MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

Dnipro University of Technology

Національний
Технічний університет
ДНІПРОВСЬКА
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V.S. KHILOV

Guidelines to laboratory works on discipline

METROLOGY FUNDAMENTALS AND ELECTRICAL MEASUREMENTS

For full-time students' education in academic discipline 141"Electric Power, Electrical Engineering and Electromechanics"

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DNIPRO

Dnipro University of Technology

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Рекомендовано до видання навчально-методичним відділом (протокол № від за поданням науково-методичної комісії зі спеціальності 141 – Електроенергетика, електротехніка та електромеханіка (протокол № 21/22-01 від 30.08.2021 р.)

Методичні вказівки англійською мовою до лабораторних робіт з дисципліни «Основи метрології та електричні вимірювання» для студентів спеціальності 141 – Електроенергетика, електротехніка та електромеханіка / В.С. Хілов; Нац. техн. ун-т. «Дніпровська політехніка» – Д.: НТУ "ДП", 2021. – 41 с.

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Методичні вказівки англійською мовою призначено для виконання лабораторних робіт з дисципліни «Основи метрології та електричні вимірювання». В інструкціях до виконання лабораторних робіт наведено основний матеріал, який викладається на протязі одної чверті семестру та відповідає затвердженій програмі. Кожна лабораторна робота складається з назви, мети, програми та етапів виконання, методичних вказівок, контрольних запитань.

Introduction

One of the most important types of classes in the course "Metrology Fundamentals and Electrical Measurements" is the performance of laboratory work. To increase the efficiency of the laboratory practicum, these methodical instructions have been developed.

Methodical instructions are intended for laboratory work in the discipline "Metrology Fundamentals and Electrical Measurements" for full-time students education in academic discipline: 141"Electric Power, Electrical Engineering and Electromechanics".

These laboratory works contain all the basic material, which is taught during two quarters of the semester and corresponds to the approved program.

Each laboratory work consists of the name, objective, program and stages of work execution, guidelines, control questions.

Duration of laboratory work is two academic hours; independent preparation for work - one hour; report - one hour.

The objective of laboratory classes is to consolidate the theoretical knowledge gained in lectures, and the acquisition of skills in experimental research of electrical circuits.

The process of laboratory work is designed for four stages: independent preparation for laboratory classes; experimental research on the stand; registration of research results; obtain the credit for laboratory work.

Independent preparation for the laboratory lesson is carried out in accordance with the topic and objective of the work. This is an in-depth study of the relevant sections of the “Metrology Fundamentals and Electrical Measurements” course, the selection of individual parameters of the schemes, recording the necessary analytical relationships, drawings of schematic diagrams and tables for experimental results, answers to questions posed in the task.

The report is compiled by each student independently and is the main document in the performance and defense of laboratory work, which is drawn up in a separate notebook (12 sheets). Graphs and vector diagrams are built at scale. The report on each laboratory work should contain the main items: 1. Number and title of the work; 2. Objective of work; 3. Program of work c; 4. Analysis of results; 5. Conclusions on the performed calculations and their experimental verification. In addition to the main points, the report should contain additional points that are listed in each paper.

Experimental research is conducted at the training and research stand by teams of 2-3 students. The team receives permission to draw up an electrical circuit only after an interview with the tutor.

The student during the laboratory work must:

• follow the rules of electrical safety, which are given in the guidelines for laboratory work;

• perform laboratory work according to the appropriate method;

• make a report on the performance of laboratory work;

• protect the results of previous laboratory work;

• to receive an assessment for a laboratory module through a certain form of modular control (protection of reports on laboratory work).

