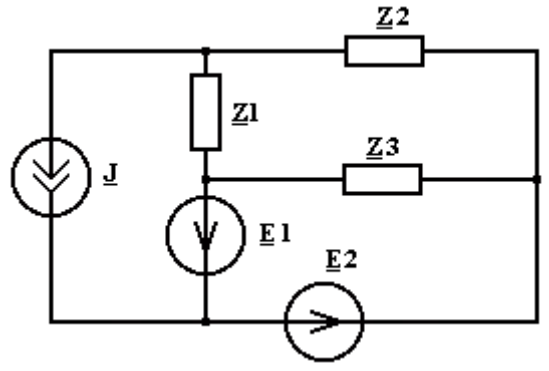


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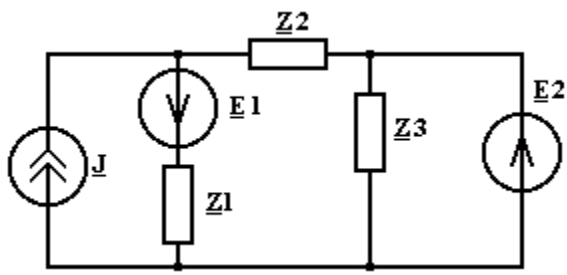


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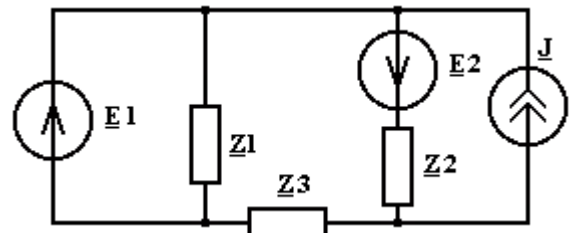


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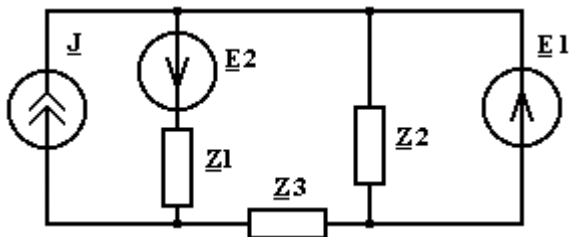


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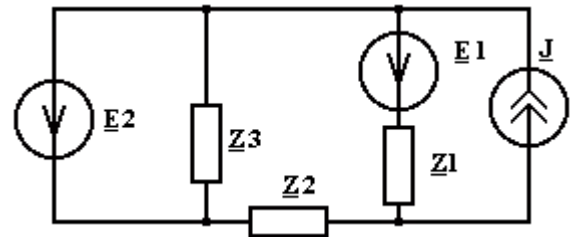


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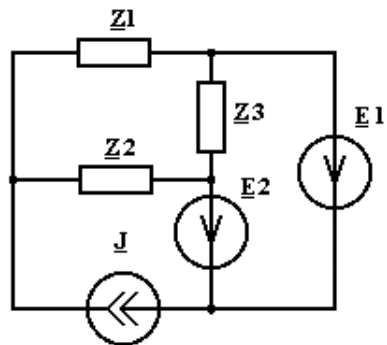


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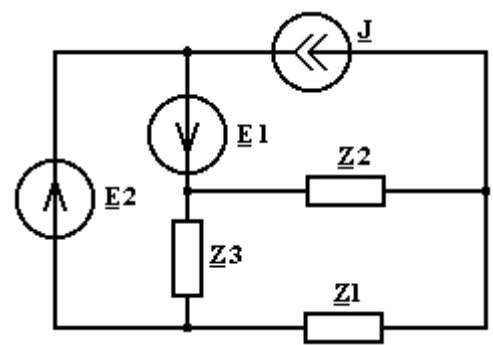


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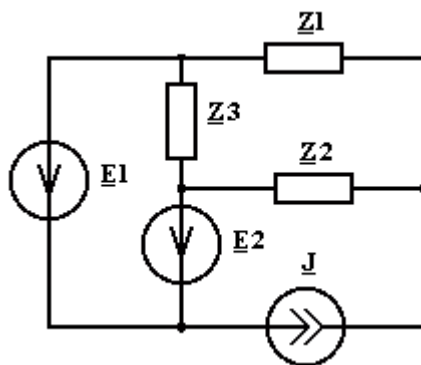


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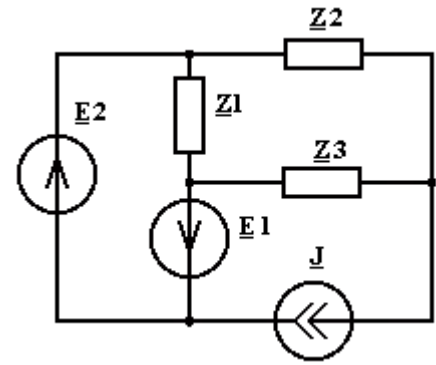


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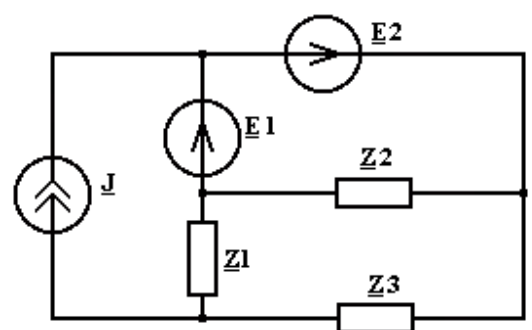
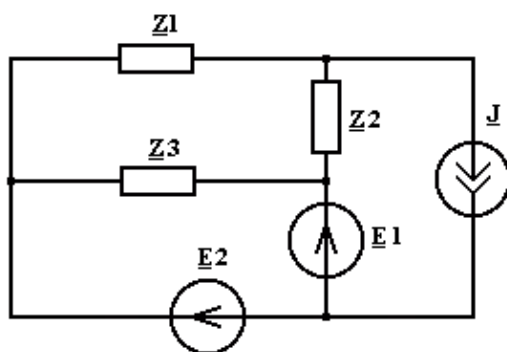


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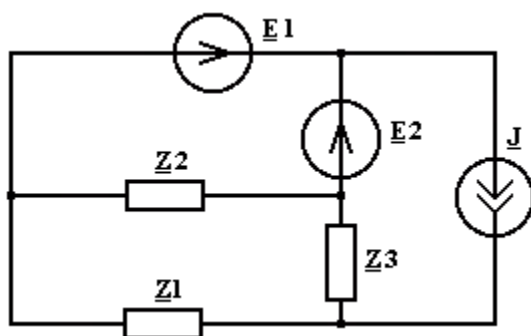


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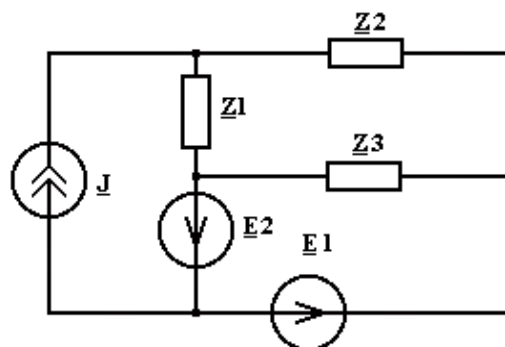


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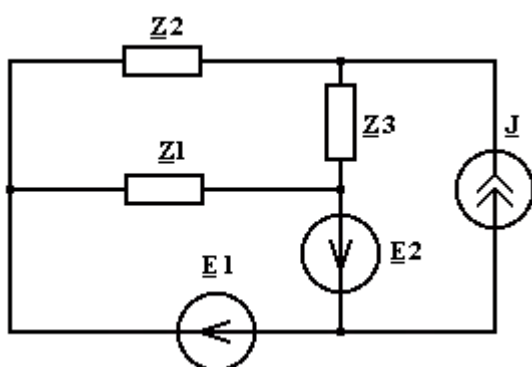


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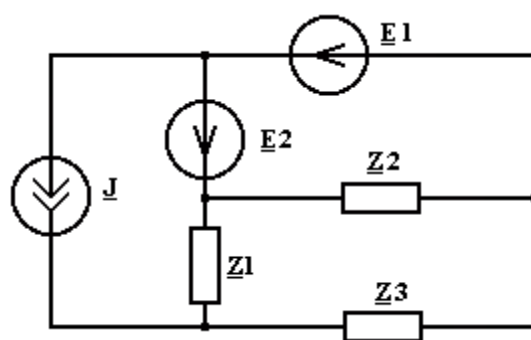


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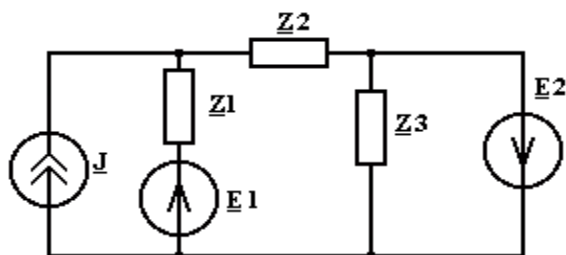


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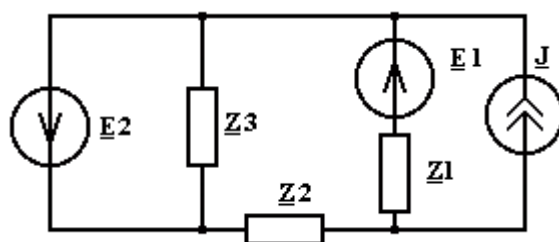


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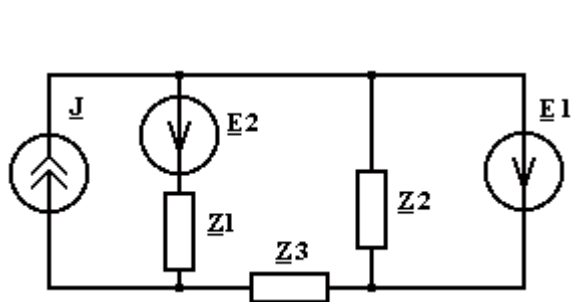


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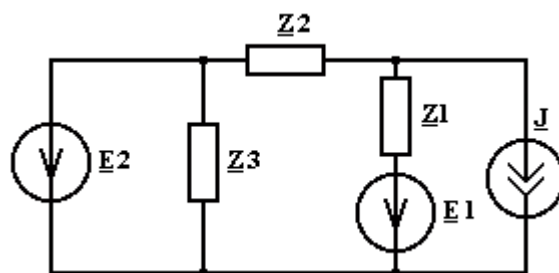
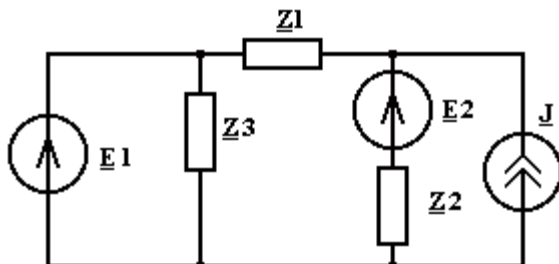


Figure 21

Figure 22



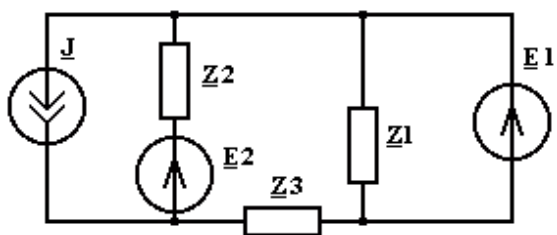


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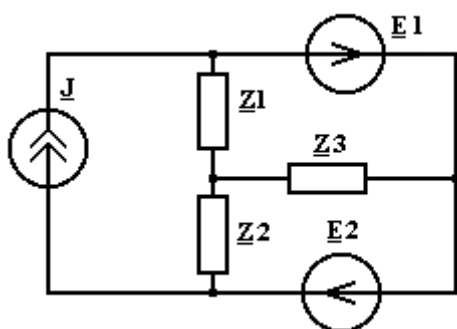


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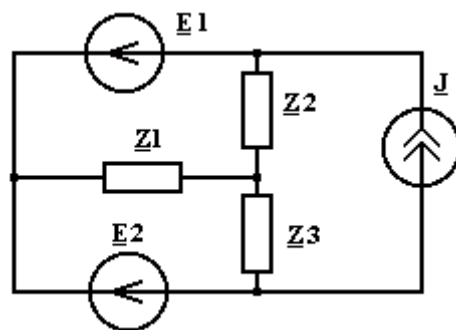


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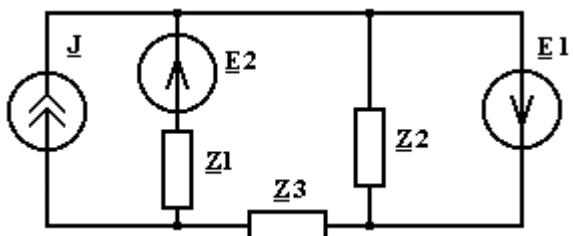


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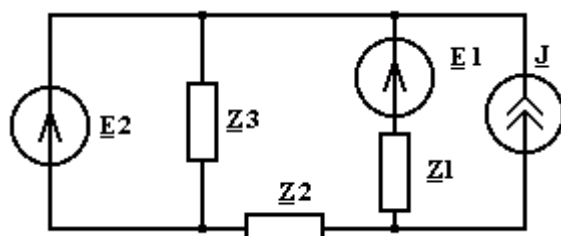


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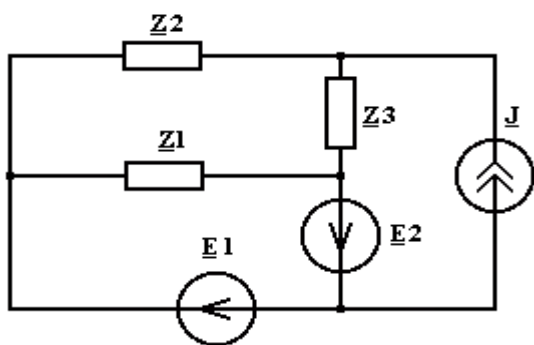


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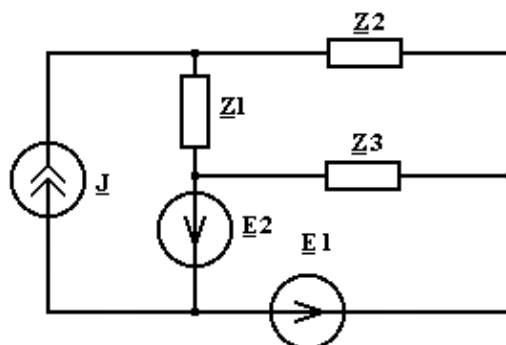


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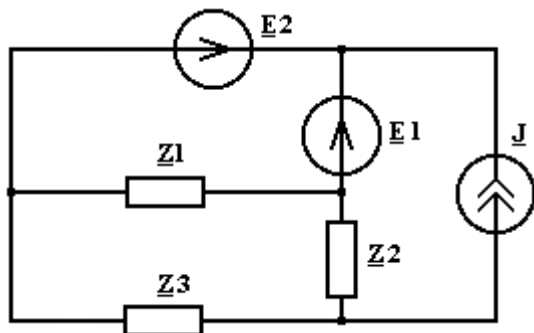


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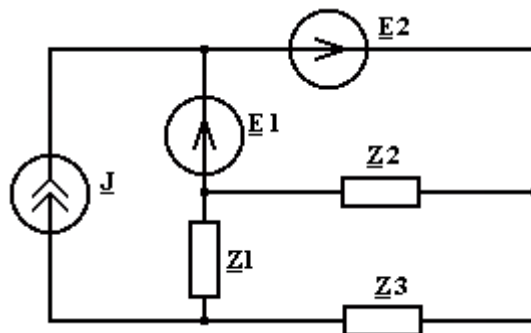


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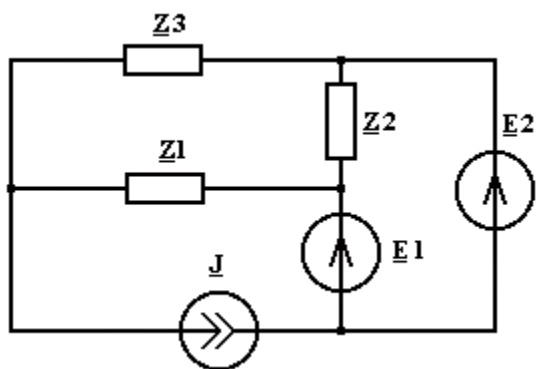


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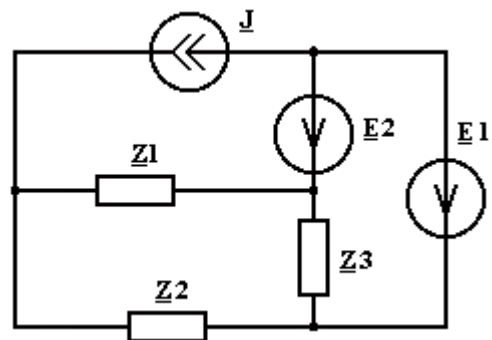


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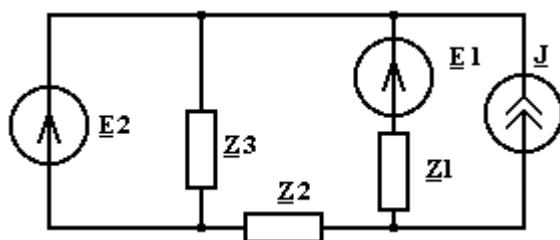


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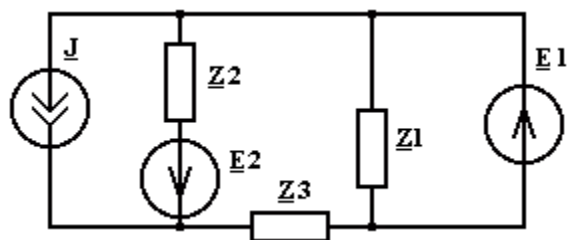


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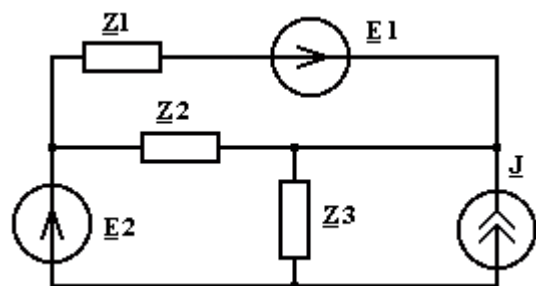


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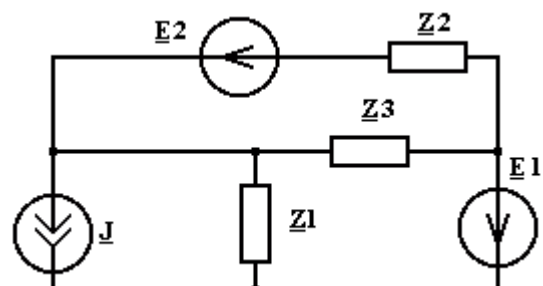


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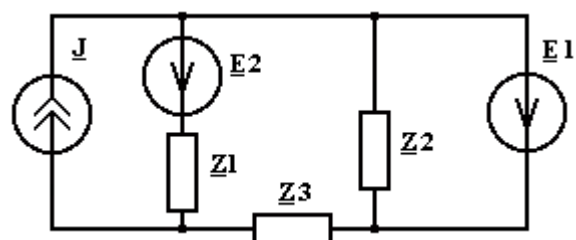


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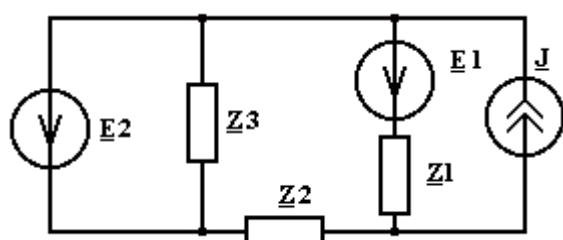


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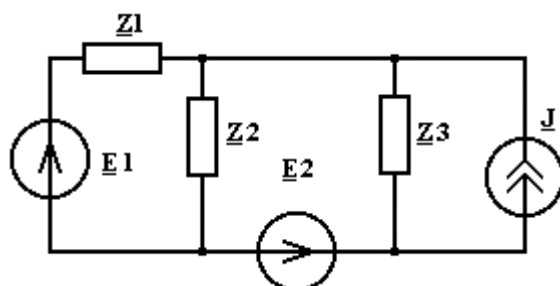


