Міністерство освіти і науки України
Тернопільський національний технічний університет
імені Івана Пулюя

кафедра
електричної інженерії

Laboratory Manual

for Electrical Engineering

Ternopil 2025

«Laboratory Manual for Electrical Engineering»

Укладач: Н.А. Куземко. Тернопіль: ТНТУ, 2025. – 39 с.

Укладач: к.т.н., доц. Куземко Н.А.

Рецензент: к.т.н., доц. Дунець В.Л.

Комп'ютерний набір: Куземко Н.А.

Затверджено на засіданні кафедри електричної інженерії Тернопільського національного технічного університету імені Івана Пулюя.
Протокол № 9 від 21 березня 2025 року

Схвалено й рекомендовано до публікації НМК факультету прикладних інформаційних систем та електроінженерії Тернопільського національного технічного університету імені Івана Пулюя.
Протокол № 7 від 4 квітня 2025 року

Посібник складено відповідно до робочих програм курсів "Електротехніка, електроніка та мікропроцесорна техніка» та «Теорія електричних та магнітних кіл».

Introduction

This manual is a guide for conducting laboratory work.

It describes 9 laboratory works that students perform according to the course "Electrical Engineering, Electronics, and Microprocessor Technology" syllabus.

The laboratory works are designed taking into account the technical specifications of the measuring instruments used in the electrical engineering laboratory.

Before starting each laboratory work, in addition to reviewing the theoretical material, the student must complete a short homework task according to the variant specified by the instructor.

Each work provides brief theoretical information relevant to the lab work: basic analytical expressions, phasor diagrams, characteristic curves necessary for calculating and analyzing the operating modes of electrical circuits. Furthermore, it includes a list of measuring instruments, a circuit diagram and description of the circuit under investigation, explains the procedure for performing the laboratory work, as well as the order of processing experimental results and report formatting requirements. Students collect the electrical circuit diagrams independently under the guidance of the instructor. Control questions at the end of each work will help students navigate the studied material and prepare for the defense of their laboratory work.

The guide also provides definitions and units of measurement of physical quantities.

LABORATORY WORK 1
Investigation
of energy transfer from source to consumer

The purpose of the work. To investigate the energy transfer from source to consumer, electrical source operating modes and to learn practically how to determine the source parameters.

The simplest electrical circuit contains three main elements: electrical source (active element), consumer (passive element) and the wires. Besides, the circuit can have also additional elements: measuring devices, switches, fuses, contactors, etc.

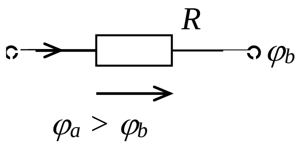


Fig.1.1

Electrical power is transformed into heating, mechanical energy, etc. at the *consumers*. The measure of this transformation is resistance R (fig.1.1). You can see the directions of the electrical values at fig.1.1.

Ohm’s law for this element is as follow $V = RI$ or $I = GV$, where R - is resistance, $G = 1/R$ - is conductivity. The power on resistive element is $P = RI^2 = GV^2$.

Heating, mechanical energy, etc. is transformed into electrical power at the *electrical sources*. The measure of this transformation is electromotive force (e.m.f.) E (fig.1.2). You can see the directions of the electrical values at fig.1.2.

The *ideal electrical source* (without losses) is characterized only by E . The power on the electrical source is $P = EI$.

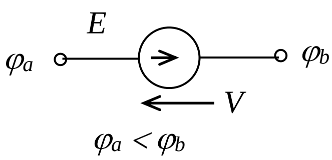


Fig.1.2

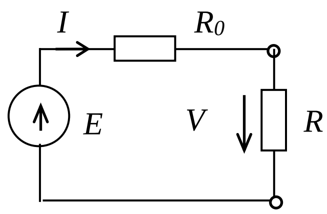
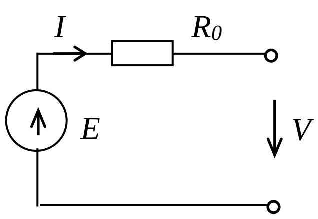


Fig.1.3

The *real electrical source* has losses and is characterized by E and R_0 (internal resistance), which reflects the losses. The simplest electrical circuit is shown at fig.1.3. For this circuit:

$$I = E/(R_0 + R), \text{ then } \quad V = E - R_0 I, \qquad V = RI, \qquad R_0 I + RI = E.$$

We can represent real electrical circuit by two substitution schemes: serial (fig.1.4) and parallel (fig.1.6). The external volt-ampere characteristic (fig.1.5) *V(I)*



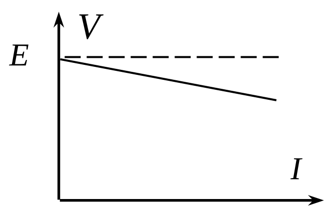


Fig.1.5

is the main characteristic of the source. Its analytical expression is $V = E - R_0 I$. At fig.1.5 solid line indicates the characteristic of real source, dashed line - the characteristic of ideal source. Boundary points of this characteristic correspond to the source boundary modes – open circuit (idle) mode (without loading), when

$I = 0$, $V = E = V_{OC}$ and short circuit mode, when $V = 0$, $I = I_{SC}$. The external characteristic of ideal source $V = E$ is represented by dashed line at fig.1.5.

Parallel substitution scheme (fig.1.6) consists of ideal current source J and internal conductivity G_0, which characterizes the losses. The external characteristic of real source (fig.1.7) is described by the equation $I = J - G_0 U$. The external characteristic of ideal source $I = J$ is represented by dashed line at fig.1.7.

Serial and parallel schemes are equivalent, it means you can transform one into another using such formulas:

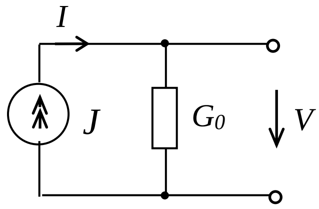


Fig.1.6

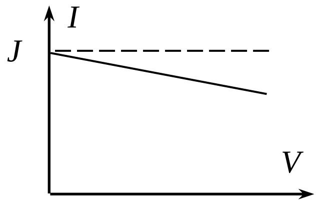


Fig.1.7

$$E = G_0 J,\ R_0 = 1/G_0,\ J = E/R_0,\ G_0 = 1/R_0.$$

The efficiency factor of the source characterizes the efficiency of energy transforming from the source to consumer:

$$\eta = \frac{P_R}{P_E} = \frac{VI}{EI} = \frac{V}{E},\quad V = \eta E,$$

where P_R - is a consumer power, P_E - is a source power.

We can also write down the efficiency factor using the elements parameters:

$$\eta = \frac{P_R}{P_R + \Delta P} = \frac{RI^2}{RI^2 + R_0 I^2} = \frac{R}{R_0 + R} = \frac{1}{1 + R_0/R},$$

where ΔP - are power losses.

There are three main *electrical circuit modes:* nominal, operating and boundary.

The nominal mode is the best mode for the working device, the device nominal parameters are shown in its technical passport (I_{NOM},V_{NOM},P_{NOM}).

Operating mode is a mode, where the deviation from the nominal parameters is not big.

Boundary modes are: open circuit or idle (non-working) and a short circuit (emergency) modes. For the open circuit (o.c.) mode $R=\infty$, then using the scheme at fig.1.3, we can write down:

$$I = \frac{E}{R_0 + R} = \frac{E}{R_0 + \infty} = 0,\ V = E - R_0 I = E,\ \eta = 1.$$

For short circuit mode (s.c.) $R=0$, then using the scheme at fig.1.3, we can write down:

$$V = RI,\ V=0,\ I = E/R_0 = I_{SC},\ \eta = 0.$$

The methods of open circuit and short circuit experiments can be used for defining the parameters of the source (E, R_0): $V_{OC} = E, R_0 = E/I_{SC}$. The experiment of s.c. mode is provided at low voltage.

Electrical source operating modes:

- voltage generator, when the voltage at the clamps of the source practically does not depend on the current, thus $V \approx E$, and this mode is close to o.c. In this mode $R_0 I << RI$ (fig.1.4), that's why the condition of it is $R_0 << R$ and $\eta \approx 1$. This is the main operating mode of electrical engineering devices.

- current generator, when the current at the clamps of the source practically does not depend on the voltage, thus $I \approx J$, and this mode is close to to s.c. In this mode $G_0 U << GU$ (fig.1.6), that's why the condition of it is $G_0 << G$ ($R_0 >> R$).

-balanced mode – the maximum power $P = RI^2$ is transferred from the source to the consumer at this mode? $I = E/(R_0 + R)$, and $P = RE^2/(R_0 + R)^2$ at this mode.

The condition of this mode comes out from the expression $dP/dR = 0$, that means $R_0 = R$ and $\eta = 0.5$. This mode is used in electronics.

Homework

At given voltage V, load resistance R, and efficiency factor η of the circuit on fig.1.8 to define source internal resistance R_0 and electromotive force E, source and consumer powers. To calculate the efficiency factor when the load will be $R/10$. Tasks variants are listed in the table 1.1.

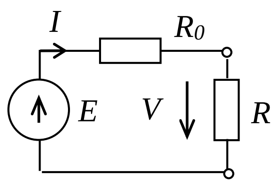


Fig. 1.8

Table 1.1

Var	1	2	3	4	5	6	7	8	9	10
η	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
R, Ω	51	62	73	84	95	106	117	128	139	150
V, V	110	120	130	140	150	160	170	180	190	100

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 5, measuring devices.

The elements of the board 5: variable resistors $R_{ЛГ}$ «Грубо», $R_{ЛТ}$ «Точно», R_C – switch of the resistors $R_2 \div R_{10}$.

Measuring devices: $PV(PΩ)$ – multimeter Щ4300 to measure voltage, options: $< -\!>$, $< V >$, $< 200\ V >$; to measure resistance, options: $< -\!>$, $< R >$, $< 2\ кΩ >$; PmA – milliamperemeter Э536, limit of measuring

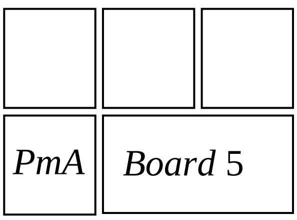


Fig. 1.9

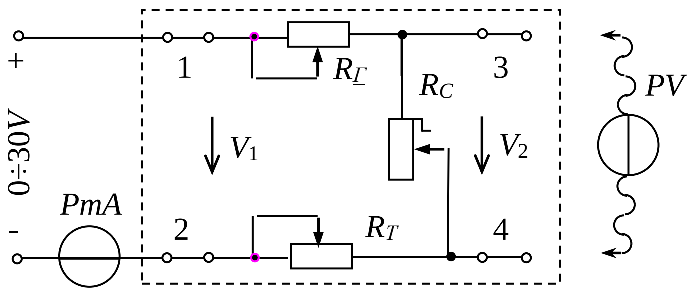


Fig. 1.10

$<100\ mA>$. The way of measuring devices placement is shown in fig. 1.9.

The work execution order

1. Connect the multimeter $P\Omega$ to clamps 3–4 and by using the switch R_C measure the resistances $R_2 \div R_{10}$. Write down the results to the table 1.2.

2. Connect the multimeter $P\Omega$ to clamps 1–2, short clamps 3–4 and set the line resistance $R_L = R_6$ by variable resistors $R_{ЛГ}$ «Грубо», $R_{ЛТ}$ «Точно».

3. Collect the circuit (fig. 1.10) and connect it to the clamps $< - >$ $< 0 \div 30\ V >$. Place *LATR* switch in position $< \ - >$, $<0 \div 30V>$.

4. Short the clamps 3–4 and set the short circuit current $I_{sc} = 100\ mA$. Write down the results of measuring to the table 1.2 item sc. Open the clamps 3–4 and measure the open circuit voltage. Write down the results of measuring to the table 1.2 item oc.