BASIC SAFETY RULES
WHEN PERFORMED A LABORATORY PRACTICUM

1. Only students who are acquainted with the rules of safety in the electrical laboratories of the university are allowed to take the laboratory practicum.
2. Before passing the next cycle of the laboratory practicum in the electrical laboratories of the university, students must study the safety instructions and receive additional instruction before starting work in each subsequent laboratory. Students, after getting acquainted with the rules of safety and instructed, must sign the logbook for compliance with safety rules and liability for violation.
3. During work in electric laboratories it is forbidden to switch on laboratory stands under voltage, to make any switching on or switching in the main distribution cabinet, to change safety locks, and after automatic switching off by the protective equipment to do switching on again without the permission of the tutor conducting laboratory practicum.
4. Drawing up of electric schemes and all changes in electric schemes should be carried out at the switched-off voltage. It is impossible to switch in the scheme in work before check of its serviceability.
5. It is forbidden to leave current conductors with or without voltage in the passages between workplaces. It is forbidden to make any switches in the power supply circuits of the research stands.
6. It is possible to use conductors for drawing up schemes only on condition of sufficient area of their section by the provided value of currents. Conductors must be intact insulation and lugs. Particular care should be taken when studying circuits with series connections of inductors and capacitors, as resonant overvoltage’s are possible in such circuits.
7. Keep in mind that a disconnected capacitor can retain a dangerous residual charge, so it must be discharged before connecting to the circuit. Do not touch uninsulated current-carrying parts of electrical circuits that are or may be with voltage.
8. If during the laboratory work on the stand there is a characteristic smell of burnt plastic, strong buzzing of electrical equipment, smoke, or a sudden movement of the arrows off-scale of measuring instruments, you must immediately turn off the voltage and notify of the tutor.
9. In the event of an emergency (may be a person under voltage, a short circuit on the lab stand, breakage of current-carrying wires, fire etc.) first of all with the switch turns off the lab stand from the power supply, and if necessary, the button "Off 95 "the power supply of the classroom is disconnected. Button "Off. 95 "is in the distribution cabinet.
10. The fire is extinguished by a carbon dioxide fire extinguisher located at the workplace of the duty laboratory assistant. There is also a first aid kit with medicines for first aid.

LABORATORY WORK MFEM – 1

AMMETER AND VOLTMETER CALIBRATION

Objective: to acquire practical skills when performing the verification of electrical instruments.

Program of operation

1. The verifiable instruments familiarization and the reference instruments selection.
2. Verification conditions determination.
3. Ammeter verification.
4. Voltmeter verification.

Work stages

Stage 1. The verifiable instruments familiarization and the reference instruments selection.

On the scale of the measuring instruments contains information about the measuring system of the device; the accuracy class to which the instrument corresponds; information about internal parameters; requirements for operating conditions; the degree of protection against the influence of external electric, magnetic fields, etc. The information is displayed in the form of labels, the list of which is approved by state standard.

You need to familiarize yourself with the instruments that are verifiable, the labels on the scales and decipher them. Establish the principle of operation of each device, purpose, accuracy class, the necessary requirements for correct measurement. Based on the information of the devices to be verifiable, it is necessary to correctly determine the metrological parameters of the reference instruments.

Specify the data on the reference and verifiable instruments in Table 1.

Table 1

Conventional symbols on the instrument scale

Instrument	Measurement system	Range of measurement	Conventional symbols on the instrument scale
Certifiable ammeter			
Reference ammeter			
Certifiable voltmeter			
Reference voltmeter			

Stage 2. Verification conditions determination.

When verification measuring instruments, it is necessary to determine the conditions of their operation: environmental temperature and humidity, atmospheric pressure, the electric and magnetic fields sources presence nearby the instruments. Pay attention to the necessary working position of the instruments (horizontal, vertical).

The obtained data on the operating conditions must be written to the Table 2. Regarding the conditions of instruments verification it needs to make a conclusion.

Table 2

Operating conditions of measuring instruments

Air temperature, ^0C	Relative humidity, %	Atmospheric pressure, mm Hg (millimeter of mercury)	The level of external magnetic and electric fields	Instrument position	Conclusion

Stage 3. Ammeter verification.

Assemble electric circuit as it shown in Figure 1.