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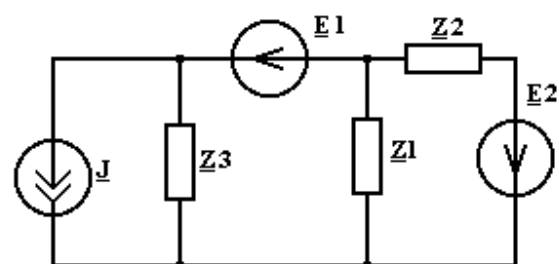


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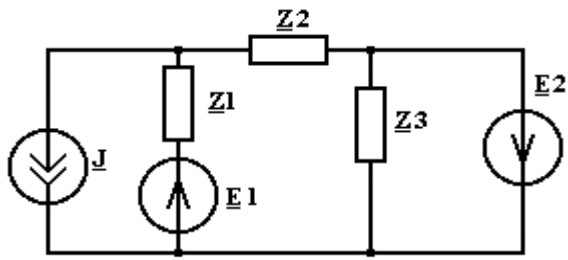


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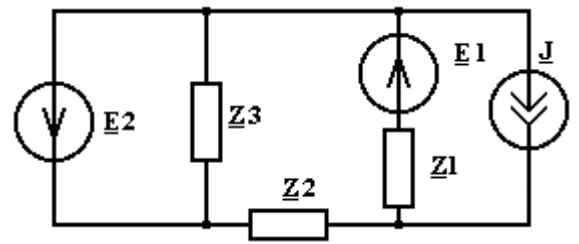


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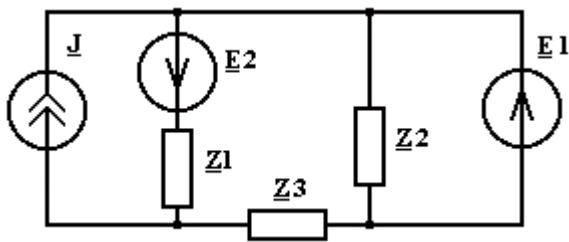


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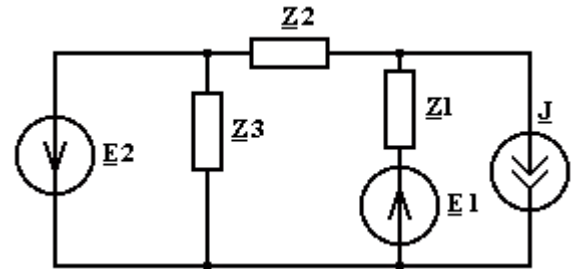


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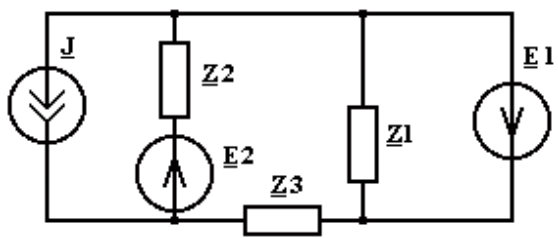


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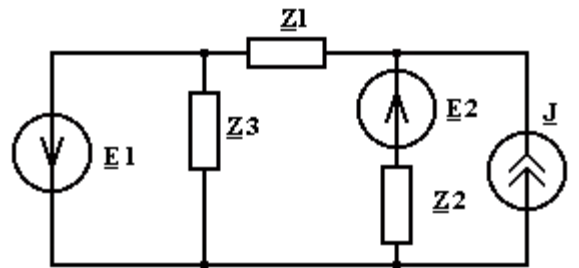


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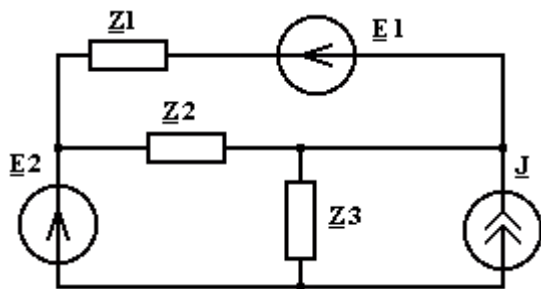


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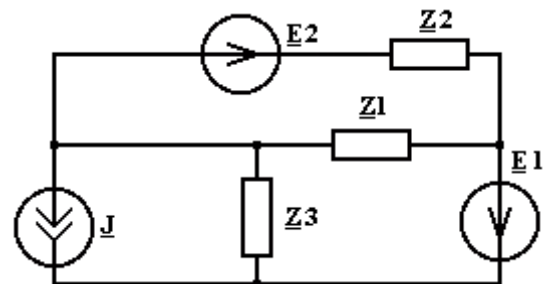


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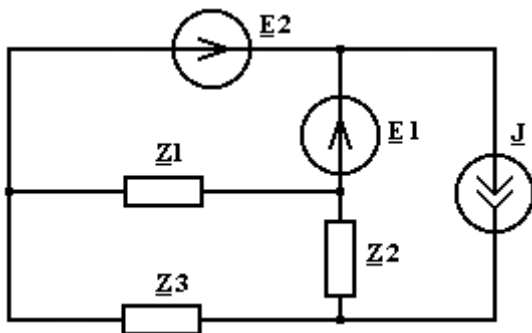


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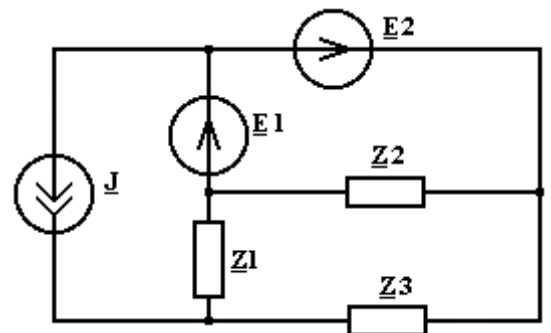


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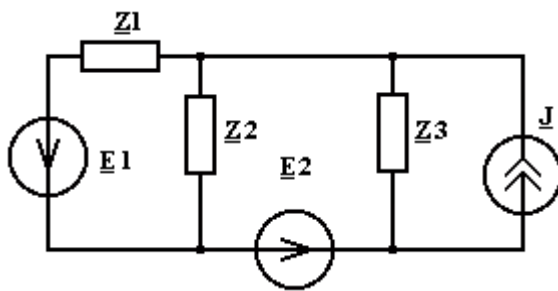


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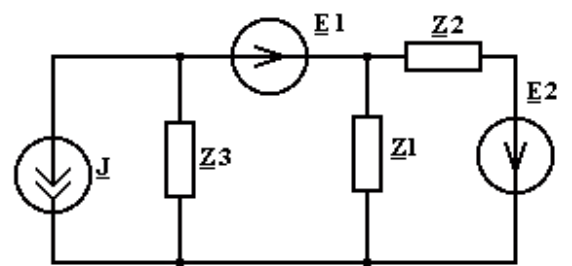


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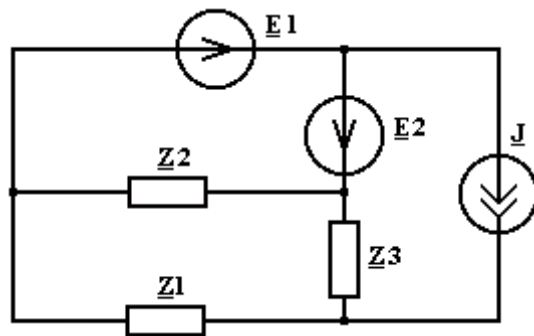


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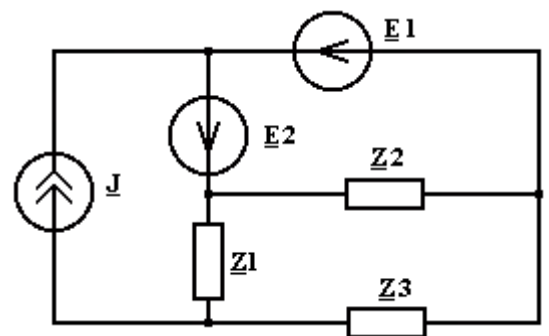


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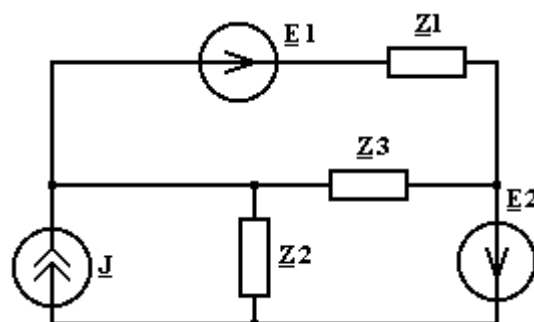


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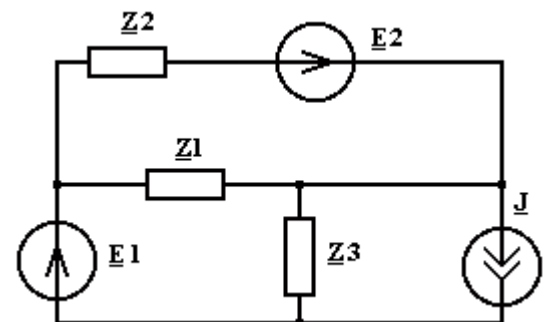


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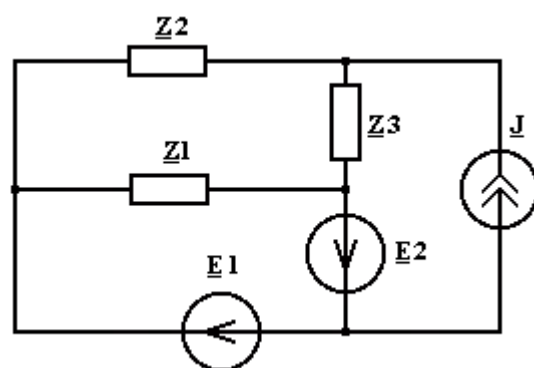


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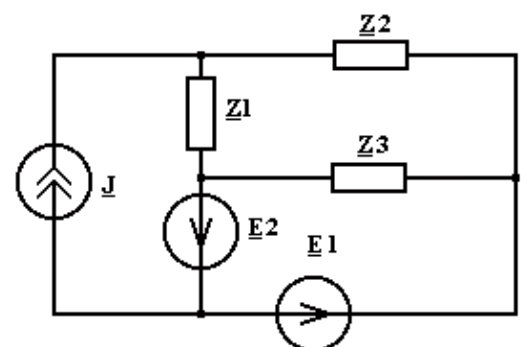


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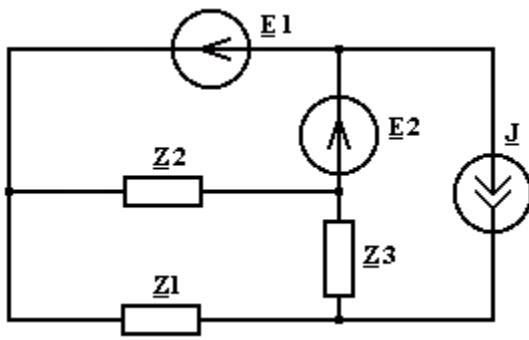


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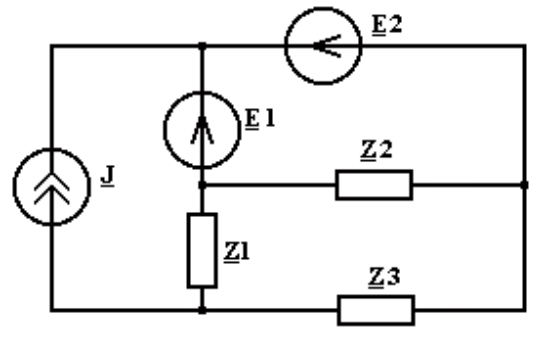


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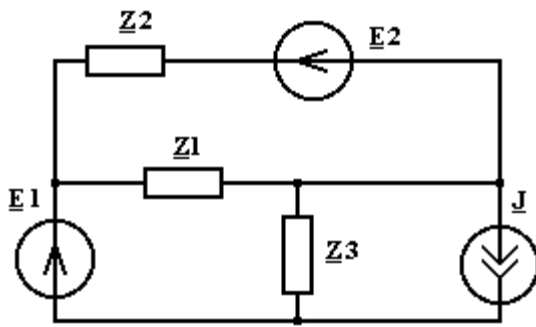


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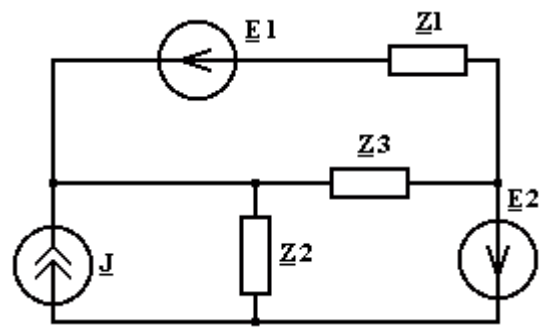


Figure 64

1.2 Three-phase electrical circuits

Goal:

1. Calculate currents, voltages and power in a three-phase circuit with an unbalanced receiver, the phases of which are connected by a star. Perform calculations of currents when a neutral wire is broken. Build vector diagrams of currents and voltages.

2. Calculate currents, voltages and power in a three-phase circuit with an unbalanced receiver, the phases of which are connected by a triangle. Perform calculations of currents when one of the line wires is broken. Build vector diagrams of currents and voltages.

Task 2.1 An asymmetrical receiver is connected to a symmetrical three-phase line with a voltage of L (Table 3), the phases of which are connected by a star to a neutral wire. Complex resistances of the phases of the receiver Z_a, Z_b, Z_c are given according to the variant (Table 3). Calculate the currents in the phases of the receiver, in the line wires and in the neutral wire. Construct vector diagrams of currents and voltages. Calculate the power consumed by the three-phase receiver.

Task 2.2 A symmetrical three-phase line with a voltage of L (Table 3) is connected to an asymmetrical receiver, the phases of which are connected by a star without a neutral wire. Complex resistances of the receiver phases Z_a, Z_b, Z_c are given according to the variant (Table 3). Calculate the currents in the phases of the receiver and in the line wires. Calculate the currents in the phases of the receiver and in the line wires in case of a short circuit of one of the phases of the receiver. Construct vector diagrams of currents and voltages. Calculate the power consumed by a three-phase receiver.

Task 2.3 A symmetrical three-phase line with a voltage L (Table 3) is connected to an asymmetrical receiver, the phases of which are connected by a triangle. Complex resistances of the receiver phases Z_a, Z_b, Z_c are given according to the variant (Table 3). Calculate the currents in the phases of the receiver, in the line wires. Calculate the currents in the phases of the receiver, in the line wires in

case of a break in one of the line wires (Table 3). Construct vector diagrams of currents and voltages. Calculate the power consumed by the three-phase receiver.

Table 3 - Initial data for the design of three-phase circuits

Option No	U _I , V	$\underline{Z}_a, \Omega$	$\underline{Z}_b, \Omega$	$\underline{Z}_c, \Omega$	Option No	Short Circuit Phase	Option No	Broken line wire
0	220	10	-j20	j30	0	a	0	A
1	360	j10	15	-j20	1	in	1	In
2	120	10-j10	j15	20	2	c	2	S
3	150	20	20-j60	40+j30	3	a	3	A
4	170	j60	10+j2	20-j40	4	in	4	In
5	225	15-j20	10	-j25	5	c	5	S
6	300	20+j50	24-j50	10+j10	6	a	6	A
7	100	20	j25	-j10	7	in	7	In
8	110	25-j60	30+j9	45-j50	8	c	8	S
9	125	150	j80	-j40	9	a	9	A
10	220	-j25	20	45+j40	10	in	10	In
11	360	10+j30	15-j35	20+j80	11	c	11	S
12	120	20+j50	24-j50	10+j10	12	a	12	A
13	150	10	-j20	j30	13	in	13	In
14	170	j10	15	-j20	14	c	14	S
15	225	10-j10	j15	20	15	a	15	A
16	300	20-j25	30-j60	30+j30	16	in	16	In
17	100	15-j90	j10	-j25	17	c	17	S
18	110	20+j80	29-j50	60+j10	18	a	18	A
19	125	j20	-j25	12-j10	19	in	19	In
20	220	25-j60	8+j40	45-j50	20	c	20	S
21	360	10-j50	j80	-j40	21	a	21	A

22	120	30-j25	20	45-j40	22	in	22	In
23	150	80+j30	15-j35	40+j80	23	c	23	S
24	170	10+j70	15-j20	80+j30	24	a	24	A
25	225	-j10	15+j8	-j20	25	in	25	In
26	300	10-j10	j15	20-j20	26	c	26	S
27	100	20+j7	20-j60	20+j30	27	a	27	A
28	110	90+j60	10+j2	20-j40	28	in	28	In
29	125	50-j20	10+j8	-j25	29	c	29	S
30	220	20+j30	20-j50	20+j10	30	a	30	A
31	360	20-j45	j25	10-j10	31	in	31	In
32	120	25-j60	30+j6	35-j50	32	c	32	S
33	150	15-j60	j80	50-j40	33	a	33	A
34	170	-j25	20+j8	45+j40	34	in	34	In
35	225	10+j40	15-j35	20+j80	35	c	35	S
36	300	10+j60	8-j20	j30	36	a	36	A
37	100	25-j10	15+j5	40-j20	37	in	37	In
38	110	10-j10	8+j15	20-j6	38	c	38	S
39	125	20	20-j60	40+j30	39	a	39	A
40	220	j60	10+j7	20-j40	40	in	40	In

1.3 Transients in linear electrical circuits

Goal:

1. Use the classical method to calculate the transient currents and voltages in the linear electrical circuit specified according to the variant (Table 4). Construct temporal diagrams of transient currents and voltages.
2. Calculate the transient currents and voltages in the linear electrical circuit specified according to the option (Table 4) using the operator method. Construct temporary diagrams of transient currents and voltages.