5. Set the voltage across clamps 1–2 $V_1 = V_{1oc}$ and maintaining it constant during the experiment ($V_1 = const$), change the resistance R_C turning it from 2 to 10 positions. Write down the results of measuring to the table 1.2, items 2-10.

6. Calculate (table 1.2): the consumer resistances $R_c = V_2/I$, the voltage drops $\Delta V = V_1 - V_2$, the input power $P_1 = V_1 I$, the output power $P_2 = V_2 I$, the power losses $\Delta P = P_1 - P_2$, the efficiency factor $\eta = P_2/P_1$. Write down the results of calculations to the table 1.2.

7. Define electromotive force $E = V_{1oc}$, the source internal resistance $R_0 = (V_{1oc} - V_{1sc})/I_{sc}$ and the line resistance $R_L = V_{1sc}/I_{sc}$.

8. Determine the current source parameters J, G_0 for known voltage source parameters E, R_0. Draw the current source and the voltage source substitutional schemes.

Table 1.2.

Measurements					*Calculations*					
№	*R_C, Ω*	*V_1, V*	*I, mA*	*V_2 V*	*R_C, Ω*	*ΔV V*	*P_1 W*	*P_2 W*	*ΔP W*	*η*
sc										
oc										
2										
3										
4										
5										
6										
7										
8										
9										
10										

9. Draw graphs: $V_1(I)$, $V_2(I)$, $\Delta V(I)$ and $P_1(I)$, $P_2(I)$, $\Delta P(I)$, $\eta(I)$ by using the table 1.2

Make conclusions about electrical source working regimes, the methods of determining the source parameters, the value of losses, the efficiency factor and how the source output voltage change when the load increase.

Report on the work

The name and the purpose of the work. Homework – the calculation of the circuit. The schematic diagram of the investigated circuit (fig 1.10). The table 1.2. The results of calculations of source parameters. The graphs. The conclusions.

Control questions

1. Give the definition of electrical circuit. Draw the simplest electrical circuit and mark the directions of electrical values in it. What are the main and the additional elements of the electrical circuit, what are their purposes?
2. Name and characterize the main circuit working regimes.
3. What devices do we call consumers? What parameter characterizes the measure of energy transfer?
4. Draw the consumer conditional designation and mark the directions of the electrical values in it. Write down the Ohm`s law and the power expression for the consumer.
5. What devices do we call the power sources? What parameter characterizes the ideal source?
6. Draw the power source conditional designation and mark the directions of electrical values in it. Write down the power expression for it.
7. How to choose the circuit current direction? What is the condition of generator working regime and consumer working regime of the electrical source?
8. What are the main parameters of the voltage source? What is the difference between real and ideal voltage source?
9. Draw the serial substitution scheme of electrical source. Write down the voltage source equation.
10. Draw the parallel substitution scheme of electrical source. Write down the current source equation.
11. How can we determine the voltage source parameters experimentally? Write down the relevant expressions.
12. Draw the external characteristics of real and ideal voltage source and current source.
13. Describe the work of electrical source in the voltage generator regime. What is the working regime condition?
14. Describe the work of electrical source in the current generator regime. What is the working regime condition?
15. Describe the agreed working regime of the electrical source. What is the working regime condition?
16. Write down the electrical source efficiency factor expression using the parameters of the source and consumer. Analyze the dependence between the source working regime and the efficiency factor.

LABORATORY WORK 2

Investigation of mixed connection of resistive elements

The purpose of the work. To learn how to use Ohm's and Kirchhoff's laws to calculate the forked DC circuits. To compare experimental and calculated data, obtained during the investigation of linear DC circuits with mixed connection of resistive elements.

There are two types of elements connections in electrical circuits, they are simple and complex. The major difference between those two types is that we know the directions of currents before we calculate the circuit with simple connection and don't know the directions of currents at the circuits with complex connections, that's why we choose them arbitrarily.

There are three types of *simple* connection: serial, parallel and mixed.

When the elements are connected in *serial* (fig.2.1), the same current I is flowing through them. The total resistance of serial connection is $R = \Sigma\ R_n$.

The input voltage (fig.2.1)

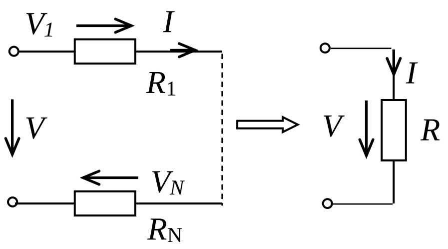


Fig.2.1

$$V = V_1 + \ldots + V_N = \Sigma V_N = \Sigma R_N I.$$

The power of this circuit

$$P = VI = \Sigma R_N II = \Sigma R_N I^2 = \Sigma P_N,$$

where $P = VI$ – the power of the source, ΣP_N – the power of the consumers.

When the elements are connected in *parallel* (fig.2.2), the same voltage V is applied to them. The total conductivity of parallel connection is $G = \Sigma\ G_n$.

The total current of the circuit (fig.2.2):

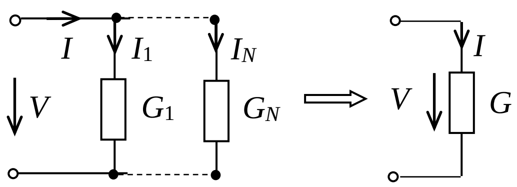


Fig.2.2

$$I = I_1 + \ldots + I_N = \Sigma I_N = \Sigma G_N V.$$

The power of this circuit:

$$P = VI = \Sigma G_N VV = \Sigma G_N V^2 = \Sigma P_N.$$

For two elements connected in parallel:

$$G = G_1 + G_2 = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_2 + R_1}{R_1 R_2},$$

$$R = \frac{1}{G} = \frac{R_1 R_2}{R_1 + R_2}.$$

The circuit with two elements connected in serial (fig.2.3) can be used as *voltage divider*.

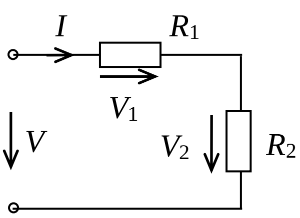


Fig.2.3

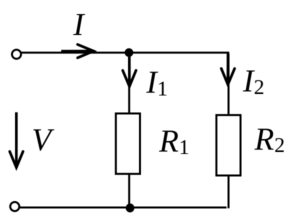


Fig.2.4

$$I = \frac{V}{R_1+R_2}, \quad V_1 = R_1 I = V\frac{R_1}{R_1+R_2}, \qquad V_2 = R_2 I = V\frac{R_2}{R_1+R_2}.$$

The circuit with two parallel connected elements (fig.2.4) can be used as *current divider*.

$$V = I\frac{R_1R_2}{R_1+R_2}, I_1 = V/R_1 = I\frac{R_2}{R_1+R_2}, I_2 = V/R_2 = I\frac{R_1}{R_1+R_2}.$$

We can replace the *mixed* (serial-parallel) connection (fig.2.5) by one equivalent (total) resistance R:

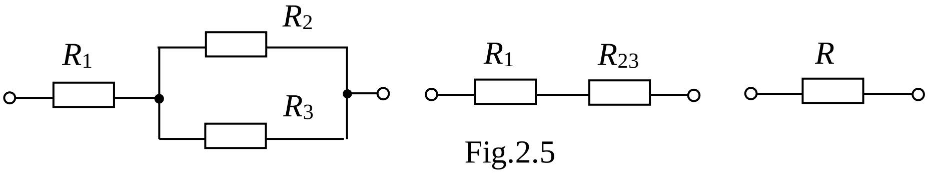


Fig.2.5

$$R_{23} = R_2R_3/(R_2+R_3), R = R_1 + R_{23}.$$

We can also replace the *mixed* (parallel-serial) connection (fig.2.6) by one equivalent (total) resistance R:

$$R_{23} = R_2 + R_3, \quad R = R_1R_{23}/(R_1 + R_{23})$$

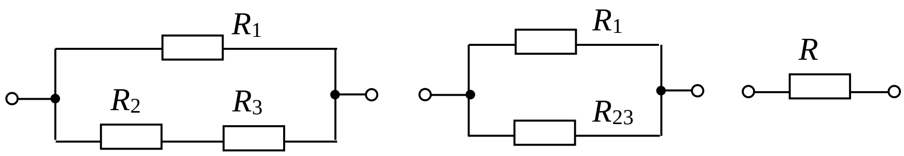


Fig.2.6

Homework

To calculalate the current in a circle (fig. 2.7), if known the resistances of resistors R_2, R_3, R_4, R_5 and the maximum power P_n allocated to the resistor R_n in the unforked circuit. To define total current, input voltage and subcircuits voltages, branches currents, power of the sircuit and the powers of subcircuits. To write down the results to the table 2.2 item 1. Tasks variants are listed in the table 2.1.

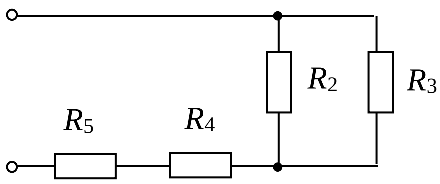


Fig.2.7

Table 2.1

Var №	1	2	3	4	5	6	7	8	9	10
P_n, *W*	7.1	7.2	7.3	7.4	7.5	7.1	7.2	7.3	7.4	7.5
R_2, *Ω*	150	155	160	165	170	165	155	160	165	170
R_3, *Ω*	204	186	232	197	203	205	195	181	203	228
R_4, *Ω*	198	193	228	198	196	197	199	208	191	231
R_5, *Ω*	198	212	235	193	201	202	164	211	192	229

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 1, measuring devices.

The elements of the board 1: resistors R_1, R_2, R_3, R_4.

Measuring devices: $PV(P\Omega)$ – multimeter Щ4300 to measure voltage, options: $<\ ->$, $<\ V>$, $<\ 200\ V>$; to measure resistance, options: $<\ ->$, $<\ R>$, $<\ 2\ \text{к}\Omega\ >$; PA – ammeters Э536, limit of measuring $<0.5\ A>$; PW – wattmeter for measuring power, limit of measuring: $<75\ V/\ 0.5\ A>$. The way of measuring devices placement is shown in fig. 2.8.

The work execution order

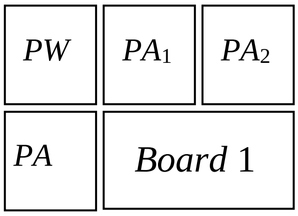


Fig. 2.8

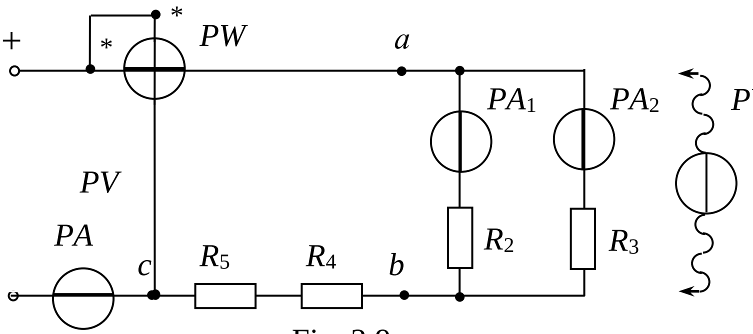


Fig. 2.9

1. To collect the circuit (fig. 2.9) and connect it to the clamps $<->$ $<0 \div 120\ V>$. To place *LATR* switch in position $<\ ->$, $<0 \div\ 120V>$.

2. To investigate the circuit with mixed connection of resistors (fig. 2.9). To set the input voltage given by tutor ($80 \le V \le 100\ V$). To write down the results to the table 2.2 item 2.

Table 2.2

Measurements										*Calculation*	
№	*V, V*	*V_{23}, V*	*V_{45}, V*	*V_4, V*	*V_5, V*	*I, A*	*I_2, A*	*I_3, A*	*P, W*	*P_{23}, W*	*P_{45}, W*
1											
2											

To verify the results for the balance of power: $P = P_{23} + P_{45}$.