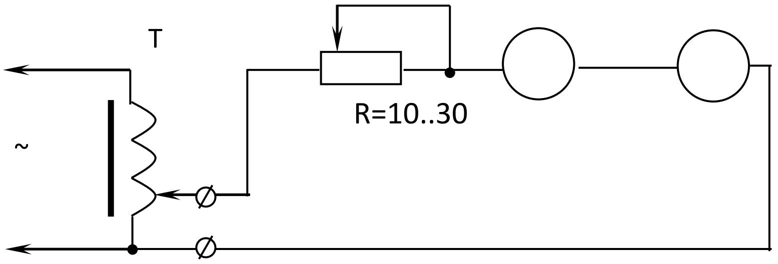

Figure 1. – Ammeter verification circuit

As a source of voltage supplied to the input of the circuit, a laboratory autotransformer (LATR), which is marked on the circuit "TV", is used. Coarse adjustment of the current in the electric circuit is achieved through the use of an autotransformer. Fine adjustment needs performed with a rheostat. Before verification, the arrows of the certifiable and the reference instrument needs to set against the zero mark on the scale.

The instruments verification is done as follows. By gradually increasing the input voltage of the electrical circuit (coarse adjustment) reach the first digitized on scale division of the certifiable ammeter. By a smooth rheostat adjustment, set the arrow exactly in front of the digitized division of the instrument being certifiable. Take the instruments readings. The readings of both instruments need to write down in Table 3 (columns 1 and 2).

Table 3

Ammeter verification results

Instruments reading				Measurement errors						
Certifiable.	Reference			**absolute**		correction	**Relative**		**Reduced**	
				increase	decrease		increase	decrease	increase	decrease
I_x, A	increase I', A	decrease. I'', A	average I_{cp}, A	$\Delta I'$, A	$\Delta I''$, A	I_n, A	δ', %	δ'', %	γ', %	γ'', %
0										
1										
2										
3										
4										
5										

Thus, it is necessary to take the readings for all digitized divisions of the certifiable ammeter, while moving the arrow in only one direction - the direction of increasing the current. If the latter requirement is not met, the study must be done from starting. After reaching the maximum value of the measured current, it is necessary to repeat the experiment in the direction of decreasing the readings of the instrument. The results write down to the Table 3 (column 3).

Note: the one prime for lettering the measured and calculated parameters corresponds to the mode of the instrument readings increase, double prime is used for decrease the measured value.

Stage 4. Voltmeter verification.

The verification procedure for the voltmeter is similar. The scheme of the test circuit when turning on two voltmeters is shown in Fig. 2. The results of the test must be written to Table 4.

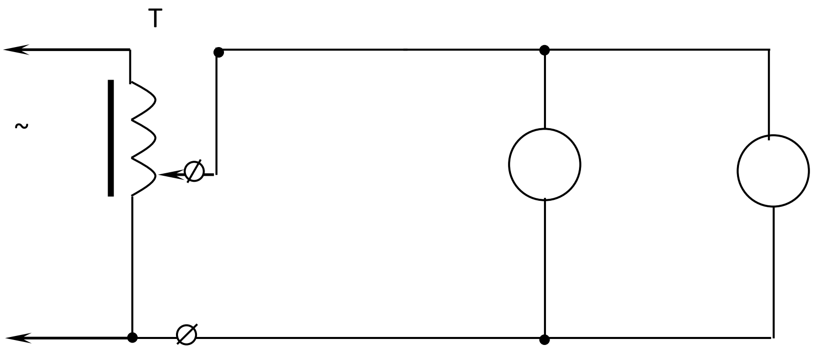

Figure 1. – Voltmeter verification circuit

To fine regulate the voltage on the voltmeters between points a and b of the circuit, it is recommended to swithed on a rheostat with a resistance of 1...1.5 kOhm.

Table 4.

Voltmeter verification results

Instruments reading				Measurement errors						
Certifiable	Reference			absolute		correction	Relative		Reduced	
	increase	decrease	average	increase	decrease		increase	decrease	increase	decrease
U_x, V	U', V	U'', V	U_{cp}, V	$\Delta U'$, V	$\Delta U''$, V	U_n, V	δ', %	δ'', %	γ', %	γ'', %

After calculations have been completed and the tables completed, it must be concluded about the certifiable ammeter and voltmeter – do they whether correspond to the declared to their accuracy class?