Table 4- Initial data for the calculation of transient currents and voltages

Option №	Scheme Fig. №	R1, kOm	R2, kOm	R3, kOm	L, mGn	S, μF	E, In	J, mA
1	3.2	1	2	3	-	0.01	25	-
2	3.3	2	3	1	-	0.02	-	0.01
3	3.4	3	1	2	10	-	-	0.02
4	3.5	4	2	3	20	-	15	-
5	3.6	2	5	3	-	0.03	10	-
6	3.7	1	3	1	25	-	-	0.03
7	3.8	3	2	2	-	0.04	-	0.04
8	3.9	4	3	1	-	0.05	24	-
9	3.10	2	6	3	35	-	27	-
10	3.11	5	4	4	40	-	-	0.025
11	3.12	1	2	2	-	0.06	-	0.035
12	3.13	4	3	1	10	-	23	-
13	3.14	2	1	3	45	-	-	0.020
14	3.15	1	2	1	-	0.03	25	-
15	3.16	3	5	2	10	-	23	-
16	3.17	4	3	2	25	-	22	-
17	3.18	2	2	3	-	0.04	-	0.080
18	3.19	5	3	1	-	0.02	30	-
19	3.20	1	6	2	35	-	20	-
20	3.21	2	4	3	20	-	28	-
21	3.22	1	2	3	-	0.07	-	0.060
22	3.23	2	3	4	35	-	20	-

23	3.24	3	1	3	-	0.03	-	0.035
24	3.2	1	5	1	-	0.05	21	-
25	3.3	2	3	2	-	0.02	-	0.015
26	3.4	1	2	2	40	-	-	0.025
27	3.5	2	3	3	30	-	29	-
28	3.6	3	6	1	-	0.03	30	-
29	3.7	2	4	2	24	-	-	0.036
30	3.8	1	2	3	-	0.02	-	0.048
31	3.2	2	5	1	-	0.01	25	-
32	3.3	3	3	2	-	0.02	-	0.01
33	3.4	4	2	3	10	-	-	0.02
34	3.5	2	3	3	20	-	15	-
35	3.6	1	6	1	-	0.03	10	-
36	3.7	3	4	2	25	-	-	0.03
37	3.8	4	2	1	-	0.04	-	0.04
38	3.9	2	3	3	-	0.05	24	-
39	3.1	5	1	1	35	-	27	-
40	3.11	1	2	2	40	-	-	0.025

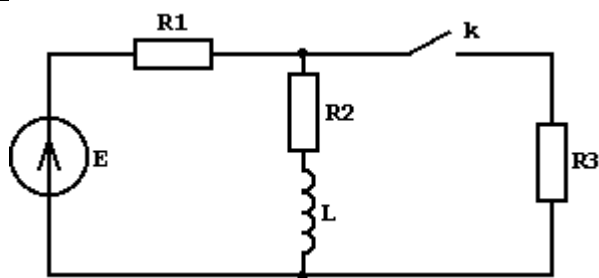


Figure 3.1

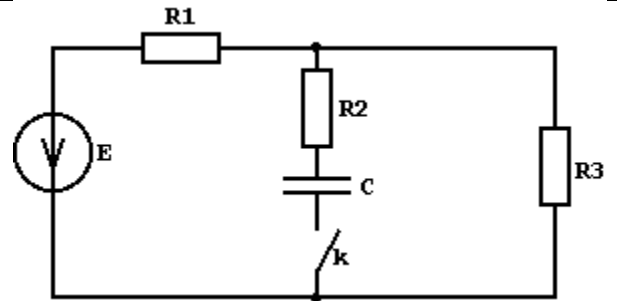


Figure 3.2

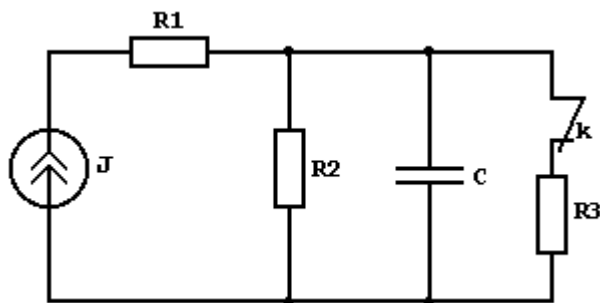


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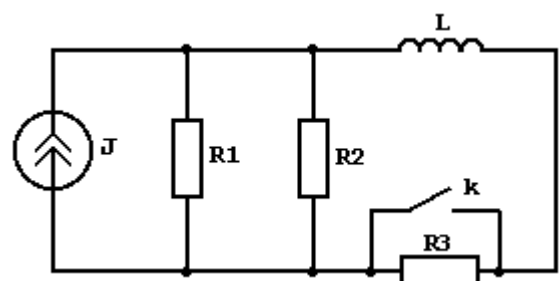


Figure 3.4

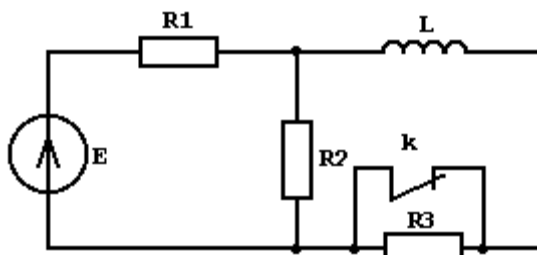


Figure 3.5

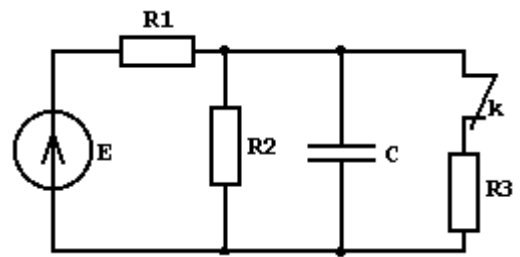


Figure 3.6

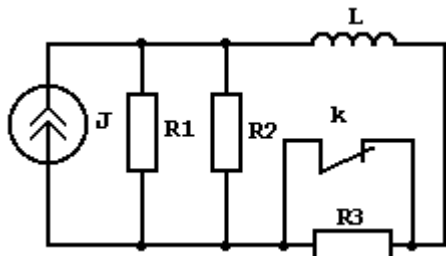


Figure 3.7

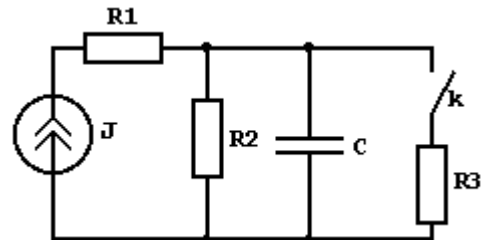


Figure 3.8

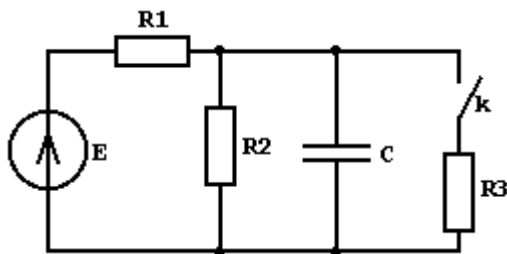


Figure 3.9

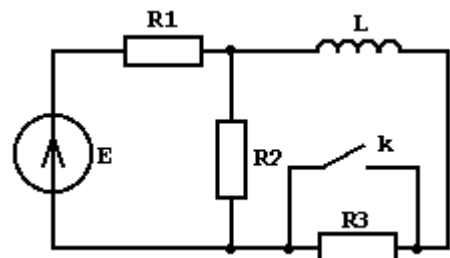


Figure 3.10

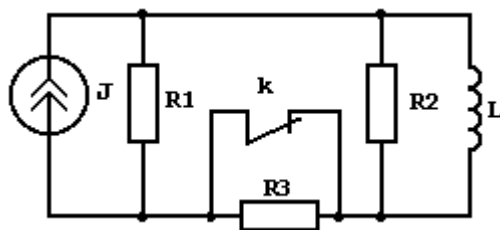


Figure 3.11

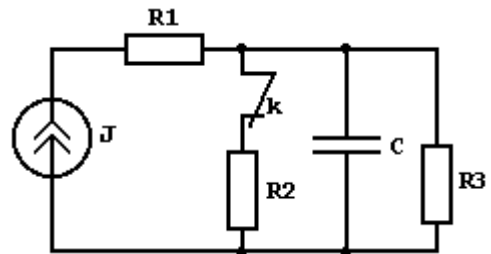


Figure 3.12

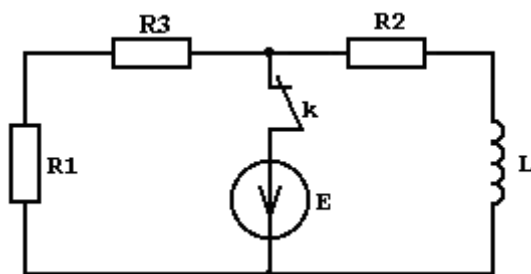


Figure 3.13

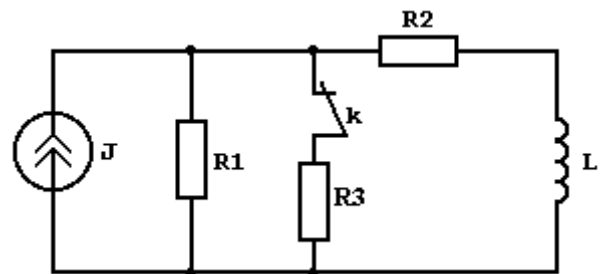


Figure 3.14

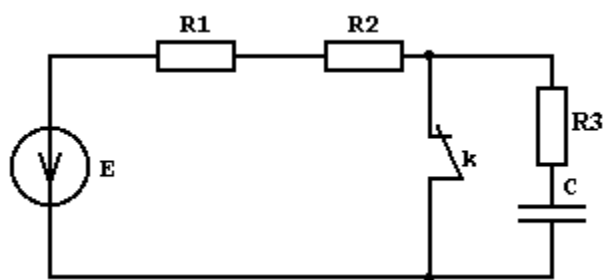


Figure 3.15

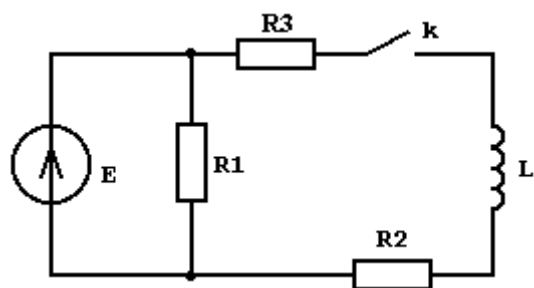


Figure 3.16

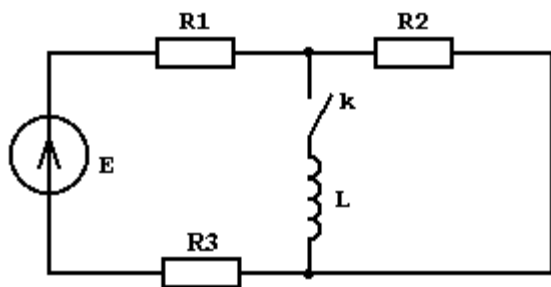


Figure 3.17

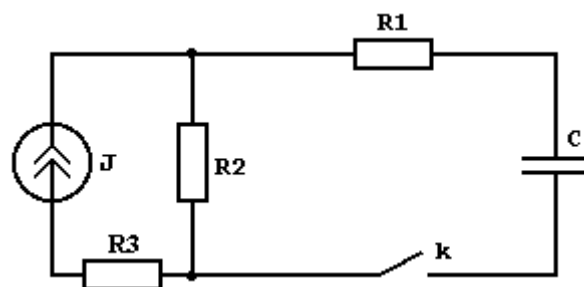


Figure 3.18

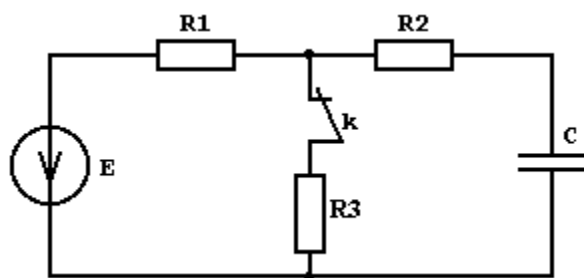


Figure 3.19

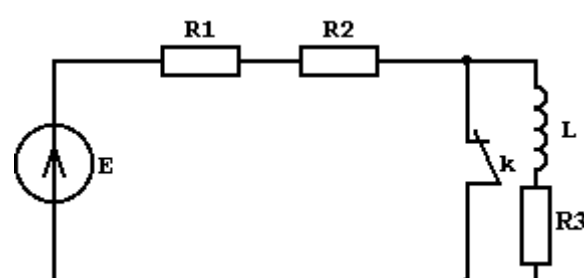


Figure 3.20

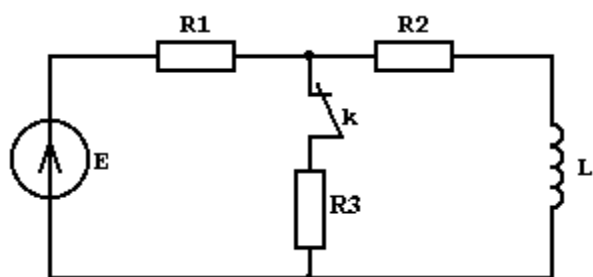


Figure 3.21

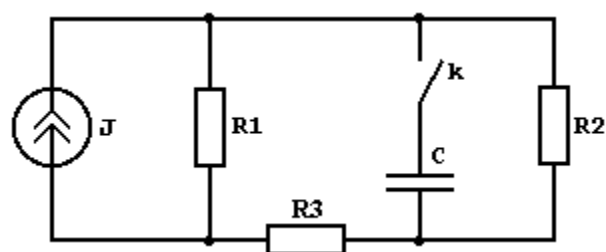


Figure 3.22

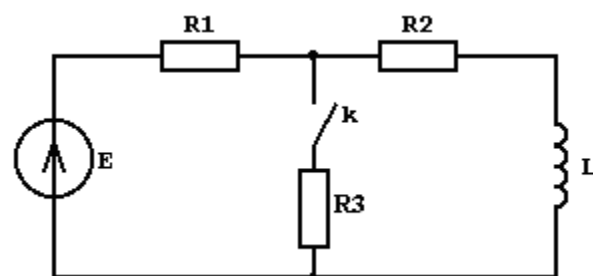


Figure 3.23

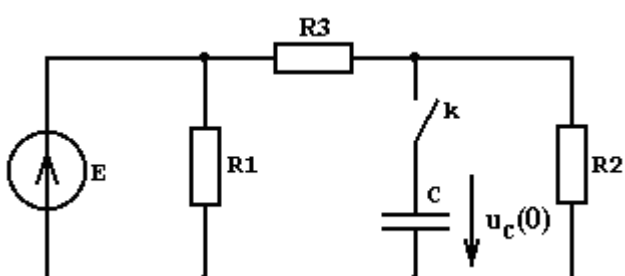


Figure 3.24

2 EXAMPLE OF A TERM PAPER

Analysis of electrical circuits in steady-state and transient modes

2.1 Analysis of single-phase electrical circuits of sinusoidal current

Initial data. Diagram of the specified electrical circuit (Figure 1.1).

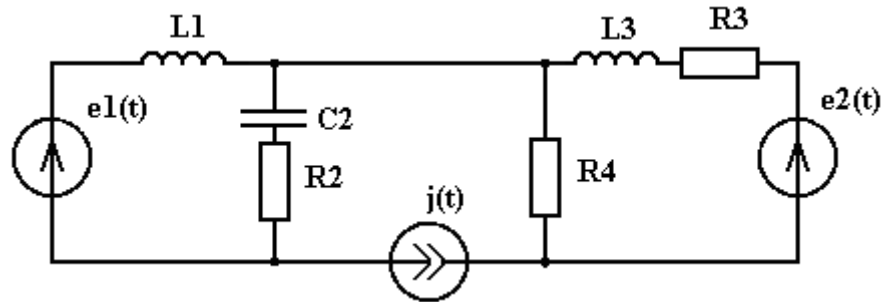


Figure 1.1 - Diagram of a given electrical circuit

EMF amplitude $E_{m1} = 20$ V, initial phase $\psi_{e1} = 450$, oscillation frequency $f = 1$ kHz, EMF amplitude $E_{m2} = 21.21$ V, initial phase $\psi_{e2} = 900$, current amplitude of current source $J_m = 0.1414$ A, initial phase $\psi_i = -900$, $L_1 = 1.592$ mH, $R_2 = 30$ Ohm, $C_2 = 3.979$ μ F, $L_3 = 2.387$ mH, $R_3 = 15$ Ohm, $R_4 = 25$ Ohm.

2.1.1 Circuit Current Analysis

1. Determine the complex resistances of the elements of the electrical circuit

$$\underline{Z}_1 = j2\pi f L_1 = j \cdot 2 \cdot 3.14 \cdot 10^3 \cdot 1.592 \cdot 10^{-3} = j10 \text{ Ohm},$$

$$\underline{Z}_2 = R_2 - j \frac{1}{2\pi f C_2} = 30 - j \frac{1}{2 \cdot 3.14 \cdot 10^3 \cdot 3.979 \cdot 10^{-6}} = 30 - j40 \text{ Ohm},$$

$$\underline{Z}_3 = R_3 + j2\pi f L_3 = 15 + j2 \cdot 3.14 \cdot 10^3 \cdot 2.387 \cdot 10^{-3} = 15 + j15 \text{ Ohm}, \quad \underline{Z}_4 = R_4 = 25$$

Ohm, the complex effective values of $\underline{E}_1 = \frac{E_{m1}}{\sqrt{2}} e^{j\psi_{e1}} = \frac{20}{1.414} e^{j450} = 10 + j10$ EMF

V, $\underline{E}_2 = \frac{E_{m2}}{\sqrt{2}} e^{j\psi_{e2}} = \frac{21.21}{1.414} e^{j900} = j15$ V, and the complex effective value of the

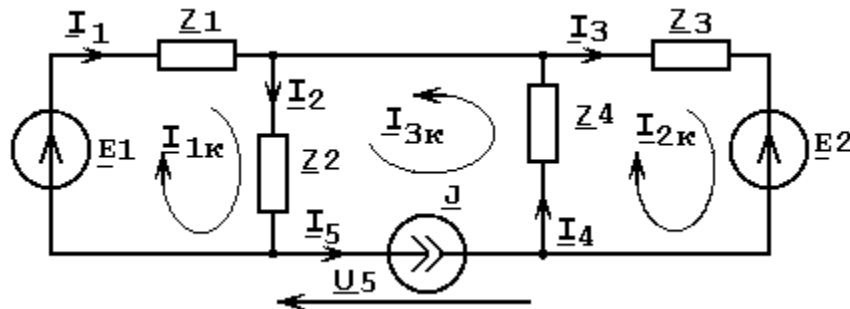
current of the source $\underline{J} = \frac{J_m}{\sqrt{2}} e^{j\psi_j} = \frac{0.1414}{1.414} e^{-j900} = -j0.1$ A.

2. Draw the circuit diagram in a complex form (Figure 1.2)

3. Determine the number of circuit currents (the number of independent circuits)

$$N = n_b - n_y + 1 = 5 - 3 + 1 = 3$$

4. Determine the number of equations $n = n_b - n_y + 1 - nJ = 5 - 3 + 1 - 1 = 2$



•Figure 1.2 - Diagram of an electrical circuit in a complex form

•5. Specify the directions of the circuit currents and currents in the circuit branches

• (Figure 1.2). In this case, the circuit currents are selected in such a way that only one circuit current passes through the branch with the current source.

• In the circuit (Figure 1.2), the circuit current is $I_{3k} = J = -j0.1$ A.

6. Writing down a system of 2 equations for three loop currents

$$\underline{Z_{11}}I_{1k} + \underline{Z_{12}}I_{2k} + \underline{Z_{13}}I_{3k} = \underline{E_{11}}$$

$$\underline{Z_{21}}I_{1k} + \underline{Z_{22}}I_{2k} + \underline{Z_{23}}I_{3k} = \underline{E_{22}}$$

7. Define the eigenresistances of the circuits $\underline{Z_{nn}}$ as the arithmetic sum of the resistances of the elements included in the circuit "n"

$$\underline{Z_{11}} = \underline{Z_1} + \underline{Z_2} = j10 + 30 - j40 = 30 - j30 \text{ ohms,}$$

$$\underline{Z_{22}} = \underline{Z_3} + \underline{Z_4} = 15 + j15 + 25 = 40 + j15 \text{ ohms.}$$

8. Determine the total resistances $\underline{Z_{kn}}$ of the circuits k and n. With the sign "+" we take the resistances of the elements in which the contour currents coincide in the direction of $\underline{Z_{12}} = \underline{Z_{21}} = 0$ Ohm, $\underline{Z_{13}} = \underline{Z_{31}} = \underline{Z_2} = 30 - j40$ Ohm, $\underline{Z_{23}} = \underline{Z_{32}} = \underline{Z_4} = 25$ Ohm.

9. Define the contour EMF $\underline{E_{nn}}$ as the algebraic sum of the EMF included in the given circuit. With the "+" sign, the sum includes the EMF that coincide in direction with the contour current. $\underline{E_{11}} = \underline{E_1} = 10 + j10$ B, $\underline{E_{22}} = -\underline{E_2} = -j15$ B.

10. After substituting the calculated values into the system of equations, we get

$$(30-j30)\underline{I1k} + (0)\underline{I2k} + (30-j40)(-j0.1) = 10+j10$$

$$(0)\underline{I1k} + (40+j15)\underline{I2k} + 25(-j0.1) = -j15$$

$$\text{or } (30-j30)\underline{I1k} = 10+j10-(30-j40)(-j0.1)$$

$$(40+j15)\underline{I2k} = -j15-25(-j0.1)$$

11. Solving a system of equations $(30-j30)\underline{I1k} = 14+j13$

$$(40+j15)\underline{I2k} = -j12.5,$$

determine the contour currents $\underline{I1k} = 0.017+j0.45 \text{ A}$, $\underline{I2k} = -0.103-j0.274$

A.

12. Determine the currents in the branches

$$\underline{I1} = \underline{I1k} = 0.017+j0.45=0.45e^{j88} \text{ A},$$

$$\underline{I2} = \underline{I1k} + \underline{I3k} = 0.017+j0.45 + (-j0.1) = 0.017+j0.35=0.35e^{j87} \text{ A},$$

$$\underline{I3} = \underline{I2k} = -0.103-j0.274 = 0.293e^{-j111} \text{ A},$$

$$\underline{I4} = \underline{I2k} + \underline{I3k} = -0.103-j0.274+(-j0.1) = -0.103-j0.374= 0.388e^{-j105} \text{ A},$$

$$\underline{I5} = \underline{I3k} = -j0.1=0.1e^{-j90} \text{ A}.$$

13. Calculate the balance of capacities:

13.1. Capacity of Electric Power Sources

$$\underline{S_{\text{ис}}}_{\text{с}} = \underline{E}_1 \underline{I}_1^* + \underline{U}_5 \underline{J}^* - \underline{E}_2 \underline{I}_3^* = (10 + j10)(0.017 - j0.45) + (11.932 + j0.484)(j0.1) - \\ - j15(-0.103 + j0.274) = 8.728 - j1.599 \text{ BA}$$

Here, $\underline{U}_5$ is the complex voltage across the current source (Figure 1.2.)

$$\underline{U5} = \underline{I}_{4Z4} + \underline{I2} \underline{Z}_2,$$

$\underline{I}_1^*, \underline{J}^*, \underline{I}_3^*$ - complex conjugate currents.