3. To investigate the circuit with parallel connection of resistors R_2, R_3. To short the series subcircuit R_4, R_5 (points b, c fig. 2.9). To set the input voltage given by tutor ($14 \le V \le 18\ V$).To write down the results to the table 2.3.

Table 2.3

Measurements						*Calculations*		
№	*V_{23}, V*	*I, A*	*I_2, A*	*I_3, A*	*P, W*	*R_2, Ω*	*R_3, Ω*	*R_{23}, Ω*
1								

To verify the results for the first Kirchhoff's law: $I = I_2 + I_3$. To calculate the resistances of resistors R_2, R_3 and the equivalent resistance of a parallel connection R_{23}.

4. To investigate the circuit serial connection of resistors R_4, R_5. To shorten the parallel subcircuit $R_2\ R_3$ (points $a,\ b$ fig. 2.9). To set the circuit current given by tutor ($170 \le I \le 200\ mA$). To write down the results to the table 2.4.

Table 2.4

Measurements						*Calculations*		
№	I mA	V_{45}, V	V_4, V	V_5, V	P, W	R_4, Ω	R_5, Ω	R_{45}, Ω
1								

To verify the results for the second Kirchhoff's law: $V_{45} = V_4 + V_5$. To calculate the resistances of resistors R_4, R_5 and the equivalent resistance of a series R_{45}.

5. To draw the circuit of current divider $R_2 R_3$. To define analytically currents I_2, I_3 at given current I (table 2.3.).

6. To draw the circuit of voltage divider $R_4 R_5$. To define analytically voltages V_4, V_5 at given voltage U_{45} (table 2.4.).

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 2.9). Tables 2.2, 2.3, 2.4. The schemes of circuits of current divider and voltage divider. The results of calculations. Conclusions.

Control questions

1. Which device is called a one-port network? To provide the examples of one-port networks. What one-port networks are called active, and what – passive?
2. Give the definition of branch, node and loop of the electrical circuit.
3. What types of the electrical connections in the circle are called simple? What is main difference the complex connection?
4. Write down the circuit electrical status equation consisting of three serially connected resistors and expression of equivalent resistance of this circuit.
5. Write down the circuit electrical status equation consisting of three parallel connected resistors and expression of equivalent conductivity of this circuit.
6. Write down the equivalent resistance of the circuit with mixed connected resistors (parallel-serial and serial-parallel).
7. What types of connections in the circuit are called complex?
8. Write down the expressions of the equivalent transformation of "delta" in „wye".
9. What is the essence of the method of simplification of electrical circuit?
10. To draw the circuit of voltage divider. Write down proper expressions for it.
11. To draw the circuit of current divider. Write down proper expressions for it.

LABORATORY WORK 3

Investigation
of resistor, inductance and capacitor in AC circuit

The purpose of the work is to define the parameters of resistor, inductance and capacitors in AC circuit.

Expressions for instantaneous current and voltage are correspondingly:

$$i = I_m \sin(\omega t + \psi_I), v = V_m \sin(\omega t + \psi_U).$$

The voltage for the *resistive element* (fig.3.1) (active resistance) is

$$v = V_m \sin(\omega t + \psi_v) = Ri = RI_m \sin(\omega t + \psi_i)$$

according to Ohm`s law, where $V_m = RI_m$, $V = RI$, phase expression $\psi_v = \psi_i$ and phase shift angle makes $\varphi = \psi_v - \psi_i = 0$. Resistance of this element is R (Ω) and conductance is thus $G = 1/R$ (Sm). Vector diagram for this element is shown on fig.3.2. Active power of resistive element is accordingly $P = RI^2 = GV^2$ (W).

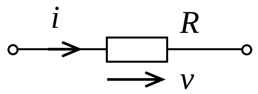


Fig.3.1

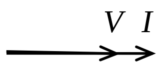


Fig.3.2

Inductance L (H) is correspondingly the main parameter for the ideal *inductive element* (fig.3.3). The differential form of Ohm`s law is thus applied accordingly:

$$v_L = V_m \sin(\omega t + \psi_V) = L\frac{di_L}{dt} = L\frac{d}{dt} I_m \sin(\omega t + \psi_i) =$$
$$= \omega L I_m \cos(\omega t + \psi_i) = \omega L I_m \sin(\omega t + \psi_i + \pi/2),$$

where $V_m = \omega L I_m$, $V = X_L I$, reactance $X_L = \omega L$ (Ω), susceptance $B_L = 1/\omega L$ (Sm), phase expression $\psi_v = \psi_i + \pi/2$, phase shift angle makes $\varphi = \psi_v - \psi_i = \pi/2$, it means voltage leads current. In case of DC: $\omega = 0$, $X_L = 0$, $B_L = \infty$. Vector diagram for this element is shown on fig.3.4. Reactive power for L-element makes $Q_L = X_L I^2 = B_L V^2$ (VAr).

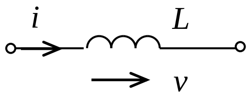


Fig.3.3

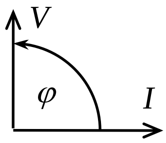
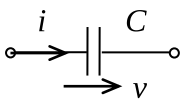


Fig.3.4

Capacitance C is the main parameter for the ideal *capacitive element* (fig.3.5). Integral form of Ohm`s law is applied in this case:

$$v_C = V_m \sin(\omega t + \psi_V) = \frac{1}{C}\int i \;\; dt = \frac{1}{C}\int I_m \sin(\omega t + \psi_i)$$
$$= -\frac{1}{\omega C} I_m \cos(\omega t + \psi_i) =$$



$$= -\frac{1}{\omega C} I_m \cos(\omega t + \psi_i) = \frac{1}{\omega C} I_m \sin(\omega t + \psi_i - \pi/2),$$

Fig.3.5

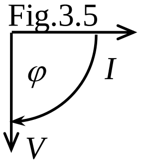


Fig.3.6

where $V_m = \frac{1}{\omega C} I_m$, $V = X_C I$, reactance $X_C = 1/(\omega C)$ (Ω), susceptance $B_C = \omega C$ (Sm) , phase expression $\psi_v = \psi_i - \pi/2$, phase shift angle makes $\phi = \psi_v - \psi_i = -\pi/2$, it means voltage lags current. In case of DC : $\omega = 0$, $X_C = \infty$, $B_C = 0$. Vector diagram for this element is shown on fig.3.6. Reactive power for this element makes thus $Q_C = X_C I^2 = B_C V^2$ (VAr).

Homework

To calculate the impedance, input voltage, phase shift angle, active and reactive powers, coil quality factor in a circuit (fig. 3.7), at given current I, inductivity L, active resistance R. To write down the results to the table 3.3 line 1. Tasks variants are listed in the table 3.1.

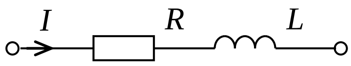


Рис. 3.7

Table 3.1.

Var.№	1	2	3	4	5	6	7	8	9	10
I ,A	0.21	0.22	0.23	0.24	0.25	0.21	0.22	0.23	0.24	0.25
L, H	0.79	1.08	1.01	1.10	1.09	1.12	1.13	1.15	1.18	1.20
R, Ω	163	181	175	185	182	186	189	187	197	195

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 2, measuring devices.

The elements of the board 2 are capacitors C_1, C_2, C_3, resistor R , coil L.

Measuring devices are: $PV(P\Omega)$– multimeter $Щ4300$ to measure voltage, options: $<\ \sim>$, $<\ V>$, $<\ 200\ \ V>$; to measure resistance, options: $<\ ->$, $<\ R>$, $<\ 2\ \ кΩ\ >$; PA – amperemeter $Э536$, limit of measuring <0.5 A >; PW – wattmeter for measuring power, limit of measuring: <$150\ V/\ 0.5\ A$ >. The way of measuring devices placement is shown in fig. 3.8.

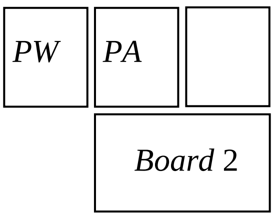


Fig. 3.8

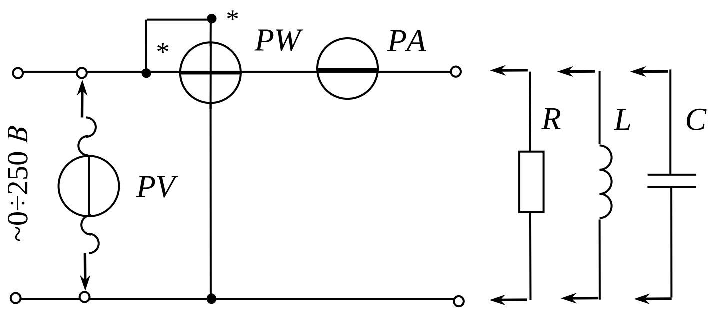


Fig. 3.9.

The work execution order

1. To collect the circuit (fig. 3.9) and connect it to the clamps $<\sim>$ $<\ 0\div 250V>$. To place *LATR* switch in position $<\ \sim>$, $0\div 250V$.

2. To investigate the circuit with resistor R . To set the input voltage as given by tutor ($100\le V\le 120\ V$). To write down the results to the table 3.2.

Table 3.2

	Measurements				*Calculations*			
	R, Ω	*V,* *V*	*I,* *A*	*P,* *W*	*R,* Ω	*G* *mSm*	*cosφ*	*φ,* *deg*

Calculate (table 3.2): active resistance $R=V/I$, conductivity $G=I/V$, phase shift angle ϕ, power factor $cos\,\phi = P/VI$. Draw the vector diagram.

3. Investigate the circuit with coil L without core. Set the input voltage as given by tutor ($70 \leq U \leq 80\ V$). Write down the results to the table 3.3, line 2.

Table 3.3

Measurements				*Calculations*						
№	*I, A*	*V, V*	*P, W*	*Z, Ω*	*R, Ω*	*X, Ω*	*φ, deg*	*Q, VAr*	*L, H*	*d*
1										
2										

Calculate and put in table 3.3: coil impedance $Z = V/I$, active resistance R ($P = RI^2$) and reactance X ($Z = \sqrt{R^2 + X^2}$), phase shift angle ϕ ($tg\phi = X/R$), reactive power $Q = XI^2$, inductance L ($X = \omega L$) and coil quality factor $d = Q/P$. Draw the vector diagram.

4. Investigate the circuit with capacitances: C_1, C_{12} serial, C_{12} parallel. Set the input voltage as given by tutor ($60 \leq U \leq\ 90\ V$). Write down the results to the table 3.4.

Table 3.4

Measurements				*Calculations*						
№	*V, V*	*I, A*	*P, W*	*Y, mSm*	*G, mSm*	*B, mSm*	*C, μF*	*Q, VAr*	*tgδ*	*φ, deg*
1										
2										
3										

Calculate and put in table 3.4: admittance Y ($I = YV$), active G ($P = GV^2$) and reactive B ($Y = \sqrt{G^2 + B^2}$) conductivities, capacity C ($B = \omega C$), reactive power $Q = BV^2$, dissipation factor $tg\delta = P/Q$, phase shift angle ϕ ($\phi = 90 - \delta$). Draw the vector diagram.

5. Draw the coil parallel substitution scheme. Calculate the conductance G' and inductance L' of parallel substitution scheme according to the parameters of serial substitution scheme R,X (table 3.3, item 2), using formulas $G' = R/Z^2$, $B' = X/Z^2$, $L' = B'/\omega$.

6. Draw the capacitor serial substitution scheme. Calculate the resistance R' and capacitance C' of serial substitution scheme according to the parameters of parallel substitution scheme G, B (table 3.4, line 2), using formulas $R' = G/Y^2$, $X' = B/Y^2$, $C' = B/\omega$.

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 3.9). Tables 3.2, 3.3, 3.4. The substitutional schemes of coil and capacitor and calculations of their parameters. Vector diagrams for resistance, coil and capacitor. Conclusions.