13.2. Electric Power Receiver Capacities

$$\underline{S_{\text{пр}}}_{\text{с}} = \underline{I}_1^2 \underline{Z}_1 + \underline{I}_2^2 \underline{Z}_2 + \underline{I}_3^2 \underline{Z}_3 + \underline{I}_4^2 \underline{Z}_4 = 0.45^2 (j10) + 0.35^2 (30 - j40) + 0.293^2 (15 + j15) + \\ + 0.388^2 (25) = 8.728 - j1.599 \text{ BA}$$

11.3. Conclusion: $\underline{S_{\text{ис}}} = \underline{S_{\text{пр}}}$ - the power developed by electric energy sources is equal to the power consumed in electric energy receivers.

13. Calculate complex stresses in the circuit sections:

$$\underline{U1} = \underline{Z1I1} = (j10)0.45e^{j88}=10e^{j90}0.45e^{j88}=4.5 e^{j178} \text{ B},$$

$$\underline{U_2=Z_2I_2=(30-j40)0.35ej87=50e^{-j530.35ej87=17.52 ej34} B,}$$

$$\underline{U_3=Z_3I_3=(15+j15) 0.293e^{-j111}=21.21e^{j450.293e^{-j111}=6.21 e^{-j65.6} B,}$$

$$\underline{U_4=Z_4I_4=(25) 0.388e^{-j105} = 9.7e^{-j105} B,}$$

14. Instantaneous EMF, voltages and currents in a circuit are determined by expressions

$$e_1(\omega t) = E_{m1} \sin(\omega t + \psi_{e1}) = 20 \sin(6280t + 45^\circ) B;$$

$$e_2(\omega t) = E_{m2} \sin(\omega t + \psi_{e2}) = 21.21 \sin(6280t + 90^\circ) B;$$

$$u_1(\omega t) = U_{m1} \sin(\omega t + \psi_{u1}) = 6.368 \sin(6280t + 178^\circ), B;$$

$$u_2(\omega t) = U_{m2} \sin(\omega t + \psi_{u2}) = 24.777 \sin(6280t + 34^\circ), B;$$

$$u_3(\omega t) = U_{m3} \sin(\omega t + \psi_{u3}) = 8.778 \sin(6280t - 65.6^\circ), B;$$

$$u_4(\omega t) = U_{m4} \sin(\omega t + \psi_{u4}) = 13.712 \sin(6280t - 105^\circ), B;$$

$$i_1(\omega t) = \sqrt{2}I_1 \sin(\omega t + \psi_{i1}) = 0.637 \sin(6280t + 88^\circ), A;$$

$$i_2(\omega t) = \sqrt{2}I_2 \sin(\omega t + \psi_{i2}) = 0.496 \sin(6280t + 87^\circ), A;$$

$$i_3(\omega t) = \sqrt{2}I_3 \sin(\omega t + \psi_{i3}) = 0.414 \sin(6280t - 111^\circ), A;$$

$$i_4(\omega t) = \sqrt{2}I_4 \sin(\omega t + \psi_{i4}) = 0.548 \sin(6280t - 105^\circ), A;$$

$$i_5(\omega t) = \sqrt{2}I_5 \sin(\omega t + \psi_{i5}) = 0.141 \sin(6280t - 90^\circ), A.$$

15. Graphs of instantaneous EMF, voltages and currents in the circuit are shown in Figures 1.3 and 1.4.

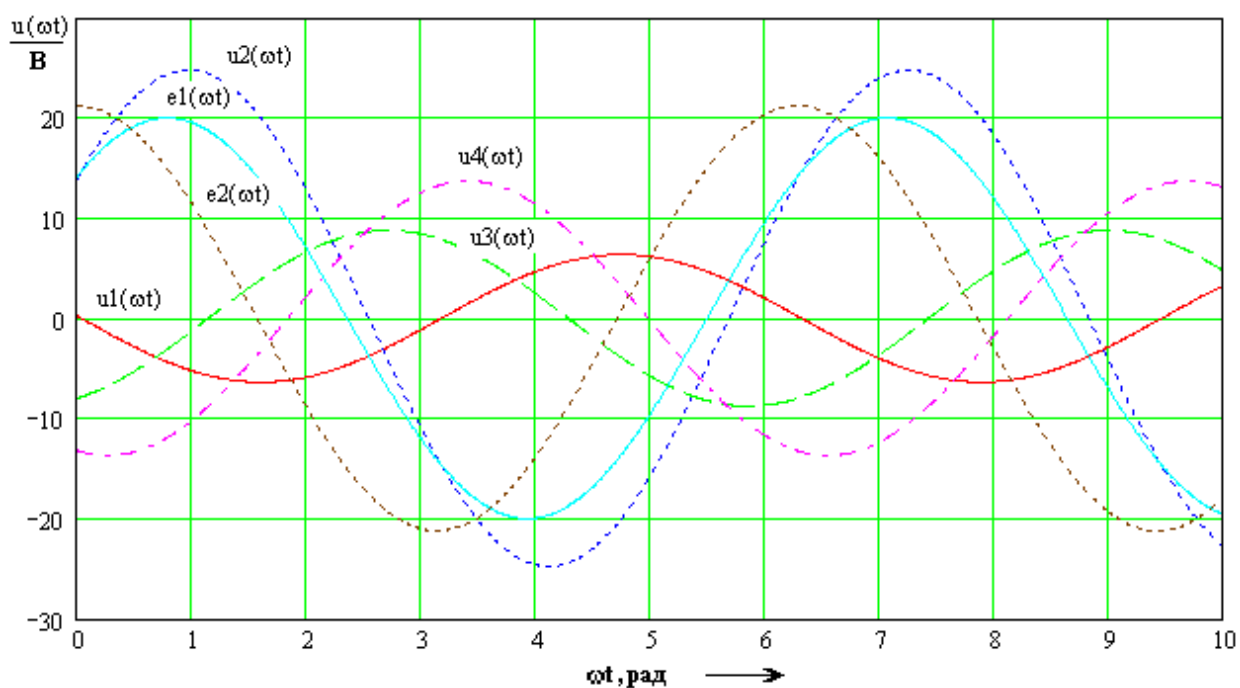


Figure 1.3 - Graphs of instantaneous EMF and circuit stresses

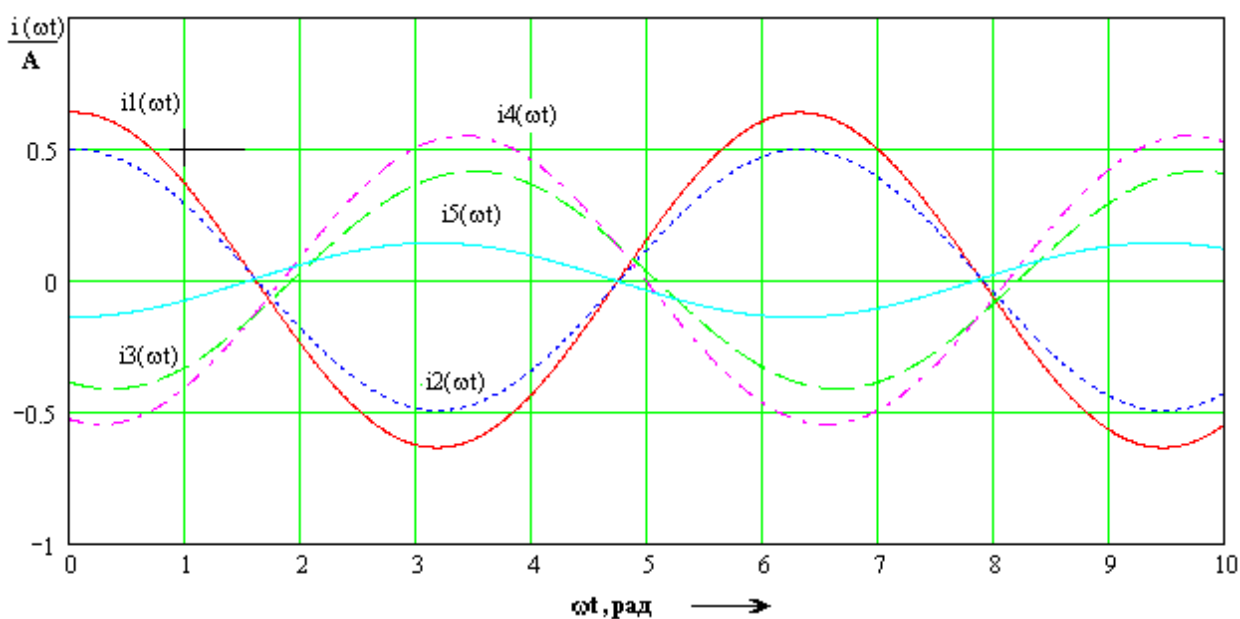


Figure 1.4 - Plots of instantaneous currents in a circuit

16. Vector diagrams of voltages and currents are shown in Figures 1.5, 1.6.

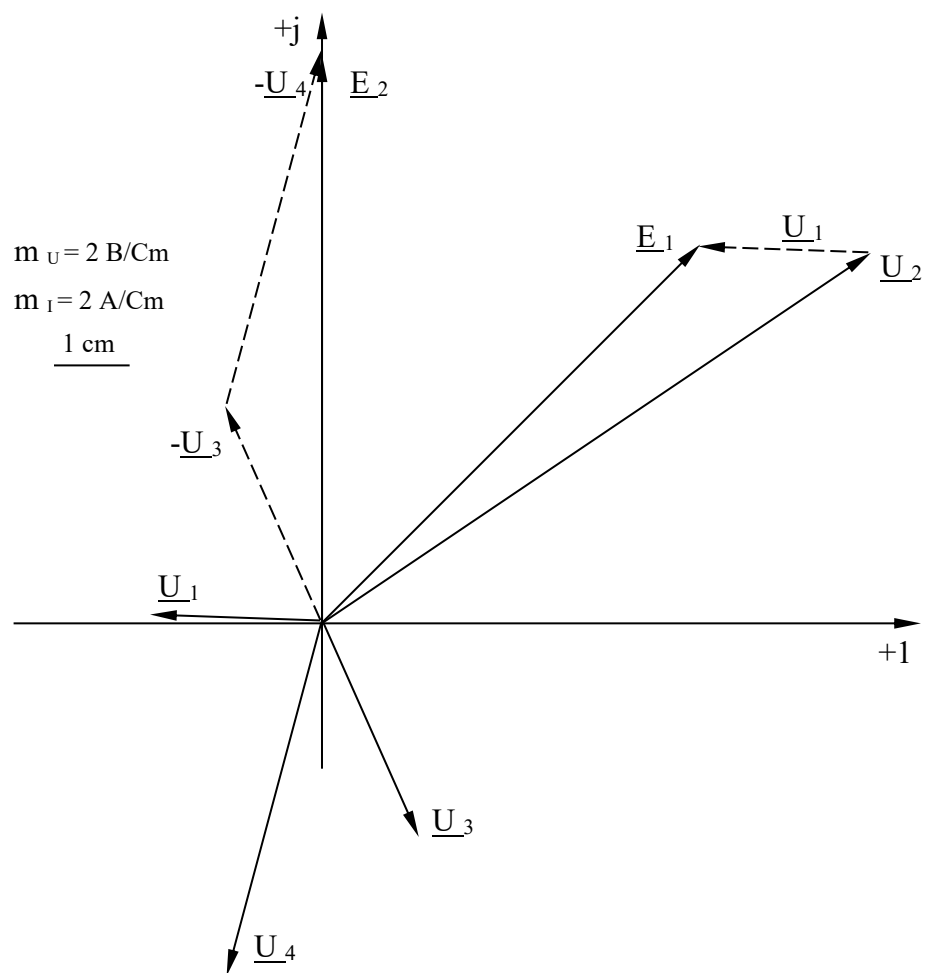


Figure 1.5 - Vector diagrams of stresses and EMF

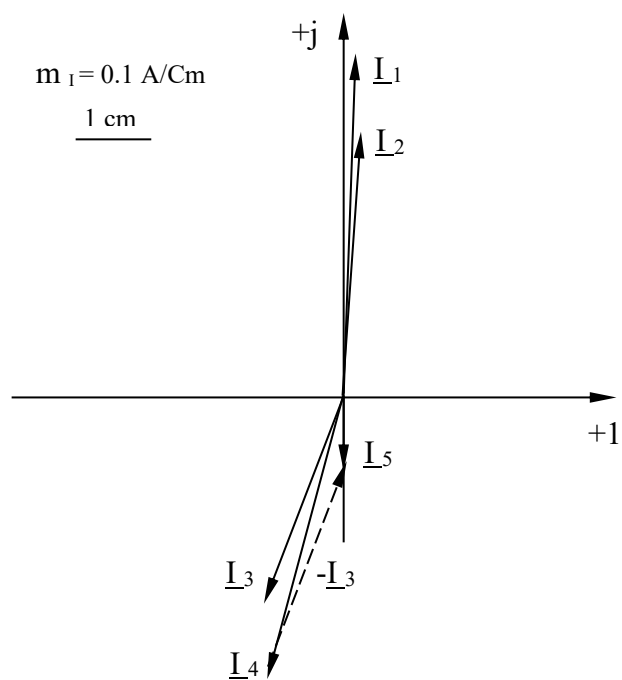


Figure 1.6 - Vector current diagrams

2.1.2 Circuit Design by Nodal Potential Method

1. Let us indicate the numbers of the nodes on the diagram (Figure 1.7). Nodes 1' and 1 should be considered as one node, since they are connected by an ideal conductor and, therefore, their potentials are equal to each other. Select node 3 as a support node and assume its potential $\phi_3 = 0$. In Figure 1.7 we show its connection with the body.

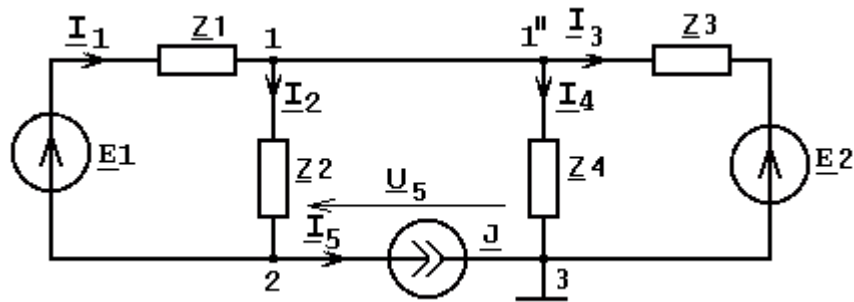


Figure 1.7

2. The number of equations $N = n_y - 1 - n_e = 3 - 1 - 0 = 2$.

Here n is the number of nodes in the chain,

n_e is the number of branches consisting only of idealized sources of EMF. In the diagram (Figure 1.7) there are no such branches, i.e. $n_e = 0$.

3. Make a system of equations
$$\begin{aligned} \underline{Y}_{11} \phi_1 - \underline{Y}_{12} \phi_2 &= \sum_1 \underline{EY} + \sum_1 \underline{J} \\ -\underline{Y}_{21} \phi_1 + \underline{Y}_{22} \phi_2 &= \sum_2 \underline{EY} + \sum_2 \underline{J} \end{aligned}$$

Here, $\underline{Y}_{11}$ is the sum of the conductivities of the branches attached to node 1,

$\underline{Y}_{22}$ - the sum of the conductivities of the branches connected to node 2,

$\underline{Y}_{12}$ - the sum of the conductivities of the branches connecting node 1 and node 2 with each other,

$\underline{Y}_{21}$ is the sum of the conductivities of the branches connecting node 2 and node 1,

$\sum_1 \underline{EY}$ - the algebraic sum of the products of the EMF of the branches connected to node 1 on the conductivity of these branches. In this case, those EMFs that have a direction to node 1 are taken with the "+" sign, and those EMFs that have a direction from node 1 are taken with the "-" sign,

$\sum_1 \underline{J}$ is the algebraic sum of the currents of the current sources connected to node 1. In this case, the "+" sign shall be those currents directed to node 1, and the "-" sign shall be those currents directed from node 1,

$\sum_2 \underline{EY}$ - the algebraic sum of the products of the EMF of the branches attached to node 2 on their conductivity. In this case, those EMFs that have a direction to node 2 are taken with the sign "+",

$\sum_2 \underline{J}$ is the algebraic sum of the currents of the current sources connected to node 2. In this case, those currents directed to node 2 are taken with the "+" sign, and those directed from node 2 are taken with the "-" sign.

4. Determine the quantities necessary to solve the system of equations

$$\underline{Y}_{11} = \frac{1}{\underline{Z}_1} + \frac{1}{\underline{Z}_2} + \frac{1}{\underline{Z}_3} + \frac{1}{\underline{Z}_4} = \frac{1}{j10} + \frac{1}{30 - j40} + \frac{1}{15 + j15} + \frac{1}{25} = 0.085 - j0.117 \text{ C}$$

$$\underline{Y}_{12} = \underline{Y}_{21} = \frac{1}{\underline{Z}_1} + \frac{1}{\underline{Z}_2} = \frac{1}{j10} + \frac{1}{30 - j40} = 0.012 - j0.084 \text{ C}_M,$$

$$\underline{Y}_{22} = \frac{1}{\underline{Z}_1} + \frac{1}{\underline{Z}_2} = \frac{1}{j10} + \frac{1}{30 - j40} = 0.012 - j0.084 \text{ C}_M$$

$$\sum_1 \underline{EY} = \underline{E}_1 \cdot \frac{1}{\underline{Z}_1} + \underline{E}_2 \cdot \frac{1}{\underline{Z}_3} = (10 + j10) \cdot \frac{1}{j10} + j15 \cdot \frac{1}{15 + j15} = 1.5 - j0.5 \text{ A},$$

$$\sum_1 \underline{J} = 0, \sum_2 \underline{EY} = -\underline{E}_1 \cdot \frac{1}{\underline{Z}_1} = -(10 + j10) \cdot \frac{1}{j10} = -1 + j \text{ A}, \sum_2 \underline{J} = -\underline{J} = j0.1 \text{ A}$$

5. Solving a system of equations $(0.085 - j0.117)\varphi_1 - (0.012 - j0.084)\varphi_2 = 1.5 - j0.5$

$$- (0.012 - j0.084)\varphi_1 + (0.012 - j0.084)\varphi_2 = -1 + j1.1$$

find potentials $\varphi_1 = 2.568 + j9.349 \text{ V}$, $\varphi_2 = -11.932 - j0.484 \text{ V}$.

6. Select the directions of currents in the branches (Figure 1.7).

7. Applying Ohm's law to a section of the circuit, we find currents in the branches

$$\underline{I}_1 = \frac{\underline{\varphi}_2 - \underline{\varphi}_1 + \underline{E}_1}{\underline{Z}_1} = 0.017 + j0.45 = 0.45e^{j88^\circ} \text{ A},$$

$$\underline{I}_2 = \frac{\underline{\varphi}_1 - \underline{\varphi}_2}{\underline{Z}_2} = 0.017 + j0.35 = 0.35e^{j87^\circ} \text{ A},$$

$$\underline{I}_3 = \frac{\underline{\varphi}_1 - \underline{\varphi}_3 - \underline{E}_2}{\underline{Z}_3} = -0.103 - j0.274 = 0.293e^{-j111^\circ} \text{ A},$$

$$\underline{I}_4 = \frac{\underline{\varphi}_1 - \underline{\varphi}_3}{\underline{Z}_4} = 0.103 + j0.374 = 0.388e^{-j105^\circ} \text{ A}.$$

8. Current in a branch with a current source $\underline{I}_5 = \underline{J} = -j0.1 = 0.1e^{-j90^\circ} \text{ A}$.

9. Let's check the fulfillment of the first Kirchhoff's law for node 2

$$-\underline{I}_1 - \underline{I}_5 + \underline{I}_2 = -0.017 - j0.45 + j0.1 + 0.017 + j0.35 = 0$$

10. Calculate the power balance:

10.1. Capacities developed by electric power sources

$$\underline{S}_{\text{ис}} = \underline{E}_1 \underline{I}_1^* + \underline{U}_5 \underline{J}^* - \underline{E}_2 \underline{I}_3^* = (10 + j10)(0.017 - j0.45) + (11.932 + j0.484)(j0.1) - j15(-0.103 + j0.274) = 8.728 - j1.599 \text{ BA}.$$

Here, $\underline{U}_5$ is the complex voltage across the current source (Figure 1.7)

$$\underline{U}_5 = -\underline{I}_4 \underline{Z}_4 + \underline{I}_2 \underline{Z}_2$$

$\underline{I}_1^*, \underline{J}^*, \underline{I}_3^*$ - complex conjugate currents.

10.2. Power consumed in electric energy receivers

$$\underline{S}_{\text{пр}} = \underline{I}_1^2 \underline{Z}_1 + \underline{I}_2^2 \underline{Z}_2 + \underline{I}_3^2 \underline{Z}_3 + \underline{I}_4^2 \underline{Z}_4 = 0.45^2(j10) + 0.35^2(30 - j40) + 0.293^2(15 + j15) + 0.388^2(25) = 8.728 - j1.599 \text{ BA}.$$

10.3. Conclusion: the power developed by electric energy sources is equal to the power consumed in electric energy receivers.

2.1.3 Circuit Analysis by Overlapping

Calculate Current in Branch with $\underline{Z}_4$ Electrical Circuit Resistance

(Figure 1.8), if $\underline{Z}_1 = 6 - j8 \text{ } \Omega$, $\underline{Z}_2 = 5 \text{ } \Omega$, $\underline{Z}_3 = 3 + j40 \text{ } \Omega$, $\underline{Z}_4 = 4 \text{ } \Omega$,

$\underline{E}_1 = 30 \text{ V}$, $\underline{E}_2 = 10 + j10 \text{ V}$, $\underline{J}_1 = 5 \text{ A}$.

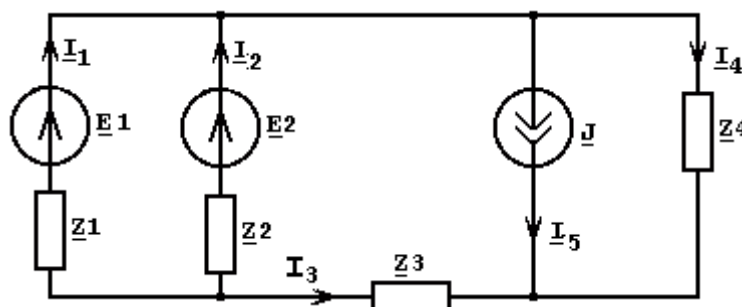


Figure 1.8

1. In the given scheme (Figure 1.8), indicate the directions of the currents.
2. Exclude sources from the circuit (Figure 1.8) $\underline{E}_2$ и $\underline{J}$ and calculate the currents in the branches with the element $\underline{Z}_4$ of the resulting circuit (Figure 1.9).

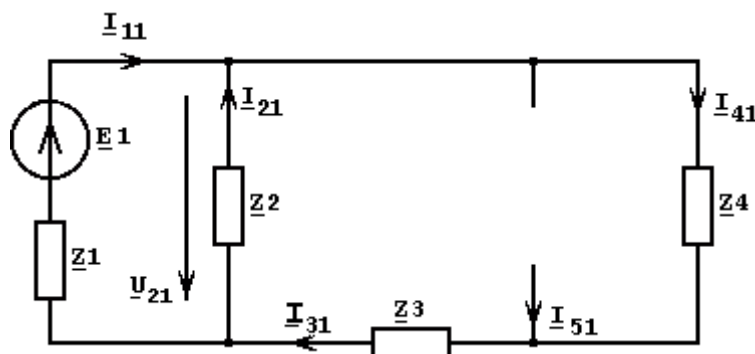


Figure 1.9

- 2.1. Indicate the directions of currents in the circuit branches (Figure 1.9).
- 2.2. In the diagram (Figure 1.9), the current $I_{51} = 0$, since the resistance of the branch from which the current source is excluded $\underline{J}_1$ has an infinitely large

value. In this case, the $I_{31} = I_{41}$ current. Consequently, the resistances Z_4 и Z_3 are connected in series. Current $I_{41} = \frac{U_{21}}{Z_4 + Z_3} = \frac{5.21 + j6.266}{4 + 3 + j4} = 0.947 + j0.354$ A.

2.3. According to Kirchhoff's second law $E_1 = I_{11} \cdot Z_1 + U_{21}$, then

$$U_{21} = E_1 - I_{11} Z_1 = 30 - (1.983 + j1.607) \cdot (6 - j8) = 6.21 + j6.266 \text{ B.}$$

2.4. Current $I_{11} = \frac{E_1}{Z_{\text{э1}}} = \frac{30}{9.125 - j7.375} = 1.989 + j1.607$ A,

here $Z_{\text{э1}}$ is the equivalent complex resistance of the circuit

$$Z_{\text{э1}} = Z_1 + \frac{Z_2(Z_3 + Z_4)}{Z_2 + (Z_3 + Z_4)} = 6 - j8 + \frac{5(3 + j4 + 4)}{5 + 3 + j4 + 4} = 6 - j8 + \frac{5(7 + j4)}{12 + j4} = 9.125 - j7.375 \text{ Ом.}$$

3. Exclude sources from the diagram (Figure 1.8) I_2 и E_1 (Figure 1.10).

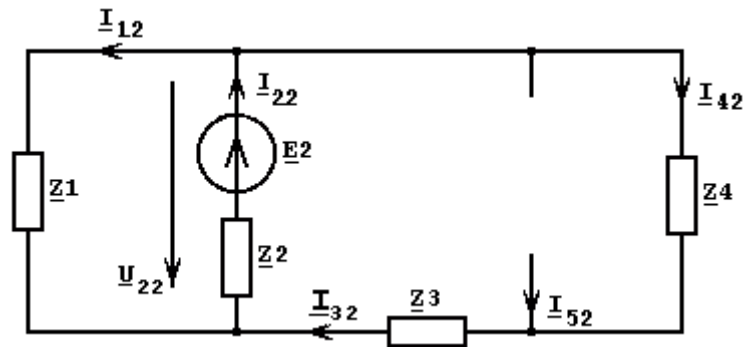


Figure 1.10

3.1. Indicate the directions of currents and voltages in the circuit (Figure 1.10).

3.2. In the resulting diagram, the elements Z_4 и Z_3 are connected in series.

Equivalent resistance of this section of the circuit $Z_{43} = Z_4 + Z_3 = 4 + 3 - j4 = 7 + j4 \text{ Ом.}$

3.3. Current $I_{42} = I_{32} = \frac{U_{22}}{Z_{43}} = \frac{4.029 + j3.644}{7 + j4} = 0.658 + j0.144$ A.

3.3.1. Using Kirchhoff's second law, we can write $E_2 = U_{22} + I_{22} Z_2$, from here $U_{22} = E_2 - I_{22} Z_2 = 10 + j10 - (0.608 + j0.685) \cdot 5 = 4.029 + j3.644 \text{ B.}$

3.3.2. To determine the current, I_{22} let's draw an equivalent circuit diagram (Figure 1.11)

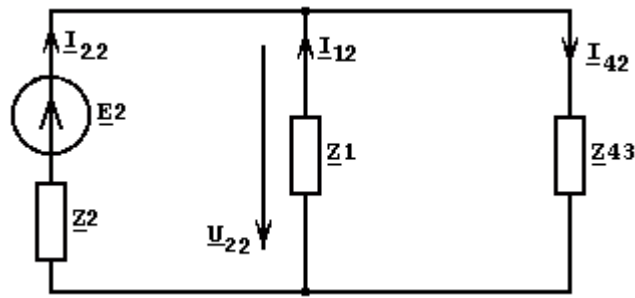
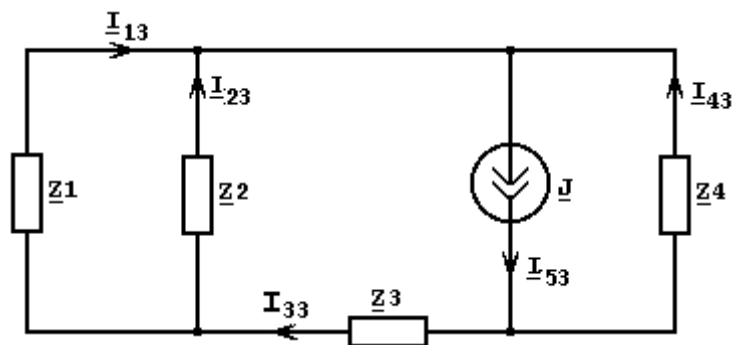


Figure 1.11

3.3.3. Complex resistances $\underline{Z}_2, \underline{Z}_1$ и $\underline{Z}_{43}$ form a mixed connection of elements. The equivalent resistance in a mixed connection is determined by the expression
$$\underline{Z}_{32} = \underline{Z}_2 + \frac{\underline{Z}_1 \cdot \underline{Z}_{43}}{\underline{Z}_1 + \underline{Z}_{43}} = 5 + \frac{(6 - j8) \cdot (7 + j4)}{6 - j8 + 7 + j4} = 10.892 - j0.649 \text{ Ом.}$$

3.3.4. According to Ohm's Law
$$\underline{I}_{22} = \frac{\underline{E}_2}{\underline{Z}_{32}} = \frac{10 + j10}{10.892 - j0.649} = 0.608 + j0.685 \text{ A.}$$

4. Exclude sources from the diagram of Figure 1.8 $\underline{E}_1$ и $\underline{E}_2$ (Figure 1.12).



•Figure 1.12

•4.1. Indicate the directions of currents and voltages in the circuit (Figure 1.12)

4.2. Complex resistances $\underline{Z}_2, \underline{Z}_1$ и $\underline{Z}_3$ form a mixed connection of elements (Figure 1.12). The equivalent complex resistance of this section of the circuit
$$\underline{Z}_{33} = \underline{Z}_3 + \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} = 3 + j4 + \frac{(6 - j8) \cdot 5}{6 - j8 + 7 + j5} = 6.514 + j2.919 \text{ Ом.}$$

4.3. The current $\underline{I}_{43}$ in the circuit (Figure 1.13) is determined by the current divider rule

$$\underline{I}_{43} = \underline{I}_{53} \cdot \frac{\underline{Z}_{33}}{\underline{Z}_{33} + \underline{Z}_4} = \underline{J} \cdot \frac{\underline{Z}_{33}}{\underline{Z}_{33} + \underline{Z}_4} = 5 \cdot \frac{6.514 + j2.919}{6.514 + j2.919 + 4} = 3.234 + j0.49 \text{ A.}$$

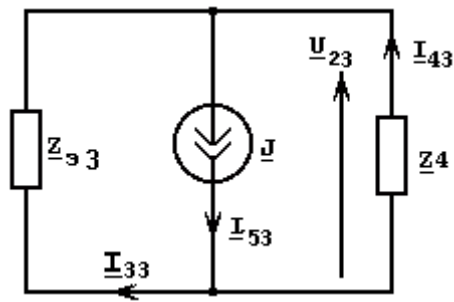


Figure 1.13

5. Using the principle of superposition, find the current in the branches with an element of a $\underline{Z}_4$ given circuit (Figure 1.8)

$$\underline{I}_4 = \underline{I}_{41} + \underline{I}_{42} - \underline{I}_{43} = 0.947 + j0.354 + 0.658 + j0.144 - 3.234 - j0.49 = -1.629 + j8.262 \cdot 10^{-3} = 1.629e^{j179.7^\circ} \text{ A}$$

6. Instantaneous current

$$i_4 = \text{Im}_4 \sin(\omega t + \psi_i) = 1.629 \cdot \sqrt{2} \sin(\omega t + 179.7^\circ) = 2.304 \sin(\omega t + 179.7^\circ) \text{ A.}$$

2.1.4 Calculation of the circuit by the equivalent generator method

Calculate Current in Branch with $\underline{Z}_4$ Electrical Circuit Resistance

(Figure 1.8) by the equivalent generator method, if

$$\underline{Z}_1 = 6 - j8 \text{ } \Omega, \quad \underline{Z}_2 = 5 \text{ } \Omega, \quad \underline{Z}_3 = 3 + j40 \text{ } \Omega, \quad \underline{Z}_4 = 4 \text{ } \Omega,$$

$$\underline{E}_1 = 30 \text{ V}, \quad \underline{E}_2 = 10 + j10 \text{ V}, \quad \underline{J}_1 = 5 \text{ A.}$$

2.1.4.1 Circuit design using the equivalent voltage generator method

1. The equivalent circuit for calculating the current in the cell $\underline{Z}_4$ is as follows (Figure 1.14).

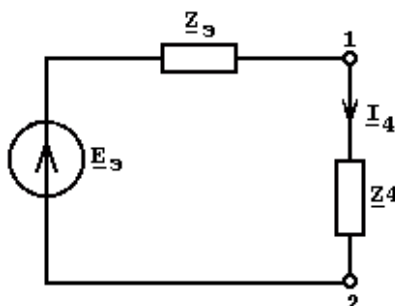


Figure 1.14

2. Determine the parameters of an equivalent voltage generator $\underline{E}_3$ и $\underline{Z}_3$.

2.1. To do this, exclude all EMF sources $\underline{Z}_3$. and the element from the $(\underline{E}_1$ и $\underline{E}_2)$ и тока $(\underline{I}_1)$ diagram (Figure 1.8) $\underline{Z}_4$ and determine $\underline{Z}_3$ relative to nodes 1-2 to which the element was connected $\underline{Z}_4$ (Figure 1.15).

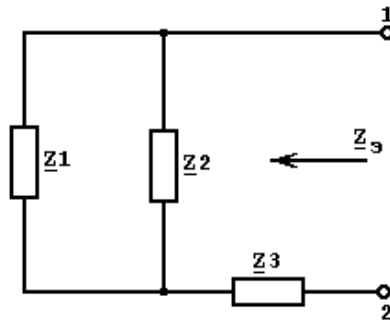


Figure 1.15

Elements $\underline{Z}_1$, $\underline{Z}_2$ and $\underline{Z}_3$ form a mixed connection scheme, therefore,

$$\underline{Z}_3 = \underline{Z}_3 + \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} = 3 + j4 + \frac{(6 - j8) \cdot 5}{6 - j8 + 5} = 6.514 + j2.919 \text{ Ом.}$$

2.2. Find $\underline{E}_3 = \underline{U}^{xx}$.

2.2.1. The scheme for calculation $\underline{E}_3$ is presented in (Figure 1.16)

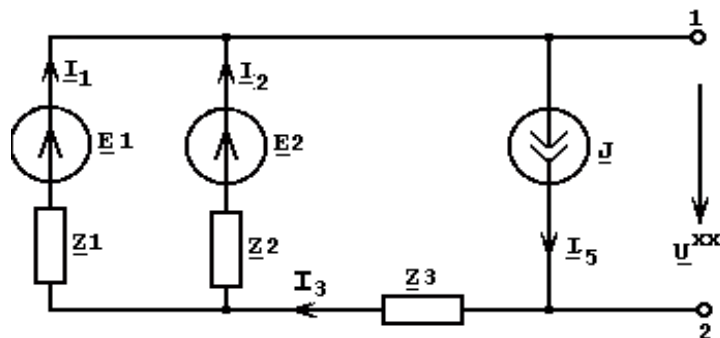


Figure 1.16

2.2.2. Indicate the directions of currents and voltages in the circuit (Figure 1.16).

2.2.3. The voltage $\underline{U}^{xx}$ is determined by the method of superposition.

2.2.3.1. Exclude and find from the diagram (Figure 1.16). $\underline{E}_2$ и $\underline{J}$ $\underline{U}^{xx}$

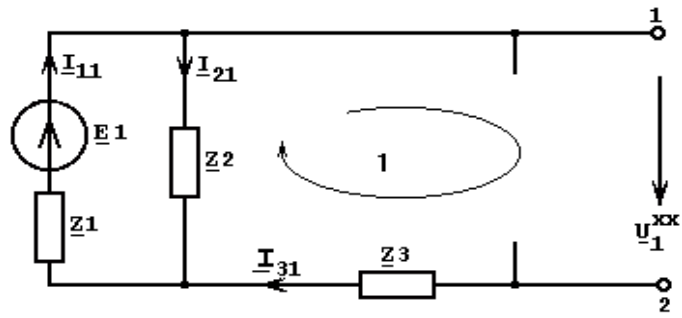


Figure 1.17

2.2.3.2. For contour 1 (Figure 1.17), in accordance with Kirchhoff's second law, you can write $\underline{U}_1^{xx} + \underline{I}_{31} \underline{Z}_3 - \underline{I}_{21} \underline{Z}_2 = 0$.

Current $\underline{I}_{31} = 0$ due to circuit break in section 1-2. $\underline{U}_1^{xx} = \underline{I}_{21} \underline{Z}_2$.

Current $\underline{I}_{21}$ is determined by Ohm's law

$$\underline{I}_{21} = \frac{\underline{E}_1}{\underline{Z}_1 + \underline{Z}_2} = \frac{30}{6 - j8 + 5} = \frac{30}{11 - j8} = 1.784 + j1.297 \text{ A.}$$

Thus, $\underline{U}_1^{xx} = \underline{I}_{21} \underline{Z}_2 = (1.784 + j1.297) \cdot 5 = 8.919 + j6.486 \text{ B.}$

2.2.3.3. Exclude and find from the diagram (Figure 1.16) $\underline{E}_1$ и $\underline{I}_1$ $\underline{U}_2^{xx}$

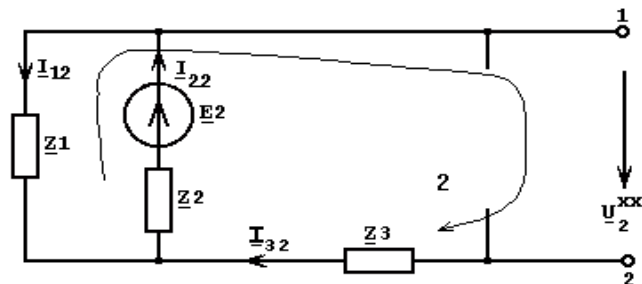


Figure 1.18

2.2.4. For contour 2 (Figure 1.18), in accordance with Kirchhoff's second law, you can write $\underline{U}_2^{xx} + \underline{I}_{32} \cdot \underline{Z}_3 - \underline{I}_{12} \underline{Z}_1 = 0$.

Current $\underline{I}_{32} = 0$ due to circuit break in section 1-2. $\underline{U}_2^{xx} = \underline{I}_{12} \underline{Z}_1$.

Current $\underline{I}_{12}$ is determined by Ohm's law

$$\underline{I}_{12} = \frac{\underline{E}_2}{\underline{Z}_1 + \underline{Z}_2} = \frac{10 + j10}{6 - j8 + 5} = \frac{10 + j10}{11 - j8} = 0.115 + j0.726 \text{ A.}$$

Thus, $\underline{U}_2^{xx} = \underline{I}_{12} \cdot \underline{Z}_1 = (0.115 + j0.726) \cdot (6 - j8) = 6.498 + j3.44 \text{ B.}$

2.2.4.1. Exclude and find from the diagram (Figure 1.16). $\underline{E}_1$ и $\underline{E}_2$ $\underline{U}_3^{xx}$

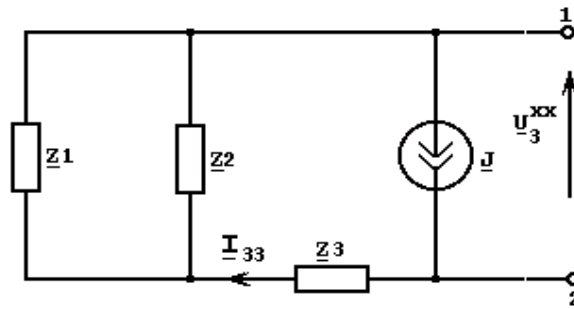


Figure 1.19

The elements Z_3, Z_2 и Z_1 form a mixed connection scheme (Figure 1.19), therefore,

$$Z_{\text{э}3} = Z_3 + \frac{Z_1 \cdot Z_2}{Z_1 + Z_2} = 3 + j4 + \frac{(6 - j8) \cdot 5}{6 - j8 + 5} = 6.514 + j2.919 \text{ OM.}$$

A simplified scheme for the case under consideration is as follows (Figure 1.20).