Control questions

1. Give a definition of alternating current. What's the period of alternating current?
2. What are the parameters of alternating current?
3. Explain what is it instantaneous value of alternating current and phase shift angle.
4. Explain what is it the effective value of alternating current and its connection with the amplitude value.
5. Write down the amplitude-phase relationship for R -element.
6. Write down the amplitude-phase relationship for L -element.
7. Write down the amplitude-phase relationship for C - element.
8. Draw vector diagrams for resistive, inductive and capacitive element.
9. Write down the expressions of reactance, conductivity and power for inductive element.
10. Write down the expressions of reactance, conductivity and power for capacitive element.
11. Explain the physical essense of the coil substitutional schemes elements and draw these schemes.
12. Explain the physical essense of the capacitor substitutional schemes elements and draw these schemes.
13. Write down the expressions for the coil quality factor and capacitor dissipation factor.

LABORATORY WORK 4

Investigation

of coil and capacitor serial connection

The purpose of the work is to investigate serial connection of coil and capacitor and the voltage resonance in AC circuit.

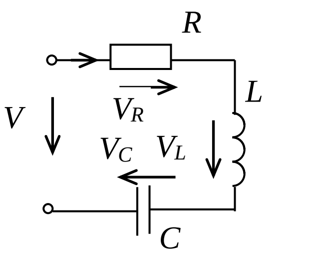


Fig.4.1

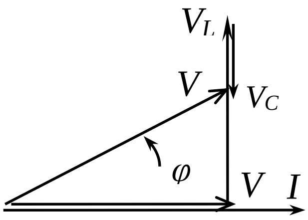


Fig.4.2

Electrical status equations for the circuit (fig.4.1) for voltage instantaneous values and voltage vectors are accordingly:

$$v_R + v_L + v_C = v, \overline{V}_R + \overline{V}_L + \overline{V}_C = \overline{V}.$$

Vector diagram is shown on fig.4.2. The calculated triangles for voltages, resistances and powers (fig.4.3) are obtained from this diagram. Out of those triangles:

$$V = \sqrt{V_R^2 + (V_L - V_C)^2},\ \varphi = arctg(V_L - V_C)/V_R,$$

$$V_R = V\cos\varphi = V_a, V_L - V_C = V\sin\varphi = V_r,$$

-these are active and reactive constituents of the applied voltage V. Therefore circuit impedance makes:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}, \varphi = arctg((X_L - X_C)/R),$$

$$R = Z\cos\varphi, X = X_L - X_C = Z\sin\varphi$$

these are resistance and reactance of the circuit.

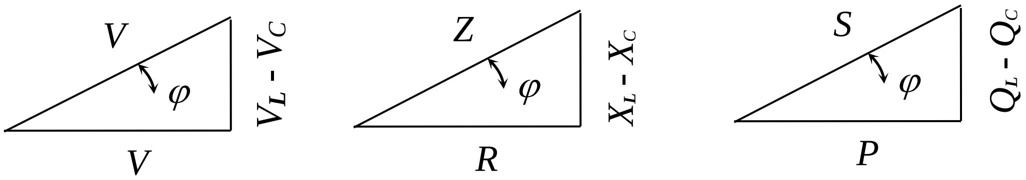


Fig.4.3

Total power makes thus:

$$S = \sqrt{P^2 + (Q_L - Q_C)^2}\ (\text{VA}),\ \varphi = arctg(Q_L - Q_C)/P,$$

$$P = S\cos\varphi = VI\cos\varphi,\ Q = Q_L - Q_C = S\sin\varphi = VI\sin\varphi$$

- these are active and reactive powers of the circuit.

Homework

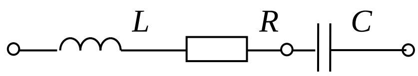


Fig. 4.4

Calculalate the input voltage, coil voltage, capacitor voltage active and reactive powers, the resistances of the elements and phase shift angles (fig. 4.4), at given current I, inductivity L, active resistance R, capacitance C. Write down the results to the table 4.2 line 1. Tasks variants are listed in the table 4.1.

Table. 4.1

Var	1	2	3	4	5	6	7	8	9	10
I, mA	180	185	190	195	200	180	185	190	195	200
R, Ω	186	189	187	197	195	186	189	187	197	195
L, H	1.12	1.13	1.15	1.18	1.20	1.12	1.13	1.15	1.18	1.20
C, μF	3.92	3.76	3.78	3.86	3.87	6.15	6.33	6.02	6.51	6.34

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 2, measuring devices.

The elements of the board 2 are capacitors C_1, C_2, C_3, coil L.

Measuring devices are: $PV(P\Omega)$– multimeter $Щ4300$ to measure voltage, options: $<\ \sim>$, $<\ V>$, $<\ 200\ \ V>$; PA – amperemeter $Э536$, limit of

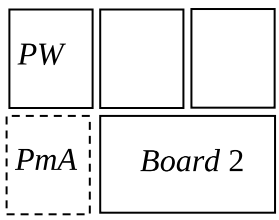


Fig. 4.5

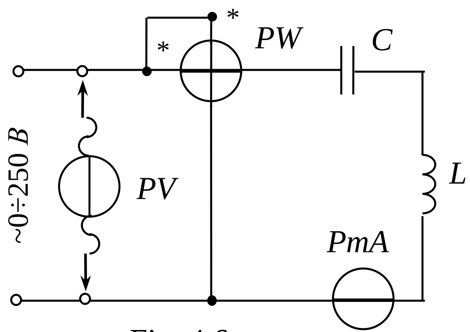


Fig. 4.6

measuring <0.5 A >; PW – wattmeter for measuring power, limit of measuring: <150 V/ 0.5 A >. The way of measuring devices placement is shown in fig. 4.5.

The work execution order

1. Collect the circuit (fig. 4.6) and connect it to the clamps $<\sim>$ $<0 \div 250V>$. Place *LATR* switch in position $<\sim>$, $0 \div 250V$.

2. Investigate the circuit with the serial connection of coil without core and capacitor C_2. Set the circuit current as given by tutor ($180 \leq U \leq 200\ mA$). Write down the results to the table 4.2, line 2.

3. Investigate the circuit with the serial connection of coil without core and capacitors C_{23} (parallel connection of C_2 and C_3). Set the circuit current as given by tutor ($180 \leq V \leq 200\ mA$). Write down the results to the table 4.2, line 3.

Table 4.2

Measurements						*Calculations*							
№	*I, mA*	*V, V*	V_C, *V*	V_L, *V*	*P, W*	*Z, Ω*	*R, Ω*	Z_L, *Ω*	X_L, *Ω*	φ_L, *deg*	X_C, *Ω*	*X, Ω*	φ *deg*
1													
2													
3													

Calculate and put in table 4.2: circuit impedance $Z = V/I$, coil impedance $Z_L = V_L/I$, active resistance R ($P = RI^2$) and coil reactance X_L ($Z_L = \sqrt{R^2 + X_L^2}$), coil phase shift angle ϕ_L ($tg\phi_L = (X_L/R)$), capacitor reactance $X_C = V_C/I$, circuit reactance $X = X_L - X_C$, circuit phase shift angle ϕ.

4. Investigate the circuit with serial connection of coil and capacitor C_1. Set the input voltage as given by tutor ($50 \leq V \leq 70\ V$):

– coil without a core (minimal inductivity) and write down the results to the table 4.3, line 1;

– coil with a core (maximum inductivity) and write down the results to the table 4.3, line 2;

– in resonance regime (moving the core in the coil till the current will be maximum (the indication of resonance) and write down the results to the table 4.3, line 3.

Table 4.3

Measurements						*Calculations*							
№	*V, V*	*I, mA*	V_C, *V*	V_L, *V*	*P, W*	*Z, Ω*	*R, Ω*	Z_L, *Ω*	X_L, *Ω*	φ_L, *deg*	X_C, *Ω*	*X, Ω*	φ *deg*
1													
2													
3													

Calculate and put in table 4.3: circuit impedance $Z = V/I$, coil impedance $Z_L = V_L/I$, active resistance R ($P = RI^2$) and coil reactance X_L ($Z_L = \sqrt{R^2 + X_L^2}$), coil phase shift angle ϕ_L ($tg\phi_L = (X_L/R)$), capacitor reactance $X_C = V_C/I$, circuit reactance $X = X_L - X_C$, circuit phase shift angle ϕ ($tg\phi = (X/R)$). Draw three vector diagrams using the data from table 4.3. Losses in capacitors are negligible, that's why the capacitor phase shift angle will be $\phi_C = -\pi/2$.

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 4.6). Tables 4.2, 4.3. The substitutional schemes of coil and capacitor and calculations of their parameters. The vector diagrams. Conclusions.

Control questions

1. Write down the electrical status equation for the circuit with serial connection of *RLC*-elements in vector form and draw the vector diagram for this circuit.
2. Draw resistances calculated triangle for the circuit with serial connection of *RLC*-elements and write down the corresponding relations for it.
3. Explain what is it the active and reactive voltage constituents.
4. Draw powers calculated triangle for the circuit with serial connection of *RLC*-elements and write down the corresponding relations for it.
5. Give the definition of voltage resonance, write down the resonance condition and explain the resonance indication.
6. Give the definition of voltage resonance frequency, circuit wave resistance and explain the ways of resonance reaching.
7. What is the impedance, phase shift factor and total power of the voltage resonance circuit? How voltage resonance is being applied?
8. Draw the voltage resonance circuit frequency characteristics.
9. Draw the resonance curve for the voltage resonance circuit. Explain why the current at resonance is the biggest.

LABORATORY WORK 5
Investigation of coil and capacitor parallel connection

The purpose of the work is to investigate parallel connection of coil and capacitor and the current resonance in AC circuit.

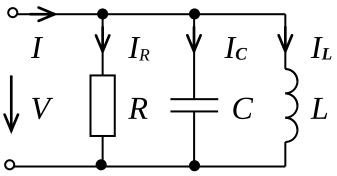


Fig.5.1

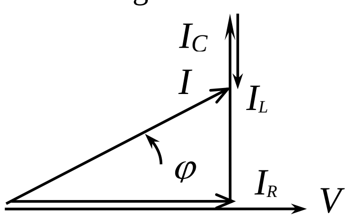


Fig.5.2

Circuit electrical status equations (fig.5.1) for current instantaneous values and current vectors are accordingly:

$$i_R + i_L + i_C = i, \bar{I}_R + \bar{I}_C + \bar{I}_L = \bar{I}.$$

Vector diagram is shown on fig.5.2. The calculated triangles of currents and conductivities are obtained from this diagram (fig.5.3). From those triangles we get subsequently:

$$I = \sqrt{I_R^2 + (I_C - I_L)^2}, \quad \varphi = arctg((I_C - I_L)/I_R),$$

$I_R = I\cos\varphi = I_a$, $I_C - I_L = I\sin\varphi = I_r$ - these are active and reactive constituents of the current.

Circuit admittance makes:

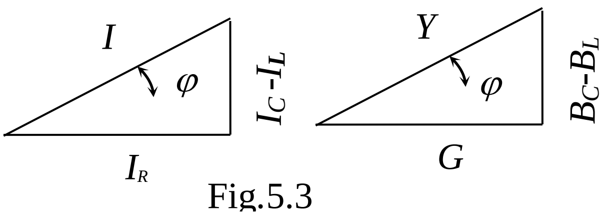


Fig.5.3

$$Y = \sqrt{G^2 + (B_C - B_L)^2},$$

$$\phi = arctg\phi(B_C - B_L)/G,$$

$$G = Y\cos\varphi,\ B = B_C - B_L = Y\sin\varphi$$

- these are conductance and susceptance of the circuit.

Homework

Calculalate the current in the unforked subcircuit, coil current I_L, capacitor current I_C, active and reactive powers, the conductivities of the elements and phase shift angles in the circuit (fig. 5.4), at given voltage V, inductivity L, active resistance R, capacitances C. Write down the results to the table 5.2 line 1. Tasks variants are listed in the table 5.1.