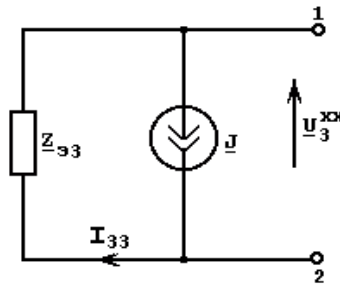


Figure 1.20

From the diagram (Figure 1.20)

$$U_3^{\text{xx}} = I_{33} Z_{\text{э}3} = J \cdot Z_{\text{э}3} = 5 \cdot (6.514 + j2.919) = 32.568 + j14.595 \text{ B.}$$

2.2.4.2. Find the tension U^{xx} using the principle of superposition

$$\begin{aligned} U^{\text{xx}} &= U_1^{\text{xx}} + U_2^{\text{xx}} - U_3^{\text{xx}} = 8.919 + j6.486 + 6.498 + j3.44 - 32.568 - j14.595 = \\ &= -17.151 - j4.668 = 17.775e^{-j165^\circ} \text{ B.} \end{aligned}$$

3. The current in element Z_4 (see Figure 1.14) is found according to Ohm's law

$$I_4 = \frac{U^{\text{xx}}}{Z_3 + Z_4} = \frac{-17.151 - j4.688}{6.514 - j2.919 + 4} = -1.629 + j8.262 \cdot 10^{-3} \text{ A.}$$

2.1.4.2 Circuit Design by Equivalent Current Generator Method

1. The equivalent circuit for calculating current I_4 is as follows (Figure 1.21)

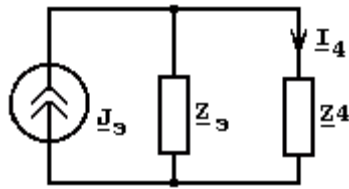


Figure 1.21

2. Determine the parameters of an equivalent current generator $\underline{I}_s, \underline{Z}_s$.

2.1. The value of Z_e is determined by the same algorithm as in the method of an equivalent voltage generator (Figure 1.15). Thus,

$$\underline{Z}_s = \underline{Z}_3 + \frac{\underline{Z}_1 \cdot \underline{Z}_2}{\underline{Z}_1 + \underline{Z}_2} = 3 + j4 + \frac{(6 - j8) \cdot 5}{6 - j8 + 5} = 6.514 + j2.919 \text{ OM.}$$

2.2. Find by $\underline{I}_s = \underline{I}_4^{K3}$ superimposition.

2.2.1. The scheme for calculating IE is shown in Figure 1.22

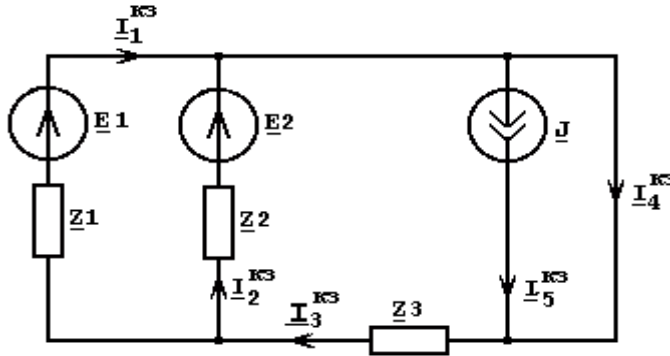


Figure 1.22

2.2.2. Indicate the directions of currents on the diagram (Figure 1.22)

2.2.3. Exclude $\underline{J}$ и $\underline{E}_2$ from the circuit (Figure 1.22) find the current $\underline{I}_{41}^{K3}$ (Figure 1.23).

$$\text{Current } \underline{I}_{41}^{K3} = \frac{\underline{U}_{21}}{\underline{Z}_3} = \frac{3.263 + j7.003}{3 + j4} = 1.512 + j0.318 \text{ A.}$$

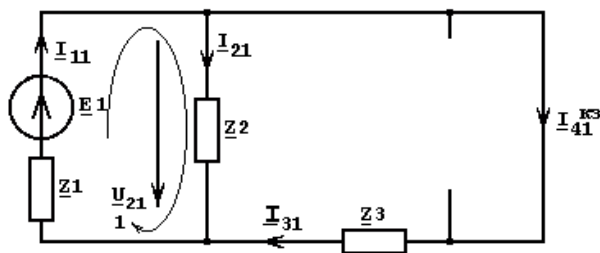


Figure 1.23

The stress $\underline{U}_{21}$ is determined using Kirchhoff's second law for circuit 1 (Figure

$$1.23) \quad \underline{U}_{21} = \underline{E}_1 - \underline{I}_{11} \underline{Z}_1 = 30 - (2.164 + j1.719) \cdot (6 - j8) = 3.263 + j7.003 \text{ B,}$$

$$\text{Current } \underline{I}_{11} = \frac{\underline{E}_1}{\underline{Z}_{\Sigma 1}} = \frac{30}{8.5 - j6.75} = 2.164 + j1.719 \text{ A,}$$

$$\text{Resistance } \underline{Z}_{\Sigma 1} = \underline{Z}_1 + \frac{\underline{Z}_2 \cdot \underline{Z}_3}{\underline{Z}_2 + \underline{Z}_3} = 6 - j8 + \frac{5 \cdot (3 + j4)}{5 + 3 + j4} = 8.5 - j6.75 \text{ OM.}$$

2.2.4. Exclude E1 and J from the circuit in Figure 1.22 and determine the current

$\underline{I}_{42}^{K3}$ (Figure 1.24).

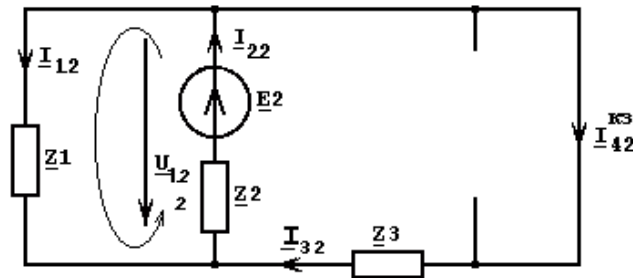


Figure 1.24

$$\text{Current } \underline{I}_{42}^{K3} = \frac{\underline{U}_{12}}{\underline{Z}_3} = \frac{2.813 + j4.314}{3 + j4} = 1.028 + j0.068 \text{ A.}$$

The stress $\underline{U}_{12}$ is determined using Kirchhoff's second law for circuit 2 (Figure

$$1.24) \quad \underline{U}_{12} = \underline{E}_2 - \underline{I}_{22} \cdot \underline{Z}_2 = 10 + j10 - (0.852 + j0.551) \cdot 5 = 2.813 + j4.314 \text{ B,}$$

$$\text{Current } \underline{I}_{22} = \frac{\underline{E}_2}{\underline{Z}_{\Sigma 2}} = \frac{10 + j10}{9.639 + j2.062} = 0.852 + j0.551 \text{ A,}$$

$$\text{Resistance } \underline{Z}_{\Sigma 2} = \underline{Z}_2 + \frac{\underline{Z}_1 \cdot \underline{Z}_3}{\underline{Z}_1 + \underline{Z}_3} = 5 + \frac{(6 - j8) \cdot (3 + j4)}{6 - j8 + 3 + j4} = 9.639 + j2.062 \text{ OM.}$$

2.2.5. Exclude from the circuit (Figure 1.22) $\underline{E}_1$ и $\underline{E}_3$ and determine the current

$\underline{I}_{43}^{K3}$ (Figure 1.25).

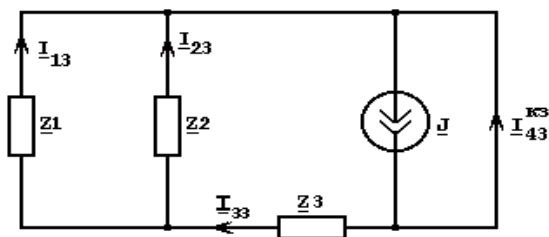


Figure 1.25

The section of the circuit containing the elements $\underline{Z}_1, \underline{Z}_2$ и $\underline{Z}_3$ (Figure 1.25) is connected in parallel to a conductor whose resistance is early than zero. The equivalent resistance of such a circuit is early than zero.

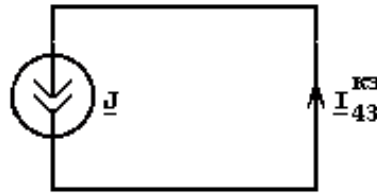


Figure 1.26

From the diagram (Figure 1.26) $\underline{I}_{43}^{K3} = \underline{J} = 5$ A.

2.2.6.

Current

$$\underline{I}_4^{K3} = \underline{I}_{41}^{K3} + \underline{I}_{42}^{K3} - \underline{I}_{43}^{K3} = 1.512 + j0.318 + 1.028 + j0.068 - 5 = -2.46 + j0.386 \text{ A.}$$

3. Find the current in the cell $\underline{Z}_4$ (Figure 1.21) using the current divider rule

$$\begin{aligned} \underline{I}_4 &= \underline{J}_3 \cdot \frac{\underline{Z}_3}{\underline{Z}_3 + \underline{Z}_4} = \underline{I}_4^{K3} \cdot \frac{\underline{Z}_3}{\underline{Z}_3 + \underline{Z}_4} = (-2.46 + j0.386) \cdot \frac{6.314 + j2.919}{6.314 + j2.919 + 4} = \\ &= -1.629 + j8.262 \cdot 10^{-3} = 1.629e^{j179.7^\circ} \text{ A.} \end{aligned}$$

4. Instantaneous Current

$$i_4 = \text{Im}_4 \sin(\omega t + \psi_i) = 1.629\sqrt{2} \sin(\omega t + 179.7^\circ) = 2.304 \sin(\omega t + 179.7^\circ) \text{ A.}$$

2.2 Analysis of Three-Phase Electrical Circuits

2.2.1 Calculation of a three-phase circuit according to the "star with neutral wire" connection scheme

A diagram of a three-phase circuit of a "star with neutral wire" connection is shown in Figure 2.1

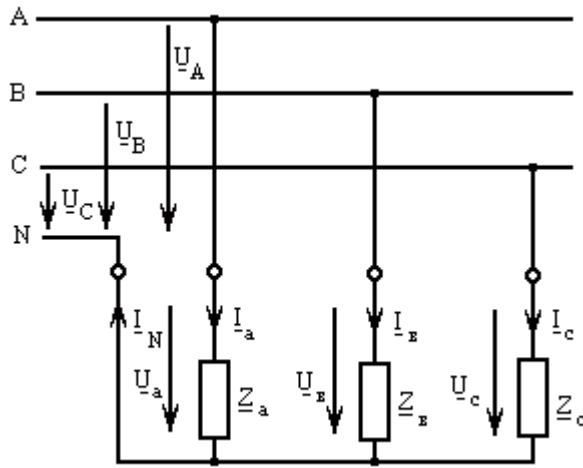


Figure 2.1 - Star-neutral receiver phase connection

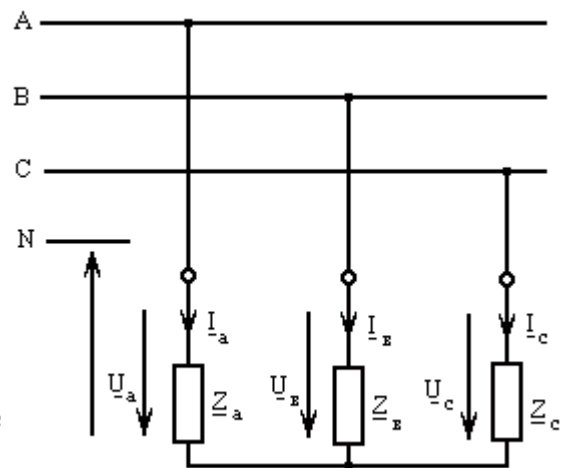


Figure 2.2 - Star-to-neutral receiver phase connection

8. We determine complex voltages at the phases of a symmetrical three-phase source (synchronous generator)

$$\underline{U}_A = \frac{U_{\pi}}{\sqrt{3}} e^{j^0} = \frac{220}{1.73} e^{j^0} = 127 e^{j^0} \text{ B,}$$

$$\underline{U}_B = \frac{U_{\pi}}{\sqrt{3}} e^{-j120^0} = \frac{220}{1.73} (\cos 120^0 - j \sin 120^0) = -63.5 - j110 \text{ B,}$$

$$\underline{U}_C = \frac{U_{\pi}}{\sqrt{3}} e^{j120^0} = \frac{220}{1.73} (\cos 120^0 + j \sin 120^0) = -63.5 + j110 \text{ B,}$$

9. Determine the complex voltages at the receiver phases. Since the resistance of the connecting wires (linear and neutral) is zero,

$$\underline{U}_A = \underline{U}_a = 127 \text{ B, } \underline{U}_B = \underline{U}_b = 127 e^{-j120^0} \text{ B, } \underline{U}_C = \underline{U}_c = 127 e^{j120^0} \text{ B.}$$

10. Determine the complex currents in the receiver phases using Ohm's law for

$$\text{a section of the circuit} \quad \underline{I}_a = \frac{\underline{U}_a}{\underline{Z}_a} = \frac{127 e^{j^0}}{10} = 12.7 e^{j^0} = 12.7 \text{ A}$$

$$\underline{I}_b = \frac{\underline{U}_b}{\underline{Z}_b} = \frac{127 e^{-j120^0}}{20 e^{-j90^0}} = 6.35 e^{-j30^0} = 5.5 - j3.175 \text{ A.}$$

$$\underline{I}_c = \frac{\underline{U}_c}{\underline{Z}_c} = \frac{127 e^{j120^0}}{30 e^{j90^0}} = 4.23 e^{j30^0} = 3.667 + j2.117 \text{ A.}$$

11. The complex current in a neutral wire can be determined using Kirchhoff's first law:

$$\underline{I}_N = \underline{I}_a + \underline{I}_b + \underline{I}_c = 12.7 + 5.5 - j3.175 + 3.667 + j2.117 = 21.868 - j1.058 = 21.894 e^{-j2.8^0} \text{ A.}$$

12. Complex interphase (linear) voltages at the receiver can be determined using Kirchhoff's second law

$$\underline{U}_{ab} = \underline{U}_a - \underline{U}_b = 127 + 63.509 + j110 = 190.5 + j110 = 220e^{j30^0} \text{ B.}$$

$$\underline{U}_{bc} = \underline{U}_b - \underline{U}_c = -63.509 - j110 + 63.509 - j110 = -j220 = 220e^{-j90^0} \text{ B.}$$

$$\underline{U}_{ca} = \underline{U}_c - \underline{U}_a = -63.509 + j110 - 127 = -190.5 + j110 = 220e^{j150^0} \text{ B.}$$

13. A vector diagram of currents and voltages is shown in Figure 2.3

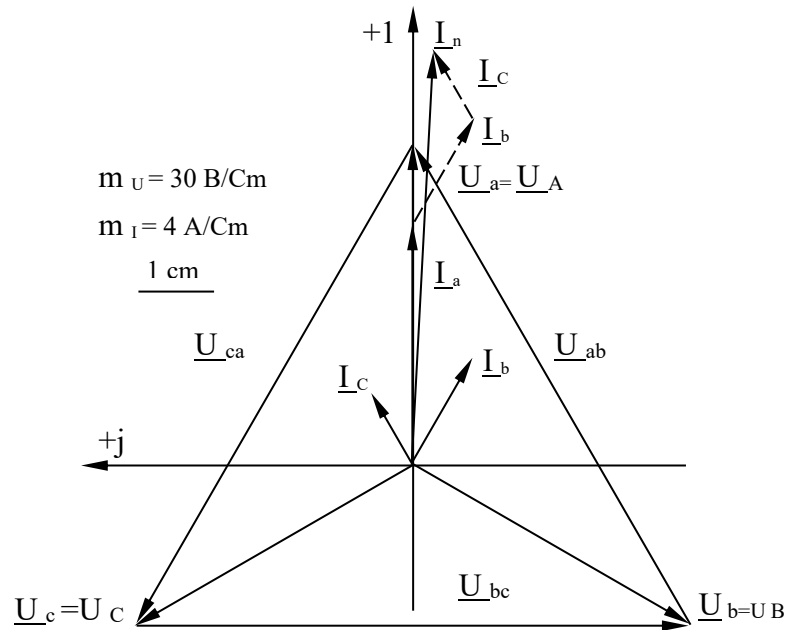


Figure 2.3

14. Let's calculate the complex power consumed by a three-phase receiver

$$\underline{S} = \underline{U}_a^* \underline{I}_a + \underline{U}_b^* \underline{I}_b + \underline{U}_c^* \underline{I}_c = 127 \cdot 12.7 + 127e^{-j120^0} \cdot 6.351e^{-j30^0} + 127e^{j120^0} \cdot 4.234e^{-j30^0} = 1613 - j269 \text{ BA.}$$

2.2.2 Calculation of a three-phase circuit connection according to the scheme
"star on a neutral wire break"

9. Determining complex voltages in the phases of a symmetrical three-phase circuit

$$\underline{U}_A = \frac{U_{\pi}}{\sqrt{3}} e^{j^0} = \frac{220}{1.73} e^{j^0} = 127e^{j^0} \text{ B,}$$

$$\underline{U}_B = \frac{U_{\pi}}{\sqrt{3}} e^{-j120^0} = \frac{220}{1.73} e^{-j120^0} = 127e^{-j120^0} \text{ B,}$$

$$\underline{U}_C = \frac{U_{\pi}}{\sqrt{3}} e^{j120^0} = \frac{220}{1.73} e^{j120^0} = 127e^{j120^0} \text{ B.}$$

10. Determining the complex conductivities of the receiver phases

$$\underline{Y}_a = \frac{1}{\underline{Z}_a} = \frac{1}{10} = 0.1 \text{ CM}, \quad \underline{Y}_b = \frac{1}{\underline{Z}_b} = \frac{1}{-j20} = 0.05e^{j90^\circ} = j0.05 \text{ CM},$$

$$\underline{Y}_c = \frac{1}{\underline{Z}_c} = \frac{1}{j30} = 0.033e^{-j90^\circ} = -j0.033 \text{ CM}.$$

11. Determine the neutral displacement voltage (voltage between neutral points of the network and the receiver)

$$\underline{U}_{nN} = \frac{\underline{U}_A \cdot \underline{Y}_a + \underline{U}_B \cdot \underline{Y}_b + \underline{U}_C \cdot \underline{Y}_c}{\underline{Y}_a + \underline{Y}_b + \underline{Y}_c} = \frac{127e^{j0^\circ} \cdot 0.1 + 127e^{-j120^\circ} \cdot 0.05e^{j90^\circ} + 127e^{j120^\circ}}{0.1 + j0.05 - j0.033} =$$

$$= 211.057 - j45.761 = 215.96e^{-j12.23^\circ} \text{ B}.$$

12. Determining complex voltages at the receiver phases

$$\underline{U}_a = \underline{U}_A - \underline{U}_{nN} = 127 - 211.057 + j45.761 = -84.04 + j45.76 = 95.69e^{j151^\circ} \text{ B}$$

$$\underline{U}_b = \underline{U}_B - \underline{U}_{nN} = -63.509 - j110 - 211.057 + j45.761 = -274.565 - j64.239 =$$

$$= 281.98e^{-j167^\circ} \text{ B}$$

$$\underline{U}_c = \underline{U}_C - \underline{U}_{nN} = -63.509 + j110 - 211.057 + j45.761 = -274.565 + j155.76 = 315.67e^{j150^\circ} \text{ B}.$$

13. Calculating complex currents in receiver phases using Ohm's law

$$\underline{I}_a = \underline{U}_a \underline{Y}_a = 95.69e^{j151^\circ} \cdot 0.1 = 9.569e^{j151^\circ} \text{ A},$$

$$\underline{I}_b = \underline{U}_b \underline{Y}_b = 281.98e^{-j167^\circ} \cdot 0.05e^{j90^\circ} = 14.1e^{-j77^\circ} \text{ A},$$

$$\underline{I}_c = \underline{U}_c \underline{Y}_c = 315.67e^{j150^\circ} \cdot 0.33 \cdot e^{-j90^\circ} = 10.5e^{j60^\circ} \text{ A}.$$

14. Using Kirchhoff's second law, let's determine the phase-to-phase (linear) voltages at the receiver

$$\underline{U}_{ab} = \underline{U}_a - \underline{U}_b = -84.04 + j45.76 + 274.565 - j64.239 = 190.526 + j110 = 220e^{j30^\circ} \text{ B}$$

$$\underline{U}_{bc} = \underline{U}_b - \underline{U}_c = -274.565 - j64.239 + 274.565 - j155.761 = -j220 = 220e^{-j90^\circ} \text{ B}$$

$$\underline{U}_{ca} = \underline{U}_c - \underline{U}_a = -274.565 + j155.761 + 84.04 - j45.761 = -190.526 + j110 = 220e^{j150^\circ} \text{ B}.$$

15. Based on the results of the calculations of currents and voltages, we build vector diagrams of currents and voltages (Figure 2.4)

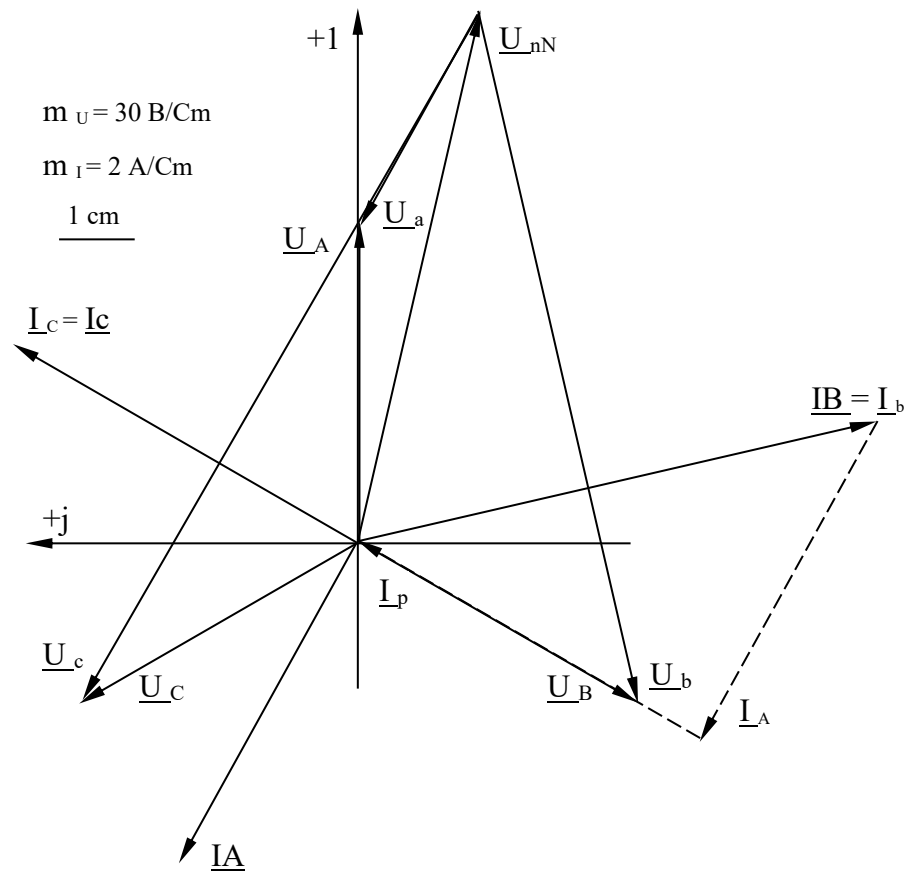


Figure 2.4

16. Let's calculate the power consumed by a three-phase receiver

$$\begin{aligned}
 \underline{S} &= \underline{U}_a^* \underline{I}_a + \underline{U}_b^* \underline{I}_b + \underline{U}_c^* \underline{I}_c = 95.691e^{j151^\circ} \cdot 9.569e^{-j151^\circ} + 281.98e^{-j167^\circ} \cdot 14.1e^{j76.8^\circ} + \\
 &+ 315.67e^{-j150^\circ} \cdot 10.522e^{-j60^\circ} = 915.676 - j654.054 \text{ BA}
 \end{aligned}$$

2.2.3. Calculation of a three-phase connection circuit according to the "star without neutral wire" scheme in case of a short circuit of phase "a" of the receiver

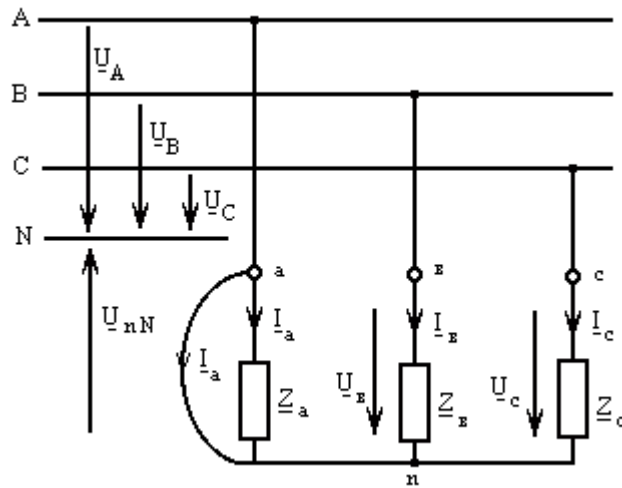


Figure 2.5 - Connection of the phases of the receiver according to the scheme "star without neutral wire" and the short circuit of the phase "a" of the receiver

9. Determining complex voltages in the phases of a symmetrical three-phase circuit

$$\underline{U}_A = \frac{U_{\pi}}{\sqrt{3}} e^{j0} \quad \underline{U}_B = \frac{U_{\pi}}{\sqrt{3}} e^{-j120^\circ} \quad \underline{U}_C = \frac{U_{\pi}}{\sqrt{3}} e^{j120^\circ}$$

10. The offset voltage is determined by the value of the complex voltage of the network phase to which the shorted phase of the receiver is connected. In the case under consideration

$$\underline{U}_{nN} = \underline{U}_A = 127 e^{j0} = 127 \text{ B.}$$

11. Determining complex voltages at the receiver phases

$$\underline{U}_a = \underline{U}_A - \underline{U}_{nN} = 127 - 127 = 0 \text{ B}$$

$$\underline{U}_b = \underline{U}_B - \underline{U}_{nN} = -63.509 - j110 - 127 = -190.526 - j110 = 220 e^{-j150^\circ} \text{ B}$$

$$\underline{U}_c = \underline{U}_C - \underline{U}_{nN} = -63.509 + j110 - 127 = -190.526 + j110 = 220 e^{j150^\circ} \text{ B}$$

12. Complex currents in phases, calculated using Ohm's law

$$\underline{I}_a = \frac{\underline{U}_a}{\underline{Z}_a} = \frac{0}{10} = 0 \text{ A}, \quad \underline{I}_b = \frac{\underline{U}_b}{\underline{Z}_b} = \frac{220 e^{-j150^\circ}}{-j20} = 11 e^{-j60^\circ} = 5.5 - j9.526 \text{ A}$$

$$\underline{I}_c = \frac{\underline{U}_c}{\underline{Z}_c} = \frac{220 e^{j150^\circ}}{j30} = 7.333 e^{j60^\circ} = 3.667 + j6.351 \text{ A.}$$

13. Complex currents in the line wire "A" are determined using Kirchhoff's first law

$$\underline{I}_A = -\underline{I}_b - \underline{I}_c = -5.5 + j9.526 - 3.667 - j6.351 = -9.167 + j3.175 = 9.7 e^{j161^\circ} \text{ A}$$

Complex currents in line wires B and C are equal to phase currents, i.e.

$$\underline{I}_B = \underline{I}_b = 11 e^{-j60^\circ} \text{ A}, \quad \underline{I}_C = \underline{I}_c = 7.333 e^{j60^\circ} \text{ A}$$

14. Interphase (linear) voltages at the receiver are determined using Kirchhoff's second law

$$\underline{U}_{ab} = \underline{U}_a - \underline{U}_b = 0 + 190.526 + j110 = 220e^{j30^\circ} \text{ B}$$

$$\underline{U}_{bc} = \underline{U}_b - \underline{U}_c = -190.525 - j110 + 190.526 - j110 = -j220 = 220e^{j90^\circ} \text{ B}$$

$$\underline{U}_{ca} = \underline{U}_c - \underline{U}_a = -190.526 + j110 - 0 = 220e^{j150^\circ} \text{ B.}$$

15. A vector diagram of currents and voltages is shown in Figure 2.6

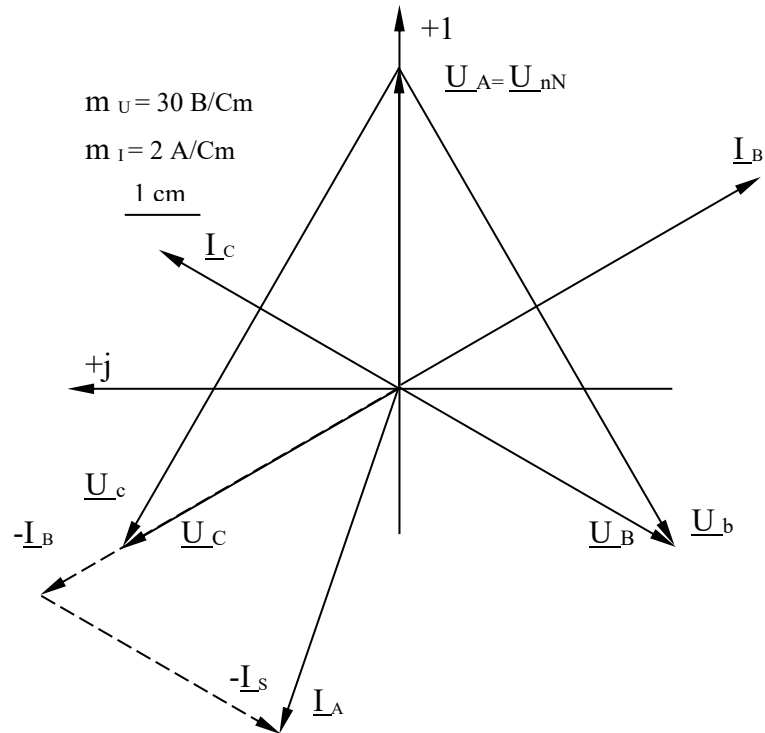


Figure 2.6

16. Let's calculate the power consumed by a three-phase receiver:

$$\underline{S} = \underline{U}_a^* \underline{I}_a + \underline{U}_b^* \underline{I}_b + \underline{U}_c^* \underline{I}_c = 220e^{-j150^\circ} 11e^{-j60^\circ} + 220e^{j150^\circ} \cdot 7.333e^{j60^\circ} = -j806.667 \text{ BA}$$

2.2.4 Calculation of the three-phase circuit of the receiver phase connection according to the "triangle" scheme

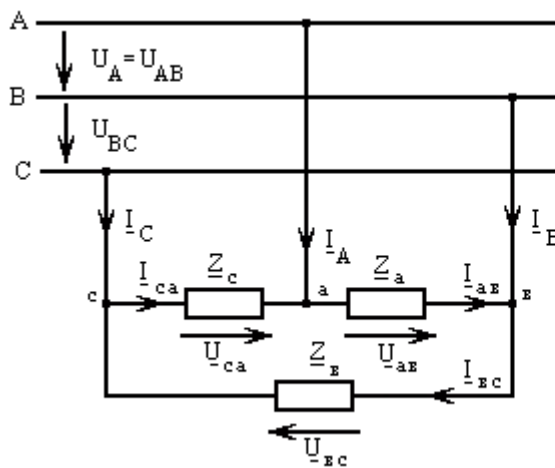


Figure 2.7 - Connection of receiver phases according to the "triangle" scheme

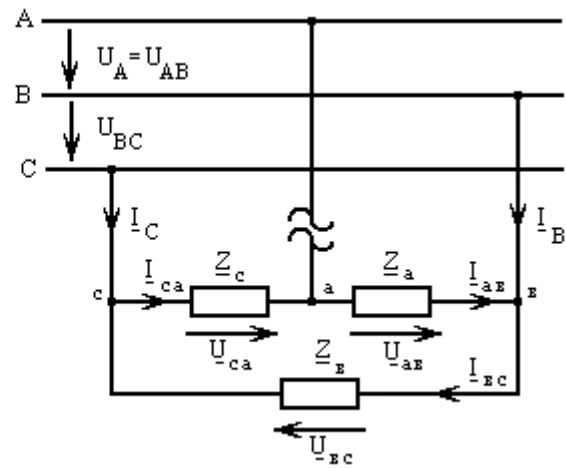


Figure 2.8 - Connection of the receiver phases according to the "triangle" scheme and the break of the line wire "A"

10. We determine the complex linear voltages of a symmetrical three-phase circuit

$$\underline{U}_{AB} = U_{\pi} e^{j0} = 220 e^{j0} = 220 \text{ B},$$

$$\underline{U}_{BC} = U_{\pi} e^{j120^\circ} = 220 e^{-j120^\circ} = -110 - j190.526 \text{ B}$$

$$\underline{U}_{CA} = U_{\pi} e^{j120^\circ} = 220 e^{j120^\circ} = -110 + j190.526 \text{ B}.$$

11. The complex stresses at the receiver phases, provided that the resistances of the connecting (line) wires are zero, will be determined by the corresponding complex line stresses:

$$\underline{U}_{ab} = \underline{U}_{AB} = 220 \text{ B}, \quad \underline{U}_{bc} = \underline{U}_{BC} = 220 e^{-j120^\circ} \text{ B}, \quad \underline{U}_{cb} = \underline{U}_{CA} = 220 e^{j120^\circ} \text{ B}.$$

12. Complex currents in the receiver phases are determined using Ohm's law:

$$\underline{I}_{ab} = \frac{\underline{U}_{ab}}{\underline{Z}_a} = \frac{220 e^{j0}}{10} = 22 e^{j0} \text{ A} = 22 \text{ A}$$

$$\underline{I}_{bc} = \frac{\underline{U}_{bc}}{\underline{Z}_b} = \frac{220 e^{-j120^\circ}}{-j20} = 11 e^{-j30^\circ} = 9.526 - j5.5 \text{ A}$$

$$\underline{I}_{ca} = \frac{\underline{U}_{ca}}{\underline{Z}_c} = \frac{220 e^{j120^\circ}}{j30} = 7.33 e^{j30^\circ} = 6.351 + j3.667 \text{ A}$$

13. Complex currents in line wires can be determined using Kirchhoff's first law

$$\underline{I}_A = \underline{I}_{ab} - \underline{I}_{ca} = 22 - 6.351 - j3.667 = 15.649 - j3.667 = 16.073 e^{-j13^\circ} \text{ A}$$

$$\underline{I}_B = \underline{I}_{bc} - \underline{I}_{ab} = 9.526 - j5.5 - 22 = -12.474 - j5.5 = 13.632 e^{-j156^\circ} \text{ A}$$

$$\underline{I}_C = \underline{I}_{ca} - \underline{I}_{bc} = 6.351 + j3.667 - 9.526 + j5.5 = -3.175 + j9.167 = 9.7 e^{j109^\circ} \text{ A}.$$

14. Based on the results of the calculations, we build a vector diagram of currents and voltages (Figure 2.9).

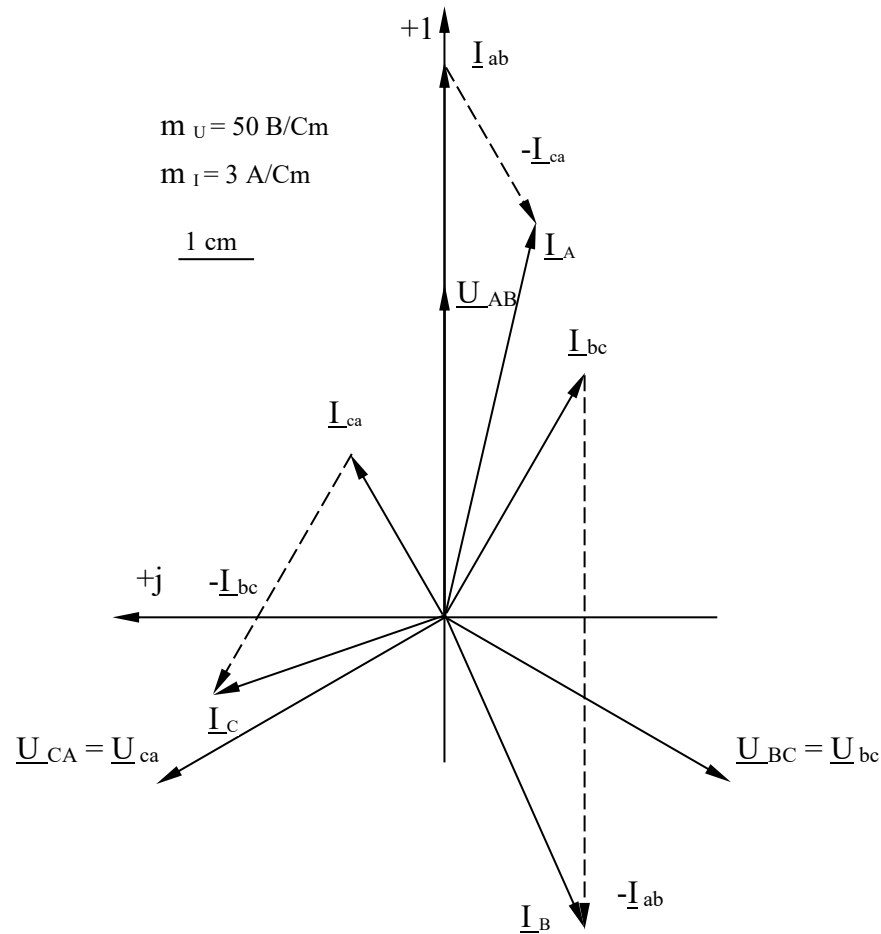


Figure 2.9

15. Calculating the Complex Power Consumed by a Three-Phase Receiver

$$\underline{S} = \underline{U}_{ab}^* \underline{I}_{ab} + \underline{U}_{bc}^* \underline{I}_{bc} + \underline{U}_{ca}^* \underline{I}_{ca} = 220.22 + 220e^{-j120^\circ} \cdot 11e^{j30^\circ} + 220e^{j120^\circ} \cdot 7.33e^{-j30^\circ} = 4840 - j806.667 \text{ BA.}$$

2.2.5 Calculation of the three-phase circuit of the receiver phase connection according to the "triangle" scheme in case of a break in the line wire "A"

1. Draw a circuit diagram when a line wire is broken (Figure 2.8). Conditionally positive directions of currents in phases are indicated as in the diagram Figure 2.7. From the analysis of the diagram (Figure 2.8) it follows that the complex voltage at

the "B" phase "B" of the receiver $\underline{Z}_b$ is equal to the phase voltage. $\underline{U}_{bc} = 220e^{-j120^\circ}$ B.

$$\underline{U}_{bc} = 220e^{-j120^\circ} \text{ B.}$$

2. Using Ohm's law, calculate the currents in the phases of the receiver

$$\underline{I}_{ab} = -\frac{\underline{U}_{bc}}{\underline{Z}_a + \underline{Z}_c} = -\frac{220e^{-j120^\circ}}{10 + j30} = 6.957e^{-j11.6^\circ} = 6.816 - j1.395 \text{ A}$$

$$\underline{I}_{bc} = \frac{\underline{U}_{bc}}{\underline{Z}_b} = \frac{220e^{-j120^\circ}}{-j20} = 11e^{-j30^\circ} = 9.526 - j5.5 \text{ A}$$

$$\underline{I}_{ca} = \frac{-\underline{U}_{bc}}{\underline{Z}_a + \underline{Z}_c} = -\frac{220e^{-j120^\circ}}{10 + j30} = 6.957e^{-j11.6^\circ} = 6.816 - j1.395 \text{ A.}$$

3. Complex currents in line wires are determined by Kirchhoff's first law

$$\underline{I}_A = \underline{I}_{ab} - \underline{I}_{ca} = 0$$

$$\underline{I}_B = \underline{I}_{bc} - \underline{I}_{ab} = 9.526 - j5.5 - 6.816 + j1.395 = 2.711 - j4.105 = 4.919e^{-j56.5^\circ} \text{ A.}$$

$$\underline{I}_C = \underline{I}_{ca} - \underline{I}_{bc} = 6.816 - j1.395 - 9.526 + j5.5 = -2.711 + j4.105 = 4.919e^{j123^\circ} \text{ A.}$$

4. Complex voltages at the phases of the receiver "a" and "c" are determined according to Ohm's law

$$\underline{U}_{ab} = \underline{I}_{ab} \cdot \underline{Z}_a = 6.957e^{-j11.6^\circ} \cdot 10 = 69e^{-j11.6^\circ} = 68.158 - j13.947 \text{ B}$$

$$\underline{U}_{ca} = \underline{I}_{ca} \cdot \underline{Z}_c = 6.957e^{-j11.6^\circ} \cdot 30e^{j90^\circ} = 208.71e^{j78.4^\circ} = 41.842 + j204.473 \text{ B.}$$

5. Comprehensive power consumed by the receiver

$$\underline{S} = |\underline{I}_{ab}|^2 (\underline{Z}_a + \underline{Z}_c) + |\underline{I}_{bc}|^2 \underline{Z}_b = 6.957^2 (10 + j30) + 11^2 (-j20) = 484 - j968 \text{ BA.}$$

6. Gross power consumed by the receiver

$$S = |\underline{S}| = \sqrt{P^2 + Q^2} = \sqrt{484^2 + 968^2} = 1082 \text{ BA.}$$

16. Construct a vector diagram of currents and voltages based on the results of calculations (Figure 2.10)

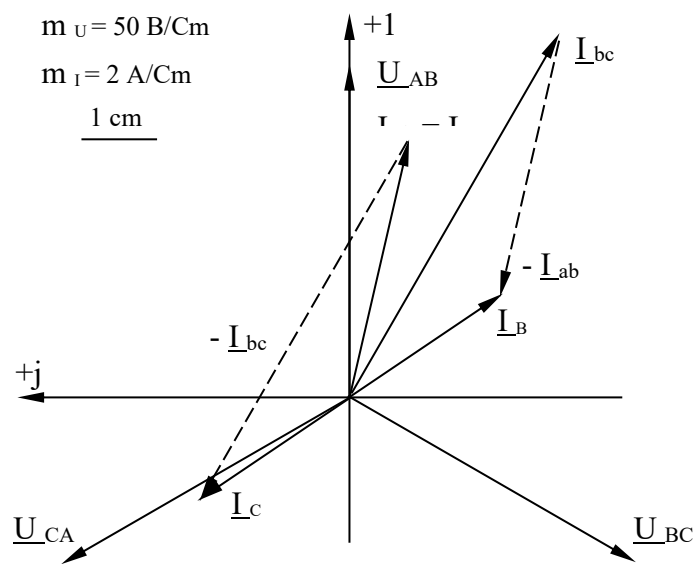


Figure 2.10

2.3 Analysis of transient processes in linear electrical circuits

In the electrical circuit (Figure 3.1), calculate and plot the transient currents $i(t)$ and the voltage on the reactive element $u(t)$ if $R_1=0.2\text{k}\Omega$, $R_2=0.2\text{k}\Omega$, $C=20\text{ pF}$, $E=20\text{ V}$.