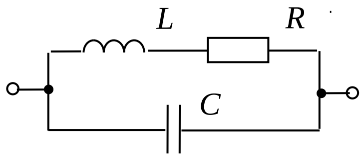


Fig.5.4

Table 5.1

Var	1	2	3	4	5	6	7	8	9	10
V, V	50	55	60	65	70	50	55	60	65	70
R, Ω	186	189	187	197	195	186	189	187	197	195
L, H	1.12	1.13	1.15	1.18	1.20	1.12	1.13	1.15	1.18	1.20
C, μF	3.99	3.77	3.83	3.82	3.79	4.17	4.15	4.12	4.17	4.11

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 2, measuring devices.

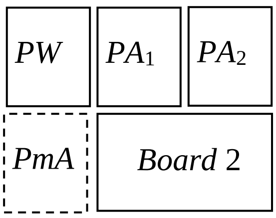


Fig. 5.5

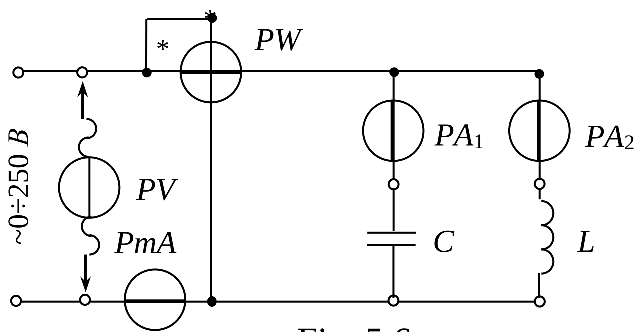


Fig. 5.6

The elements of the board 2 are capacitors C_1, C_2, C_3, coil L.

Measuring devices are: PV– multimeter Щ4300 to measure voltage, options: $< \sim >$, $< V >$, $< 200\ V >$; PA – ammeters Э536, limit of measuring <$0.5\ A$ >; PmA – miliamperemeter, limit of measuring <$200\ mA$ >, PW – wattmeter for measuring power, limit of measuring: <$150\ V/\ 0.5\ A$ >. The way of measuring devices placement is shown in fig. 5.5.

The work execution order

1. To collect the circuit (fig. 5.6) and connect it to the clamps $< \sim >$ $< 0 \div 250V >$. To place *LATR* switch in the position $< \sim >, 0 \div 250V$.

2. To investigate the circuit with parallel connection of coil without a core

and capacitor C_1. To set the input voltage as given by tutor ($50 \leq U \leq 70\ V$). To write down the results to the table 5.2, line 2.

3. To investigate the circuit with parallel connection of coil without a core and capacitors C_{13} (parallel connection of C_1 and C_3). To set the input voltage as given by tutor ($50 \leq U \leq 70\ V$). To write down the results to the table 5.2, line 3.

Table 5.2

Measurements						*Calculations*						
№	*V, V*	*I, mA*	*I_C A*	*I_L A*	*P, W*	*G, mSm*	*B_L, mSm*	*Y_L, mSm*	*φ_L, deg*	*B_C, mSm*	*B, mSm*	*φ, deg*
1												
2												
3												

Calculate and put in table 5.2: coil admittance $Y_L = I_L/V$, coil active $G = R \cdot Y_L^2$ ($R = P/I_L^2$) and reactive B_L ($Y_L = \sqrt{G_L^2 + B_L^2}$) conductivities, coil phase shift angle ϕ_L ($tg\phi_L = (-B_L/G)$); capacitor reactive conductivity $B_C = I_C/V$, circuit reactive conductivity $B = B_C - B_L$, circuit phase shift angle ϕ ($tg\phi = (B/G)$).

4. To investigate the circuit with parallel connection of coil and capacitor C_2. To set the input voltage as given by tutor ($90 \leq V \leq 110\ V$):

– coil without a core (minimal inductivity) and write down the results to the table 5.3, line 1;

– coil with a core (maximum inductivity) and write down the results to the table 5.3, line 2;

– in resonance regime (by moving the core in the coil till the current will be minimum – what is an indication of resonance) and write down the results to the table 5.3, line 3.

Table 5.3

Measurements						*Calculations*						
№	*V, V*	*I, mA*	*I_L, A*	*I_C, A*	*P, W*	*G, mSm*	*B_L, mSm*	*Y_L, mSm*	*B_C, mSm*	*B, mSm*	*φ_L, deg*	*φ, deg*
1												
2												
3												

Calculate and put in table 5.3: coil admittance $Y_L = I_L/V$, coil active $G = R \cdot Y_L^2$ ($R = P/I_L^2$), reactive B_L ($Y_L = \sqrt{G_L^2 + B_L^2}$) conductivities, capacitor reactive conductivity $B_C = I_C/V$, circuit reactive conductivity $B = B_C - B_L$, coil phase shift angle ϕ_L ($tg\varphi_L = (B_L/G)$), circuit phase shift angle ϕ ($tg\phi = (B/G)$). Draw three vector diagrams using the data from table 5.3. Losses in capacitors are negligible, that's why the capacitor phase shift angle should be $\phi_C = -\pi/2$.

Report on work

The name and purpose of the work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 5.6). Tables 5.2, 5.3. The vector diagrams. Conclusions.

Control questions

1. Write down the electrical status equation for the circuit with parallel connection of *RLC*-elements in vector form and draw the vector diagram for this circuit.

2. Draw conductivities calculated triangle for the circuit with parallel connection of *RLC*-elements and write down the corresponding expressions for it.

3. Explain what is it the active and reactive current constituents.

4. Draw powers calculated triangle for the circuit with parallel connection of *RLC*-elements and write down the corresponding expressions for it.

5. Give the definition of current resonance, write down the resonance condition and explain the resonance indication.

6. Give the definition of voltage resonance frequency, circuit wave resistance and explain the ways of resonance reaching.

7. What is the admittance of the circuit, phase shift factor and full power of the current resonance circuit? How current resonance is applied?

8. Draw the current resonance circuit frequency and phase characteristics.

9. Draw the resonance curves of currents of the current resonance circuit. Explain why the current at resonance is at minimum.

LABORATORY WORK 6

Investigation of WYE connection of three-phase circuit

<u>The purpose of the work</u> is to investigate „wye" connection of three phases circuit with balanced and non-balanced loading, to investigate the role of the neutral.

At WYE connection the ends of source phases windings (fig.6.1) are connected in common neutral point N, and the beginnings of phases A, B, C are connected to the linear wires. The ends of consumer phase windings (fig.6.1) are connected in common neutral point n, and the beginnings of phases a, b, c are connected to the linear wires.

The source phase voltages are called the voltages between phase and neutral points V_A, V_B, V_C, for consumer V_a, V_b, V_c. The source linear voltages are called the voltages between phase points (fig.6.1) V_{AB}, V_{BC}, V_{CA}, for consumer V_{ab}, V_{bc}, V_{ca}. The directions of these voltages are shown at fig.6.1. The effective values of phase and linear voltages are related according to the expression $V_L = \sqrt{3}V_{ph}$.

For WYE connection (fig.6.1) *phase currents* (flowing through the phase)

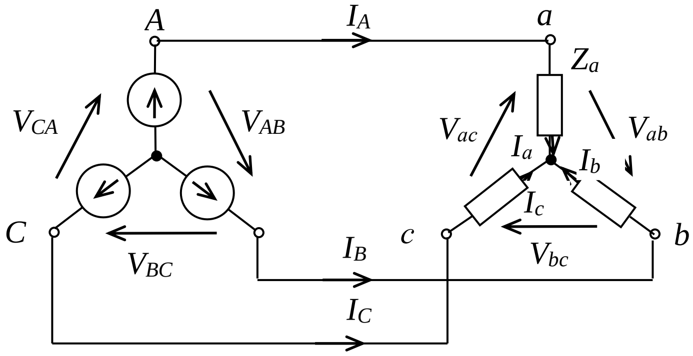


Fig.6.1

I_{ph} (I_a, I_b, I_c), are equal to the *linear currents* (flowing through the lines connecting the source and the consumer) I_L (I_A, I_B, I_C), $I_{ph} = I_L$. The directions of these currents are shown at fig.6.2. Balanced load is one in which the phase impedances are equal in magnitude and in phase:

$$\underline{Z}_a = \underline{Z}_b = \underline{Z}_c = \underline{Z}_{ph}.$$

In this case:

$$\underline{V}_a = \underline{V}_A, \qquad \underline{V}_b = \underline{V}_B, \qquad \underline{V}_c = \underline{V}_C.$$

$$\underline{I}_A = \underline{V}_a/\underline{Z}_a, \qquad \underline{I}_B = \underline{V}_b/\underline{Z}_b, \qquad \underline{I}_C = \underline{V}_c/\underline{Z}_c.$$

The effective values of the currents are also equal: $I_A = I_B = I_C = I_{ph} = I_L$.

If the load is unbalanced $(\underline{Z}_a \neq \underline{Z}_b \neq \underline{Z}_c)$ the voltage between the neutral points of source and consumer appears – $\underline{V}_{nN}$. This voltage is called the *bias neutral* and can be calculated by using the method of two nodes:

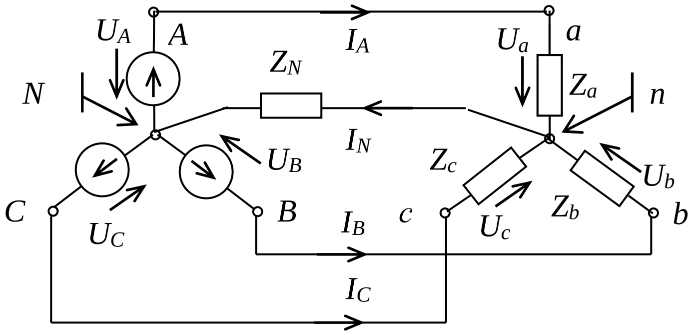


Fig.6.2

$$\underline{V}_{nN} = \frac{\underline{V}_A\underline{Y}_a + \underline{V}_B\underline{Y}_b + \underline{V}_C\underline{Y}_c}{\underline{Y}_a + \underline{Y}_b + \underline{Y}_C},$$

where $\underline{Y}_a = 1/\underline{Z}_a = I_a/V_a$, $\qquad \underline{Y}_b = 1/\underline{Z}_b = I_b/V_b$, $\qquad \underline{Y}_c = 1/\underline{Z}_c = I_c/V_c$.

In that case the consumer phase voltages are calculated according to the following expressions:

$$\underline{V}_a = \underline{V}_A - \underline{V}_{nN}, \quad \underline{V}_b = \underline{V}_B - \underline{V}_{nN}, \quad \underline{V}_c = \underline{V}_C - \underline{V}_{nN},$$

Phase currents complexes are:

$$\underline{I}_a = \underline{V}_a/\underline{Z}_a, \underline{I}_b = \underline{V}_b/\underline{Z}_b, \underline{I}_c = \underline{V}_c/\underline{Z}_c.$$

There is also a *neutral wire* at three-phase four-wires circuits, which connects neutral points of source N and consumer n (fig.6.2). In this case $\underline{V}_{nN} = 0$.

The following is true according to the Kirchhoff`s first law for node n:

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

When the load is balanced ($\underline{Z}_a = \underline{Z}_b = \underline{Z}_c$): $\underline{I}_A + \underline{I}_B + \underline{I}_C = 0$, $\underline{I}_N = 0$, $\underline{V}_{nN} = 0$.

Homework

Write down the phase voltages in complex form for the three-phase power source with linear voltage $V_L = 220\ V$. To calculate phase active resistances, phase complex currents, neutral complex current for the three-phase consumer (fig.6.3), at given phase powers. Tasks variants are listed in the table 6.1.