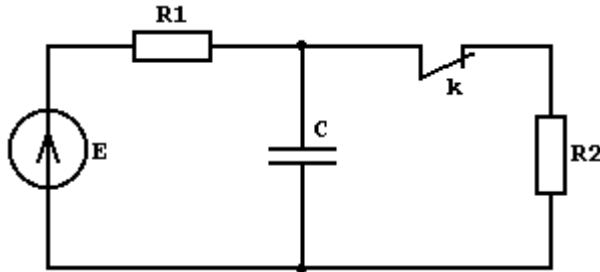


Figure 3.1

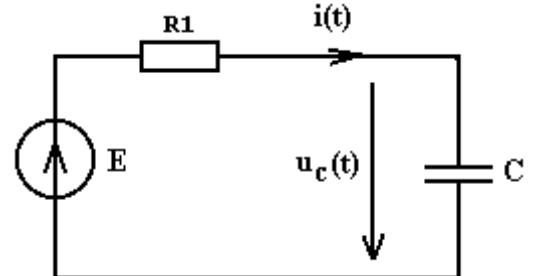


Figure 3.2

2.3.1 Analysis of transient processes by the classical method

Solution

1. In a given electrical circuit (Figure 3.1) there is only one capacitive element, in the electric field of which energy can be gasped, therefore, to determine the initial conditions, the second switching law is used, according to which

$$u_c(+0) = u_c(-0) = u_c(0) = \frac{E \cdot R_2}{R_1 + R_2} = \frac{E \cdot 200}{400} = \frac{E}{2} = \frac{20}{2} = 10 \text{ B.} \quad (3.1)$$

2. Let us construct an equation for voltages according to Kirchhoff's second law for a circuit after switching in a circuit (Figure 3.2) $u_{R1} + u_c = E$ or $R_1 i + u_c = E$

$$, \quad R_1 C \frac{du_c}{dt} + u_c = E \quad (3.2)$$

3. The transient voltage is defined as $u_c(t) = u_c^{CB} + u_c^{yCT}$ (3.3).

4. u_c^{yCT} From equation (3.2) we find at $\frac{du_c}{dt} = 0$, i.e. $u_c^{yCT} = E = 20 \text{ B.}$

5. $u_c^{CB}(t) = Ae^{st}$ - general solution of a homogeneous linear equation $R_1 C \frac{du_c}{dt} + u_c = 0$

To determine the root s , let us make a characteristic equation $R_1 C \cdot s + 1 = 0$

$$\text{Hence } s = -\frac{1}{R_1 C} = -\frac{1}{200 \cdot 2 \cdot 10^{-12}} = -\frac{1}{4 \cdot 10^{-10}} = -25 \cdot 10^8 \text{ c}^{-1}.$$

We find the constant A from equation (3.3) taking into account the initial conditions $u_c(0) = u_c^{yCT}(0) + u_c^{CB}(0)$, $\frac{E}{2} = E + Ae^{s \cdot 0}$, $A = -\frac{E}{2} = -10 \text{ B,}$

$$\text{therefore, } u_c^{CB}(t) = -\frac{E}{2} e^{-\frac{t}{R_1 C}} = -\frac{E}{2} e^{-\frac{t}{\tau}} = -10 e^{-\frac{t}{4 \cdot 10^{-10}}} = -10 \cdot e^{-25 \cdot 10^8 t} \text{ B.}$$

Here $\tau = R_1 C = 4 \cdot 10^{-10} \text{ c}$, is τ the time constant of the chain.

6. Transient voltage

$$u_c(t) = u_c^{yct} + u_c^{cb} = E - \frac{E}{2} \cdot e^{-\frac{t}{R_1 C}} = E \left(1 - 0.5 \cdot e^{-\frac{t}{R_1 C}} \right) = 20 \left(1 - 0.5 \cdot e^{-25 \cdot 10^8 \cdot t} \right) \text{ B.}$$

7.

Transient

Current

$$i(t) = C \frac{du_c}{dt} = C \frac{d}{dt} \left(E - \frac{E}{2} \cdot e^{-\frac{t}{R_1 C}} \right) = -C \cdot \frac{E}{2} \cdot \left(-\frac{1}{R_1 C} \right) \cdot e^{-\frac{t}{R_1 C}} =$$

$$= \frac{1}{2} \cdot \frac{E}{R_1} \cdot e^{-\frac{t}{R_1 C}} = \frac{20}{2 \cdot 200} e^{-25 \cdot 10^8 \cdot t} = 0.05 e^{-25 \cdot 10^8 \cdot t} \text{ A.}$$

8. To build graphs $i(t)$ and $u_c(t)$, let's perform calculations (Table 1)

Table 1- Results of transient currents and voltages calculations

$t \cdot 10^{-10}, \text{ c}$	0	2	4	6	8	10	12	14	16	18	20
t/τ	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$e^{-t/\tau}$	1	0.61	0.37	0.22	0.14	0.08	0.05	0.03	0.018	0.011	0.007
$i(t), \text{ mA}$	0.05	0.03	0.018	0.011	0.007	0.004	0.0025	0.002	0.001	0.0005	0.0003
$u(t), \text{ B}$	10	14	16	17.8	18.6	19.2	19.5	19.7	19.8	19.89	19.9

9. Build Charts $u_c(t)$ and $i(t)$

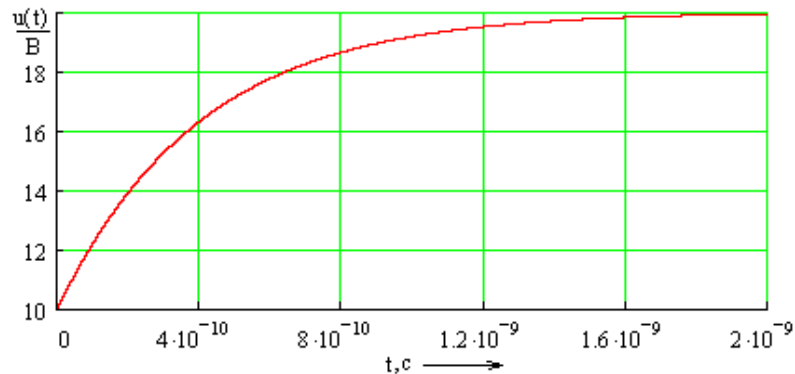


Figure 3.3

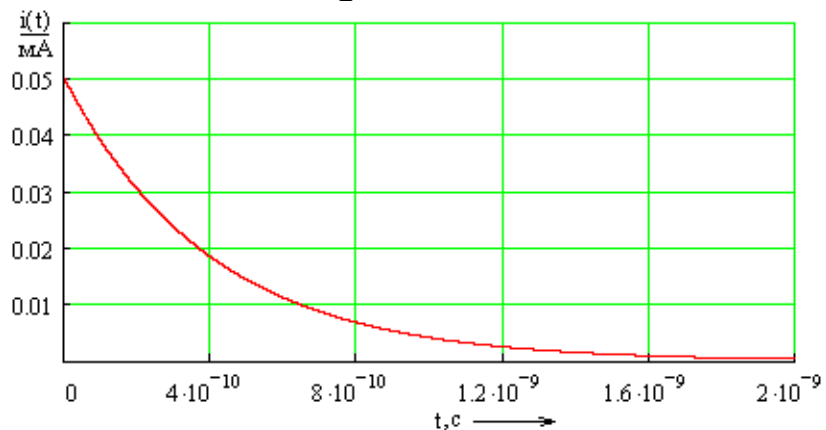


Figure 3.4

2.3.2 Analysis of transient processes by the operator method

Solution

1. In a given electrical circuit (Figure 3.1), determine the initial conditions according to the second switching law $u_c(0) = \frac{ER_1}{R_1 + R_2} = 10 \text{ B}$.
2. Draw up an operator replacement scheme (Figure 3.5), provided that the key "k" in the electrical circuit (Figure 3.1) is open

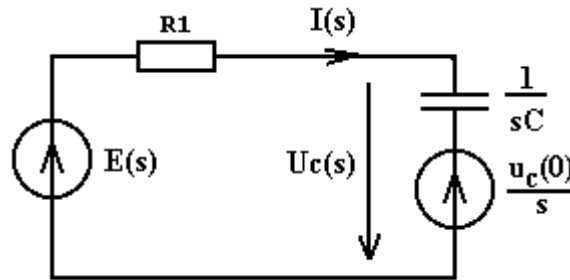


Figure 3.5

3. According to Ohm's law, we find $I(s) = \frac{E(s) - \frac{u_c(0)}{s}}{Z(s)} = \frac{\frac{E}{s} - \frac{u_c(0)}{s}}{\left(R_1 + \frac{1}{sC}\right)}$
4. Convert the expression for the operator current $I(s)$ into a form convenient for the Laplace tabular conversion (see Table 2, Item 4).

$$I(s) = \frac{\frac{E}{s} - \frac{u_c(0)}{s}}{\left(R_1 + \frac{1}{sC}\right)} = \frac{E - u_c(0)}{\frac{sRC + 1}{C}} = \frac{E - u_c(0)}{R\left(s + \frac{1}{RC}\right)} = \frac{1}{200} \cdot \frac{10}{s + 25 \cdot 10^8}$$

5. Using the Laplace transform table (see Table 2, item 4), using the linearity property of the Laplace transformation, we find the transient current $i(t) = 0.05e^{-25 \cdot 10^8 t} \text{ A}$.
6. The transient voltage is determined using Kirchhoff's second law for the circuit (Figure 3.6)

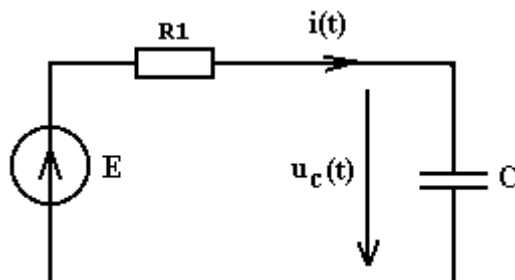


Figure 3.6

$$u_c(t) = u(t) = E - R_1 i(t) = 20 - 200 \cdot 0.05 \left(e^{-25 \cdot 10^8 t} \right) = 20 - 10 e^{-25 \cdot 10^8 t} \text{ B.}$$

7. To build graphs $i(t)$ and $u(t)$, we will perform calculations, and the results will be presented in Table 3

Table 2 - Table of Laplace transformations

№ p/n	F(s)	f(t), (t > 0)
1	1	$\delta(t)$
2	$\frac{1}{s}$	1
3	$\frac{A}{s}$	A
4	$\frac{1}{s+a}$	e^{-at}
5	$\frac{s}{s+a}$	$\delta(t) - ae^{-at}$
6	$\frac{1}{s(s+a)}$	$\frac{1}{a}(1 - e^{-at})$
7	$\frac{1}{(s+a)(s+b)}$	$\frac{1}{b-a}(e^{-at} - e^{-bt})$
8	$\frac{s}{(s+a)(s+b)}$	$\frac{1}{a-b}(ae^{-at} - be^{-bt})$
9	$\frac{1}{(s+a)^2}$	te^{-at}
10	$\frac{s}{(s+a)^2}$	$e^{-at}(1 - at)$
11	$\frac{1}{s(s+a)^2}$	$\frac{1}{a^2}(1 - e^{-at} - ate^{-at})$
12	$\frac{1}{s(s+a)(s+b)}$	$\frac{1}{ab(a-b)}[(a-b) + be^{-at} - ae^{-bt}]$

13	$\frac{1}{s^2 + a^2}$	$\frac{1}{a} \sin at$
14	$\frac{s}{s^2 + a^2}$	$\cos at$
15	$\frac{1}{s(s^2 + a^2)}$	$\frac{1}{a^2} (1 - \cos at)$
16	$\frac{1}{(s+b)^2 + a^2}$	$\frac{1}{a} e^{-bt} \sin at$
17	$\frac{s}{(s+b)^2 + a^2}$	$e^{-bt} \left(\cos at - \frac{b}{a} \sin at \right)$
18	$\frac{1}{s((s+b)^2 + a^2)}$	$\frac{1}{a^2 + b^2} \left[1 - e^{-bt} \left(\cos at + \frac{b}{a} \sin at \right) \right]$

Table 3- Results of the calculation of transient current and transient voltage

$t \times 10^{-10}, c$	0	2	4	6	8	10	12	14	16	18	20
t/τ	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
$e^{-t/\tau}$	1	0.61	0.37	0.22	0.14	0.08	0.05	0.03	0.018	0.011	0.007
$i(t), mA$	0.05	0.03	0.018	0.011	0.007	0.004	0.0025	0.002	0.001	0.0005	0.0003
$u(t), B$	10	14	16	17.8	18.6	19.2	19.5	19.7	19.8	19.89	19.9

8. Plotting the Graphs of $u(t)$ and $i(t)$

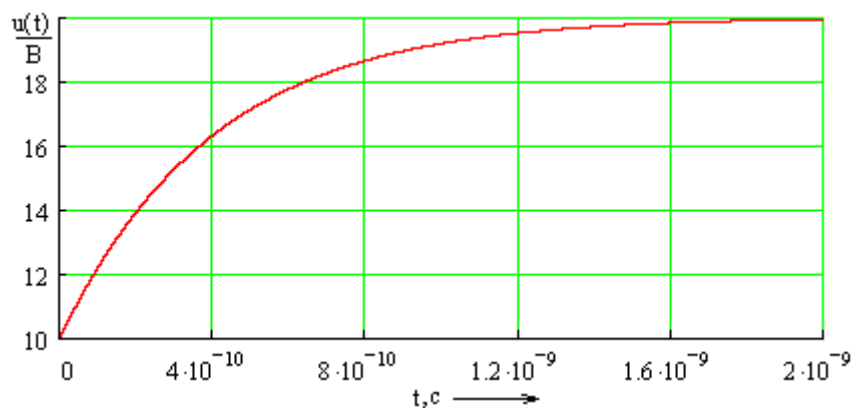


Figure 3.7

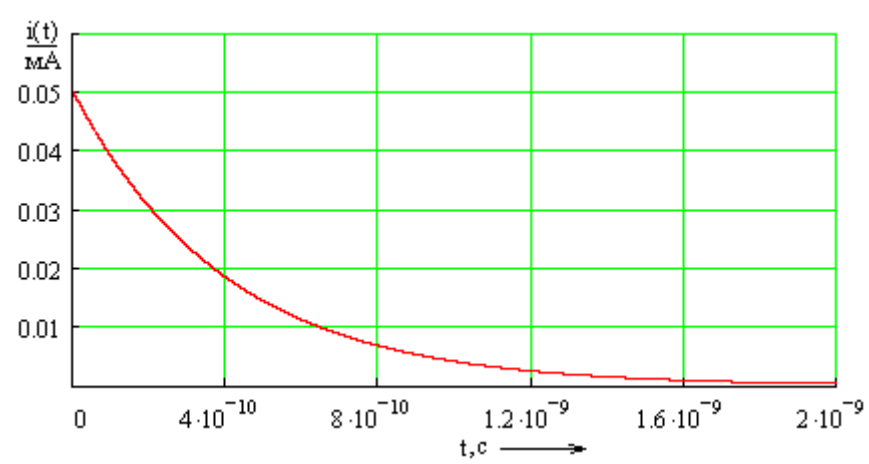


Figure 3.8

3 Requirements for the design of the term paper

The explanatory note is drawn up on A4 sheets in handwritten form.

When registering, comply with the requirements for explanatory notes of qualification works.

Tables, schemes, graphs are made in accordance with the requirements of GOST.

Write down formulas according to the requirements of GOST.

Letter designations of physical quantities must comply with the requirements of GOST.

The explanatory note is submitted for verification 3-4 days before the date of the defense of the term paper.

4 Questions for the defense of the term paper

4.1 Basic Concepts and Definitions

1. Current, voltage, EMF, power.
2. Electrical circuit, electrical circuit diagram, circuit replacement diagram.
3. A section of an electrical circuit, a branch, a node, a circuit.
4. Series, parallel, mixed connection of elements (branches) of an electrical circuit.
5. Ohm's law: for a homogeneous and inhomogeneous section of an electrical circuit, generalized Ohm's law.
6. Kirchhoff's laws.
7. Instantaneous current, active current, complex current, complex amplitude of current.
8. Forms of representation of complex numbers: algebraic, trigonometric, exponential and their interrelation.
9. Operations with complex numbers: addition, subtraction, multiplication, division, exponentiation.
10. Algorithm for calculating an electric circuit by the method of contour currents
11. Algorithm for calculating an electric circuit by the method of nodal potentials.

12. Algorithm for calculating an electrical circuit by the superposition method.
13. Algorithm for calculating an electric circuit by the method of an equivalent current generator.
14. Algorithm for calculating an electrical circuit using the equivalent voltage generator method.

4.2 Loop Current Method

1. For a given scheme (Figures 01-64), make a system of equations for calculating contour currents.
2. Determine the current in the specified branch by known contour currents.
3. Record the instantaneous current according to the given complex current.
4. For a given scheme (Figures 01-64), make an equation for the balance of capacities.
5. For the given instantaneous currents, build a vector diagram.

4.3 Method of nodal potentials

1. For a given scheme (Figures 01-64), make a system of equations for calculating nodal potentials.
2. Write down Ohm's law for the specified section of the circuit.
3. Determine the current in the specified branch.

4.4 Overlay Method

1. For a given circuit, determine the equivalent resistance.
2. Draw auxiliary circuits (Figures 01-64) for calculating the current in the specified branch.
3. Determine the current in the specified branch.

4.5 Equivalent Current Generator Method

1. For a given circuit (Figures 01-64) determine the current I_{kz} .
2. For a given circuit (Figures 01-64), determine the equivalent resistance of the generator.
3. Determine the current in the specified branch.

4.6 Equivalent Voltage Generator Method

1. For a given circuit (01-64 instructions for DKZ), determine the voltage U_{xx} .

2. For a given circuit (Figures 01-64), determine the equivalent resistance of the generator.
3. Determine the current in the specified branch.

4.7 Three-phase circuits

1. Write down the expression for the instantaneous EMF of a three-phase circuit.
2. Write down the expression for complex amplitudes and operating EMF of a three-phase circuit.
3. To construct a vector diagram for complex amplitudes and operating EMF of a three-phase circuit.
4. What are the Relationships Between Line and Phase Voltages in a Symmetrical Three-Phase Circuit?
5. How to determine the current in a neutral wire in a three-phase circuit when connecting the phases of the receiver according to the "star" scheme?
6. How to determine the neutral bias voltage of a three-phase circuit when connecting the phases of the receiver according to the "star" scheme?
7. What are the relations between linear and phase currents in a symmetrical three-phase circuit when connecting the phases of the successor according to the "triangle" scheme?

4.8 Transients

1. Formulate the 1st and 2nd laws of commutation.
2. Write down a first-order linear differential equation.
3. Which linear differential equation is called inhomogeneous? Give examples. Explain the algorithm for solving this equation. What is the general and partial solution of a linear differential equation?
4. Name the stages of the algorithm of the classical method of calculating transient currents and voltages in an electrical circuit.
5. Draw in operator form the substitution schemes of the ideal inductive and capacitive elements under zero and non-zero initial conditions.

6. List the main properties of Laplace's transformations.
7. Write the expression for Ohm's law in operator form at zero and non-zero initial conditions for a circuit containing R, L, C elements connected in series.
8. Name the stages of the algorithm of the operator method for calculating transient processes in an electrical circuit.

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