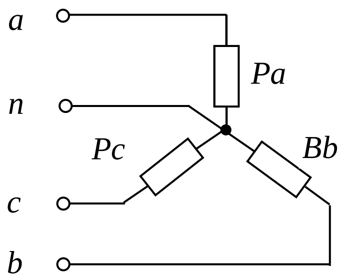


Fig. 6.3

Table. 6.1

Var	1	2	3	4	5	6	7	8	9	10
Pa, W	20	40	60	80	100	20	40	60	80	100
Pb, W	40	60	80	100	20	40	60	80	100	20
Pc, W	60	80	100	20	40	60	80	100	20	40

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 3, measuring devices.

The elements of the board 2 are: consumers (lamps $L1-L9$ ($220\ V,\ 25\ W$)), phase switches $SB1$, $SB2$, neutral switch $SB3$, coil, switch «$X_L \leftrightarrow R$».

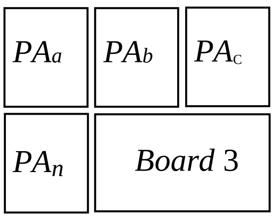


Fig. 6.4

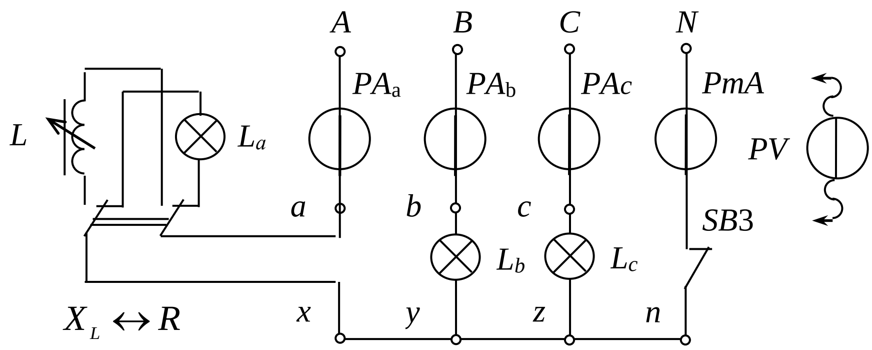


Fig.6.5

Measuring devices are: $PV(P\Omega)$– multimeter Щ4300 to measure voltage, options: $<\ \sim>$, $<\ V>$, $<\ 200\ \ V>$; PA – ammeters Э536, limit of measuring <0.5 A >; PmA – miliamperemeter, limit of measuring <200 mA >. The way of measuring devices placement is shown in fig. 6.4.

The work execution order

1. To collect the circuit (fig. 6.5) and connect it to the clamps A, B, C, N of the three-phase voltage power source $< 3{\sim}220V >$.

2. To investigate the circuit (fig. 6.7) with balanced loading $R_a = R_b = R_c = R_p$ ($SB1$ and $SB2$ closed, switch «$L \leftrightarrow Л$» in position $Л$) with neutral ($SB3$ closed) and without neutral ($SB3$ open). To write down the results to the table 6.2.

Draw the vector diagram of currents using the data from table 6.2, line 1.

Table 6.2

Measurements											
№	V_A,	V_B,	V_C,	V_a,	V_b,	V_c,	I_a,	I_b,	I_c,	V_{nN},	I_n,
	V	*V*	*V*	*V*	*V*	*V*	*A*	*A*	*A*	*V*	*mA*
1											
2											

3. To investigate the circuit (fig. 6.5) with non-balanced loading $R_a \neq R_b \neq R_c$ ($SB1$ and $SB2$ are open, switch «$L \leftrightarrow$ Л» in position Л) with neutral ($SB3$ closed) and without neutral ($SB3$ open). To write down the results to the table 6.3.

Draw the vector diagram of currents using the data from table 6.3, line 1.

Table 6.3

Measurements											
№	V_A, *V*	V_B, *V*	V_C, *V*	V_a, *V*	V_b, *V*	V_c, *V*	I_a, *A*	I_b, *A*	I_c, *A*	V_{nN}, *V*	I_n, *mA*
1											
2											

4. To investigate the circuit (fig. 6.5) with balanced loading $I_A = I_B = I_C$ ($SB2$ closed, switch «$L \leftrightarrow$ Л» in position L) with neutral ($SB3$ closed) and without neutral ($SB3$ open). In order to balance the phase currents it is necessary to move the core in the coil. To write down the results to the table 6.4.

Table 6.4

Measurements											
№	V_A, *V*	V_B, *V*	V_C, *V*	V_a, *V*	V_b, *V*	V_c, *V*	I_a, *A*	I_b, *A*	I_c, *A*	V_{nN}, *V*	I_n, *mA*
1											
2											

Draw the vector diagram of currents using the data from table 6.4, line 1.

Report on work

The name and purpose of work. Homework – the calculation of the circuit. Schematic diagram of the investigated circuit (fig 6.5). Tables 6.2, 6.3, 6.4. The vector diagrams. Conclusions.

Control questions

1. Give the definition of three-phase electromotive force system. Explain how we can receive it. When the system will be balanced? Draw the vector diagram of three-phases electromotive forces.
2. Explain what is called the order of phase changing and how we can change it. What load we call balanced and write down the condition of balanced load.
3. Write down the expressions of instantaneous phases electromotive forces and their effective value complexes.
4. Explain the main types of source and consumer connection in three-phase system.

5. Write down the expressions of active, reactive and total power of three-phase system using phase voltages and currents and line voltages and currents.

6. Write down the expressions of active, reactive and total power of three-phase system using line voltages and currents.

7. Draw the three-phase source „wye” connection and mark the phases and line voltages and currents.

8. Write down the relationships between effective values of phase and line voltages and currents for „wye” connection.

9. Explain the neutral role in three-phase system. How can the current be defined in it?

10. Write down how we can define the complex line voltages for the known complex phase voltages for the consumers’ „wye” connection.

11. Explain what voltage is called neutral bias voltage and how we can define it.

12. Draw the phase and line voltages for the consumers „wye” connection at vector diagram. What is the phase shift angle for them?

13. Explain how the three-phase circuit with non-balanced „wye” connected load can be calculated.

LABORATORY WORK 7

Investigation
of DELTA connection of three-phase circuit

The purpose of the work is to investigate „DELTA” connection of three phases circuit with balanced and non-balanced loading.

At DELTA connection the end of one source (consumer) winding is connected to the beginning to the second source (consumer) winding (fig.7.1). For this connection the following is true: $V_{ph} = V_L$, $V_{AB} = V_{BC} = V_{CA} = V_L$.

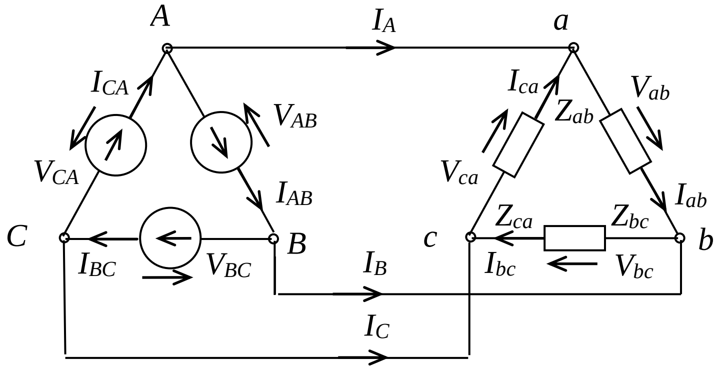


Fig.7.1

The phase (linear) complex voltages can be represented:

$$\underline{V}_{AB} = V_{AB}e^{j0}, \qquad \underline{V}_{BC} = V_{BC}e^{-j120^\circ}, \qquad \underline{V}_{CA} = V_{CA}e^{j120^\circ}.$$

The consumer linear (phase) voltages are equal to the source linear voltages:

$$\underline{V}_{ab} = \underline{V}_{AB}, \qquad \underline{V}_{bc} = \underline{V}_{BC}, \qquad \underline{V}_{ca} = \underline{V}_{CA}.$$

If the phase load is active ($\phi = 0$), the vectors of phase currents I_{ab}, I_{bc}, I_{ca} have the same directions as the vectors of corresponding phase voltages V_{AB}, V_{BC}, V_{CA}.

If the phase load is an active-inductive one ($\phi > 0$), the phase current lags behind the corresponding phase voltage by an angle of $\phi = arctg(X_{ph}/R_{ph})$.

If the phase load is an active-capacitive one ($\phi < 0$), the phase current leads the corresponding phase voltage by an angle of $\phi = arctg(X_{ph}/R_{ph})$.

The load is balanced when $\underline{Z}_{ab} = \underline{Z}_{bc} = \underline{Z}_{ca} = \underline{Z}_{ph}$ and unbalanced when $\underline{Z}_{ab} \neq \underline{Z}_{bc} \neq \underline{Z}_{ca}$.

The following is true for the nodes a, b, c (fig.7.1) according to the first Kirchhoff law:

$$\underline{I}_A + \underline{I}_{ca} - \underline{I}_{ab} = 0, \qquad \underline{I}_B + \underline{I}_{ab} - \underline{I}_{bc} = 0, \qquad \underline{I}_C + \underline{I}_{bc} - \underline{I}_{ca} = 0,$$

Then:

$$\underline{I}_A = \underline{I}_{ab} - \underline{I}_{ca}, \qquad \underline{I}_B = \underline{I}_{bc} - \underline{I}_{ab}, \qquad \underline{I}_C = \underline{I}_{ca} - \underline{I}_{bc}.$$

The linear current is equal to the difference between corresponding phase currents and lags the first one for $30°$.

The effective values of the phase and the linear currents are connected by expression: $I_L = \sqrt{3} I_{ph}$.

Complex phase currents can be defined according to Ohm's law:

$$\underline{I}_{ab} = \underline{V}_{ab}/\underline{Z}_{ab}, \underline{I}_{bc} = \underline{V}_{bc}/\underline{Z}_{bc}, \underline{I}_{ca} = \underline{V}_{ca}/\underline{Z}_{ca}.$$

For balanced load: $I_A = I_B = I_C$, $I_{ab} = I_{bc} = I_{ca}$.

Homework

Write down the phase voltages in complex form for the three-phase power source with a linear voltage $V_L = 380\ V$. Three groups of consumers are connected to these sources. The consumers phase powers are: P_{ab}, P_{bc}, P_{ca} (fig.7.2). Calculate phase resistances, phase complex currents. Define the power of the circuit.

Tasks variants are listed in the table 7.1.

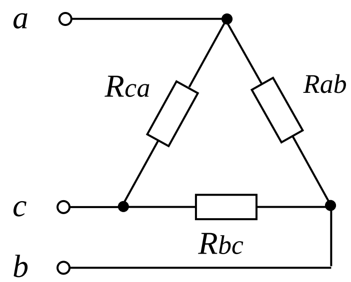


Fig. 7.2

Table 7.1

Var.	1	2	3	4	5	6	7	8	9	10
Pab, W	100	80	60	40	20	100	80	60	40	20
Pbc, W	20	100	80	60	40	20	100	80	60	40
Pca, W	40	20	100	80	60	40	20	100	80	60

Elements of laboratory settings

Laboratory settings consist of the power supply $БП4822-2$, clamps terminal, board 3, measuring devices.

The elements of the board 3 are: consumers (lamps $L1-L9$ $(220\ V,\ 25\ W)$), phase switches $SB1$, $SB2$, neutral switch $SB3$, coil, switch «$X_L \leftrightarrow R$».

Measuring devices are: $PV(P\Omega)$– multi-meter Щ4300 to measure voltage, options: $< \sim >$, $< V >$, $< 200\ V >$; PA –Ammeters Э536, limit of measuring <0.5 A >. The way of measuring devices placement is shown in fig. 7.2.

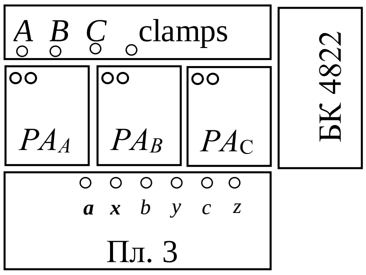


Fig. 7.2

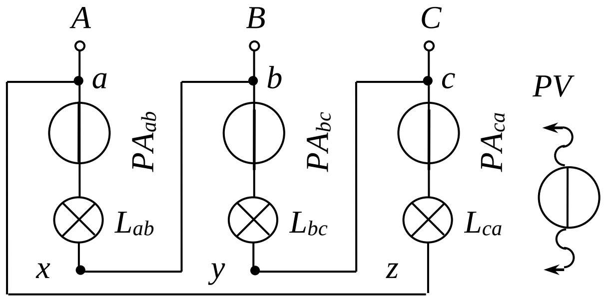


Fig. 7.3

The work execution order

1. Collect the circuit (fig.7.3) and connect it to the clamps A, B, C of the three-phase voltage power source $< 3{\sim}220V >$

2. Investigate the circuit (fig.7.3) with balanced loading ($SB1$ and $SB2$ closed, switch «$L \leftrightarrow Л$» in position $Л$). Fill in the table 7.2 with results.
Draw the vector diagram of currents and voltages using the data from table 7.2.

Table 7.2

	Measuring					
	V_{ab} V	V_{bc} V	V_{ca} V	I_{ab} A	I_{bc} A	I_{ca} A

3. Investigate the circuit (fig.7.3) with non-balanced loading ($SB1$ and $SB2$ opened, switch «$L \leftrightarrow Л$» in position $Л$). Fill in the table 17.3 with results.
Draw the vector diagram of currents and voltages using the data from table 17.3.

Table 7.3

	Measuring					
	V_{ab} V	V_{bc} V	V_{ca} V	I_{ab} A	I_{bc} A	I_{ca} A

4. Investigate the circuit (fig.7.3) with balanced loading ($SB1$ and $SB2$ closed, switch «$L \leftrightarrow$ Л» in position Л) when the phase ab is cut (no wire between x and b). Write down the results to the table 7.4, line 1. Investigate the circuit (fig.7.5) with a non-balanced loading ($SB1$ and $SB2$ open, switch «$L \leftrightarrow$ Л» in position Л) when the phase ab is cut (no wire between x and b). Fill in the line 2 of table 7.4 with results. Draw the vector diagrams of currents and voltages using the data from table 7.4.

Table 7.4

	Measuring					
	V_{ab} V	V_{bc} V	V_{ca} V	I_{ab} A	I_{bc} A	I_{ca} A

Report on work

The name and purpose of work. Homework – the calculation of the circuit. The schematic diagram of the investigated circuit (fig 7.3). The tables 7.2, 7.3, 7.4. The vector diagrams. The conclusions.

Control questions

1. Give the definition of three-phase electromotive force system. When the system is balanced?
2. Draw the vector diagram of three-phases electromotive forces.
3. Write down the expressions of instantaneous phases, electromotive forces and their effective value complexes.
4. Write down the expressions of active, reactive and total power of three-phase system using phase voltages and currents.
5. Draw the three-phase source DELTA connection and mark phase and line voltages.
6. Explain the main types of source and consumer connection in three-phase system.
7. Write down the relationships between effective values of phase and line voltages and currents for DELTA connection.
8. Write down how we can define the complex line currents for the known complex phase currents for the consumers DELTA connection.
9. Draw the phase and line currents for the consumers DELTA connection at vector diagram. What is the phase shift angle for them?
10. Explain how the three-phase circuit with DELTA connected load can be calculated.

LABORATORY WORK 8

Investigation
of inductive coil with ferromagnetic core

The purpose of the work is to investigate inductive coil with ferromagnetic core and adjustable nonmagnetic gap as well as its current-voltage characteristics.

The coil electromagnetic circuit is shown in fig.8.1. Applied to the coil voltage v initiates current i, which results in a magnetic flux. Magnetic flux Φ is the vector sum of the main magnetic flux Φ_o, which is closed through the core, and the magnetic flux of dissipation Φ_D, which closes in the air around the coils $\underline{\Phi} = \underline{\Phi}_o + \underline{\Phi}_D$. Dissipation magnetic flux is not involved in energy transmission (in transformers). The core permeability (μ>>1) is much higher than air permeability (μ=1), that means $\Phi_o >> \Phi_D$, but the magnetic fluxes can shift the phase.

Fig. 8.2 shows a series-parallel equivalent circuit of the coil with core, where $\Delta P_E = R\,I^2$ are electrical losses in the coil winding; $X_D = \omega L_D$- coil reactance caused by dissipation; L_D - inductance, equivalent to the dissipation magnetic flux Φ_D; G_0- the conductance, equivalent to core magnetic losses $\Delta P_M = G_0\,E^2$; B_0 - susceptance, equivalent to the main magnetic flux Φ_0.

Fig. 8.3 shows a serial equivalent circuit of the coil, where $\underline{V} = \underline{E} + R_0\underline{I} + jX_0\underline{I}$.

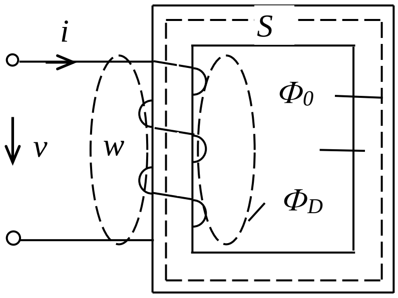


Fig. 8.1

Electromotive forces induced by the main magnetic flux are:

$$e = -w\,d\Phi / dt\,,$$

$$E = \omega w\,\Phi_m / \sqrt{2} = 4.44\,fw\,\Phi_m\ .$$

Electromotive forces induced by the dissipation magnetic flux are: $e_D = -L_D di/dt$, .

$\underline{E}_D = -j\omega L_D I = -X_D\underline{I}$.

The equation of electric state of the coil is written by the second Kirchhoff 's law in complex form: $\underline{V} = -\underline{E} + R\underline{I} + jX_D\underline{I}$.

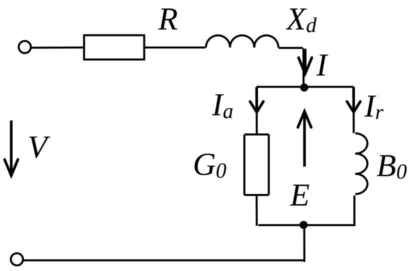


Fig. 8.2

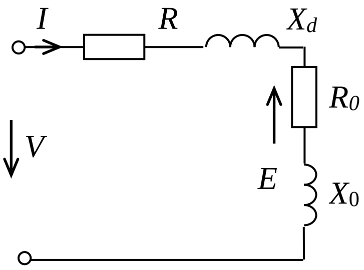


Fig. 8.3

Homework

To calculate magneto-motive force *F*, magnetic field tension *H*, magnetic flux Φ, magnetic resistance $R_{m,}$ coil induction *L* for the coil with toroidal ferromagnetic core at given medial line magnetic circuit length *l*, cross-section area *S*, coil current *I*, number of winding turns *w*, steel relative magnetic permeability $\mu_{r,}$ vacuum magnetic permeability μ_0=4π·10^{-7} . Tasks variants are listed in the table 8.1.

Table 8.1.

Var.№	1	2	3	4	5	6	7	8	9	10
I ,A	0.5	0.7	1	1.2	1.4	1.6	1.8	2.	2.2	2.4
w	30	40	50	60	70	80	90	100	120	110
l, sm	20	19	18	17	16	15	14	12	11	10
S, sm²	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4

μ_r	950	850	900	800	700	600	200	300	400	500

The work execution order

1. Collect the electrical circuit (fig. 8.4)

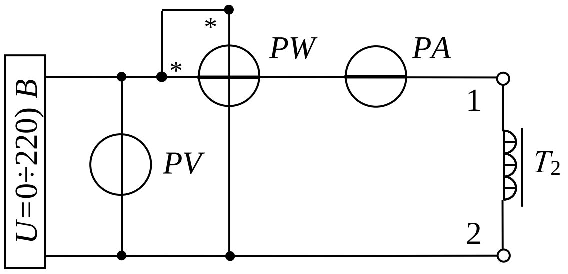


Fig. 8.4

PV – Volt-meter, PW – Watt-meter, PA –Ammeter.

2. Get down the set of inductive coil current-voltage characteristics $I(V)$ at different values of nonmagnetic gap δ $0 \le V \le 210V$ $(\Delta V = 35V)$.

Fill in the table 8.2 with results and draw them as graphs $V(I)$.

Table 8.2

		Measuring						
□, *mm*	*V, B*	0	35	70	105	140	175	210
0	*I, mA*							
1.2	*I, mA*							
2.4	*I, mA*							

3. Get the dependence of current and power from nonmagnetic gap δ, $0 \le \delta \le 2.4$ $(\Delta\delta = 0.4mm)$ for voltage $V = 210V$.

Fill in the table 8.3 with results and draw the graphs $I(\delta)$, $Z(\delta)$ $Z = V_{NOM}/I$.

Table 8.3

□, *mm*		0.0	0.4	0.8	1.2	1.6	2.0	2.4
Meas.	*I, A*							
Meas.	*P, W*							
Calc.	*Z,*							

4. Calculate the coil parameters for the gap δ and fill in the table 8.4 using the results from table 8.3:

– total power $S = V_{NOM} I$;

– magnetic losses $\Delta P_M = P - \Delta P_E$.

– power factor $\cos\varphi = P / S$;

– electrical losses $\Delta P_E = RI^2$ where $R = 46\Omega$;

Table 8.4

	Measuring			*Calculation*			
δ *mm*	V_{nom} *V*	*I, A*	*P W*	*S VA*	$\cos\varphi$	ΔP_e *W*	ΔP_m *W*

Report on work

The name and purpose of the work. The schematic diagram of the investigated circuit (fig.8.4). The tables 8.2, 8.3, 8.4. The characteristics graphs. Conclusions.

Control questions

1. Explain the principle of electromagnetic devices and the roles of their components.
2. State the law of electromagnetic induction. What affects the value and direction of the electromotive force?
3. State the law of electromagnetic force. What affects the value and direction of the electromagnetic force?
4. Write down full current law expression for the inhomogeneous magnetic circuit and explain the difference between the intensity and induction of magnetic field.
5. Draw a diagram of the electromagnetic induction coil with a core. What are the losses in the coil and the core?
6. What are the losses in ferromagnetic core and how they can be reduced?
7. Draw a coil series-parallel substitutional scheme and explain the physical meaning of its elements.
8. Write down the e.m.f. instantaneous and effective values expressions, induced by coil main and dissipation magnetic fluxes.
9. Write down coil electrical state equation and draw a vector diagram.

LABORATORY WORK 9

Investigation of transformer

The purpose of the work is to investigate the work of the transformer, define the basic parameters (characteristics) of the transformer by experiments of open and short circuit.

Transformer electromotive forces e_1 and e_2 create the resulting magnetic flux in the core.

$$e_1 = -w_1\, d\Phi / dt, \qquad E_1 = \omega w_1\, \Phi_m / \sqrt{2},$$

$$e_2 = -w_2 d\Phi / dt, \qquad E_2 = \omega\, w_2\, \Phi_m / \sqrt{2},$$

where $\omega/\sqrt{2} = 2\pi f/\sqrt{2} = 4.44 f$; f – is an AC frequency, Φ_m – is the resulting flux amplitude. Induced electromotive force phase lags behind the magnetic flux phase by an angle of $\pi/2$. The e.m.f. effective values are as follows:

$$E_1 = 4.44\, w_1\, f\, \Phi_m, \qquad E_2 = 4.44\, w_2\, f\, \Phi_m.$$

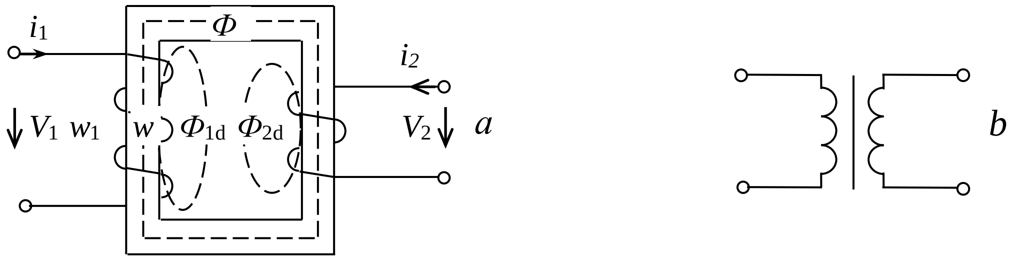


Fig.9.1

If $w_1 > w_2$ the transformer is a down transformer and its transformation ratio is $k_{12} = w_1/w_2 = E_1/E_2 > 1$. If $w_1 < w_2$ the transformer is an up transformer and its transformation ratio is $k_{21} = w_2/w_1 = E_2/E_1 > 1$ (i.e. higher than one).

Transformer electromagnetic substitutional scheme (fig.9.2) represents an idealized real transformer, which includes active R_1 R_2 (winding) resistances and

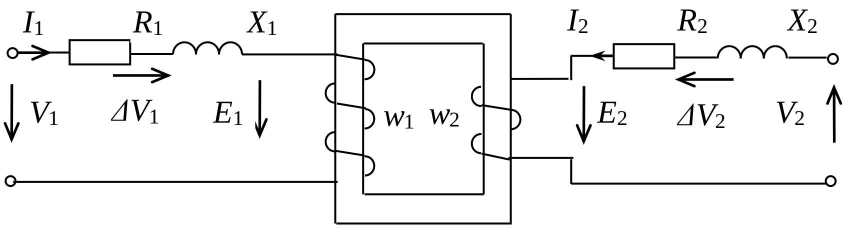


Fig.9.2

(dissipation) reactances X_1, X_2.

The transformer electrical state equations are (fig.5.4):

$$\begin{cases} \underline{V}_1 = -\underline{E}_1 + (R_1 + jX_1)\underline{I}_1 = -\underline{E}_1 + \Delta\underline{V}_1 \\ \underline{V}_2 = \underline{E}_2 - (R_2 + jX_2)\underline{I}_2 = \underline{E}_2 + \Delta\underline{V}_2, \end{cases}$$

where $\Delta\underline{V}_1$, $\Delta\underline{V}_2$ – are accordingly voltage drops across the primary and secondary windings of the transformer. Since $\Delta\underline{V}_1 \approx (0{,}02 \div 0{,}05)V_1$, it can be considered $V_1 \approx E_1$.

Thus, $V_1 \approx E_1 = 4.44 w_1 f_1 \Phi_m$. When $V_1 = const$, the magnetic flux is practically independent of the transformer load.

Electrical state equations corresponds to the scheme on fig.9.2, where E_1 is a receiver of electrical energy (primary winding) and E_2 is an electric energy source (secondary winding).

Homework.

To calculate transformation ratio *k*, primary and secondary windings currents I_1, I_2 , primary and secondary windings powers P_1, P_2, transformer losses ΔP at given total power *S*, primary and secondary windings voltages V_1, V_2, power factor

$cos\,\phi_1$, efficiency factor η, load impedance $\underline{Z}$. Tasks variants are listed in the table 9.1.

Table. 9.1

Var	1	2	3	4	5	6	7	8	9	10
S, VA	800	850	830	880	900	920	950	980	930	780
V_1, *V*	220	220	220	220	220	380	380	380	126	126
V_2,*V*	20	22	11	110	55	20	10	5	42	2
$cos\,\phi_1$	0.7	0.75	0.8	0.73	0.82	0.72	0.71	0.81	0.85	0.83
η	0.9	0.8	0.85	0.95	0.83	0.87	0.93	0.78	0.75	0.78
$\underline{Z}$,Ω	4+j3	2+j2	5+j8	4-j3	2-j2	5-j8	3+j5	3-j5	6+j9	5-j8

Work execution order

1. Collect the electrical circuit (fig. 9.3), where *PV* – is a Volt-meter, *PW* – a Watt-meter and *PA* – Ammeter.

2. Investigate the transformer at open circuit mode with a nominal input voltage $V_{1N}=220V$. Fill in the table 9.2 with results.

3. Investigate the transformer at nominal mode with a nominal input voltage $V_{1N}=220V$ and a nominal input current $I_{1N}=1A$. Vary the current by changing load resistance. Fill in the table 9.2 with results.

4. Investigate the transformer at short circuit mode with a nominal input

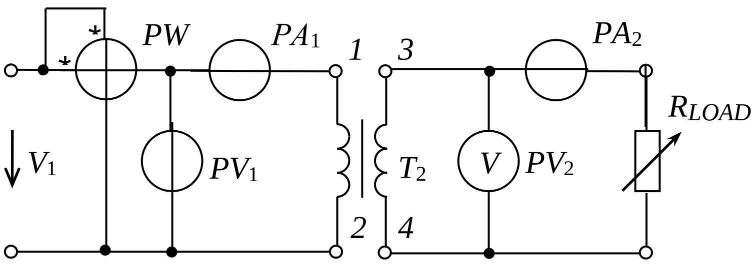


Fig. 9.3.

current $I_{1N}=1A$. Vary the current by changing input voltage. Fill in the table 9.2 with results.

Table 9.2

Regimes	*Measuring*				
	V_1 *V*	I_1 *A*	P_1 *W*	V_2 *V*	I_2 *A*
Open circuit					
Nominal					
Short circuit					

5. Define the transformer parameters from the table 9.2.

$S_N = V_{1N} I_{1N}$ – nominal total power; $K = V_{1OC}/V_{1N}$ – transformation ratio;

$\eta_N = P_{2\,N}/P_{1N}$ – efficiency factor;

P_{oc} – open circuit power; P_{sc} – short circuit power;

$P_{2N} = V_{2\,N} I_{2N}\, cos\,\phi_{2N}$, $cos\,\phi_{2N} = 1$– output nominal power;

$cos\,\phi_{1N} = P_{1N}/(V_{1N} I_{1N})$ – power factor;

$I_{OC}(\%) = (I_{1\ OC}/I_{1\ N}) \cdot 100\ \%$ – open circuit current;
$V_{SC}(\%) = (V_{1SC}/V_{1N}) \cdot 100\%$ – short circuit voltage.
Fill in the table 9.3 with results.

Table 9.3

Transformer parameters									
V_{1N} *V*	I_{1N}, *A*	S_N, *VA*	*K*	η_{1N} *%*	$\cos\varphi_N$	P_{oc} *W*	I_{oc} *%*	P_{sc} *W*	V_{sc} *%*

6. Define the parameters of transformer *T* substitutional scheme. Fill in the table 9.4 with results:

– R_0, X_0 from open circuit mode by the following calculations:

$$Z_0 = V_{1N}/I_{OC}, P_{OC} = R_0 I_{OC}^2\ ,\ Z_0 = \sqrt{R_0^2 + X_0^2}.$$

– R_{SC}, X_{SC} from short circuit mode by the following calculations:

$$Z_{SC} = V_{SC}/I_{1N},\ P_{SC} = R_{SC} I_{1N}^2,\ Z_{SC} = \sqrt{R_{SC}^2 + X_{SC}^2}.$$

– resistances and reactances of the wires by the following calculations:

$$R_1 = R_{SC}/2, X_1 = X_{SC}/2\ R_2' = R_{SC}/2, R_2 = R_2'/K^2, X_2' = X_{SC}/2, X_2 = X_2'/K^2.$$

Table 9.4

Transformer substitutional scheme parameters									
Z_0 Ω	R_0 Ω	X_0 Ω	Z_{SC} Ω	R_{SC} Ω	X_{SC} Ω	R_1 Ω	X_1 Ω	R_2 Ω	X_2 Ω

Report on work

The name and purpose of the work. The schematic diagram of the investigated circuit (fig 9.3). The tables 9.2, 9.3, 9.4. Conclusions.

Control questions

1. Draw a conventional graphical representation of transformers and specify their classification.
2. Explain the principle of the transformer and draw its electromagnetic scheme. Explain the role and purpose of the scheme elements.
3. Write the transformer electrical state equation and draw the transformer substitutional scheme.
4. Write the transformer magnetical state equation and write the primary winding current expression.
5. Explain how the transformation ratio is defined.
6. Draw a T-shaped transformer substitutional scheme and explain the physical meaning of its elements.
7. How the parameters of T-shaped transformer substitutional scheme can be defined experimentally?
8. Draw the transformer substitutional scheme for open circuit experiment and explain how the parameters of this scheme are determined.

9. Draw the transformer substitutional scheme for short circuit experiment and explain how the parameters of this scheme are determined.

10. Explain what the specific transformer parameters are.

11. Draw a graph - a dependence of the trnsformer external characteristics from loading. Why does the voltage increase with the active-capacitive loading?

12. Draw the transformer power diagram and explain its losses.

13. Write down the transformer expressions for power (input, output, losses).

14. Write down the expression for transformer efficiency factor. What is the load factor?

15.Draw and explain the dependence between efficiency factor and transformer loading.

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Attachments

№	***Greek letters***		
1	*Α*	*α*	*alfa*
2	*Β*	*β*	*beta*
3	*Γ*	*γ*	*gamma*
4	*Δ*	*δ*	*delta*
5	*Ε*	*ε*	*epsilon*
6	*Ζ*	*ζ*	*dzeta*
7	*Η*	*η*	*eta*
8	*Θ*	*θ,*	*teta*
9	*Ι*	*ι*	*jota*
10	*Κ*	*κ*	*kapa*
11	*Λ*	*λ*	*lambda*
12	*Μ*	*μ*	*miu*
13	*Ν*	*ν*	*niu*
14	*Ξ*	*ξ*	*ksi*
15	*Ο*	*ο*	*micron*
16	*Π*	*π*	*pi*
17	*Ρ*	*ρ*	*ro*
18	*Σ*	*σ,ς*	*sigma*
19	*Τ*	*τ*	*tau*
20	*Υ*	*υ*	*ipsilon*
21	*Φ*	*φ*	*fi*
22	*Χ*	*χ*	*hi*
23	*Ψ*	*ψ*	*psi*
24	*Ω*	*ω*	*omega*

Physical values designation and units

Value	***Designation***	***Dimension***
Resistance	*R,* Ω	***Om***
Reactance	*X,* Ω	***Om***
Impedance	*Z,* Ω	***Om***
Conductance	*G, Sm*	***Simens***
Susceptance	*B, Sm*	***Simens***
Admittance	*Y, Sm*	***Simens***
Capacity	*C, F*	***Farada***
Inductance	*L, H*	***Henry***
Inductance mutual	*M, H*	***Henry***
Electromotive force	*E, V*	***Volt***
Potential	*φ, V*	***Volt***
Voltage	*V, V*	***Volt***

Current	*I, A*	***Amper***
Active power	*P, W*	***Watt***
Reactive power	*Q, VAr*	***Volt-Amper reactive***
Total power	*S, VA*	***Volt-Amper***
Magnetomotive force	*F, A*	***Amper***
Magnetic induction	*B, T*	***Tesla***
Magnetic field tension	*H, A/m*	***Amper per meter***
Magnetic stream	*Ф, Wb*	***Weber***
Linkage	ψ, *Wb*	***Weber***
Magnetic permeability (absolute)	μ_a,, *Гн/м*	***Henry per meter***
Magnetic permeability (relative)	μ	
Magnetic constant	μ_0, *Гн/м*	$4\pi \cdot 10^{-7}$
Frequency	*f, Hz*	***Herz***
Angular frequency	ω, *rad/s*	***radian per second***
Length	*1, m*	***meter***
Hight, depth	*h, m*	***meter***
Layer	δ, *d, m*	***meter***
Arial	*S*, m^2	***square meter***
Magnetic resistance	R_m	
Number of turns	*w*	
Force	*F, N*	***Newton***
Work (energy)	*W, J*	***Joule***
Charge	*Q, C*	***Coulomb***

Content