The report must contain

1. Number, name, objective and program of laboratory work.
2. Instruments data (Tables 1, 2).
3. Circuits for verification the ammeter and voltmeter.
4. Table. 3 and 4 with tested results.
5. Conclusions on the conformity of the instruments to the specified accuracy class.

Methodical instructions

Stage 1. The following rules must be followed when selecting reference instruments:

- the main reduced error for the reference instrument shall be not less than three, but preferably five times below the main reduced error for the certifiable instrument;

- the AC instruments should be verification using the reference electrodynamic system. It is assumed using that ammeters and voltmeters of the same system as those certifiable, but with better metrological characteristics, are used as reference devices;

- the upper limit of measurement of the reference instrument must be the same as that of the certifiable instrument, or it may not exceed it by more than 25%.

Stage 2. The normative documents set out the conditions of the measuring instruments operation in relation to values (except the one to be measured), under the action of which the true value of the measure, the instrument or the equation of conversion of the converter changes. The factors that affect the readings of the instrument are the temperature and humidity of the air, the atmospheric pressure, the level of external electric and magnetic fields, the position of the instrument, the vibration frequency and others.

Measurement error under normal operating conditions is called a main error. The conclusion about normal conditions of use one can made when comparing the true values of these factors with the permissible values specified in the sertificate data of the instruments. The main measurement errors are to be determined based on the instrument accuracy class. If the test conditions of the devices are different from normal, then an additional error must be taken into account when processing the measurement results.

Stage 3, 4. The absolute error of the instrument readings is the difference between the readings of the certifiable instrument A_x and the true value of the measured value A (reference instrument):

$$\Delta A = A_x - A.$$

Absolute error has the same units of measure as the measured value.

The relative error of the instrument is defined as the ratio of the absolute error to the true value of the device, so it is measured in fractions of one or in percent:

$$\delta = \frac{\Delta A}{A} \cdot 100\%.$$

The correction is the value of the value that is added to the value obtained during the measurement in order to eliminate systematic error. Amendments determine for each mark of the scale of the test instrument according to the arithmetic mean of two measurements by increasing and decreasing the measured value:

$$A_n = A_{cp} - A_x, \text{ where } A_{cp} = \frac{A' + A''}{2},$$

A', A'' is the true value of the measured value as it increases and decreases.

The reduced error is calculated as the ratio of absolute error to the normalized value:

$$\gamma = \frac{\Delta A}{A_H} \cdot 100\%,$$

where A_H is normalizing value (equal to the length of the measurement range the instrument was operated on).

In order to account for the error introduced by the reference instrument, it is considered that the instrument is in accordance with its accuracy class if

$$\gamma_{max} \le K_{пов} - K_{зр},$$

where γ_{max} is greatest of the calculated values of the error obtained as a result of the verification;
$K_{пов}, K_{зр}$ is respectively the accuracy classes of the certifiable and reference instruments.

The instrument does not meet the assigned accuracy class if

$$\gamma_{max} \ge K_{пов} + K_{зр}.$$

The conclusion about the conformity of the instrument to the assigned accuracy class cannot be made if

$$K_{пов} - K_{зр} < \gamma_{max} < K_{пов} + K_{зр}.$$

There are casuses when an instrument with an accuracy class for a reduced error to be needs tested by an instrument with an accuracy class for the relative error, or vice versa. In this case, the maximum absolute error of the reference instrument $\Delta_{зр}$ shall be three or more times less than the maximum absolute error of the certifiable instrument $\Delta_{пов}$. Absolute errors of instruments are found by formulas:

$$\Delta = \frac{\gamma \cdot A_H}{100}; \qquad \Delta = \frac{\delta \cdot A}{100}.$$

The instrument corresponds to its accuracy class if $\Delta A_{max} \le \Delta_{пов} - \Delta_{зр}$, where ΔA_{max} is greatest of the absolute errors are taken from a number of verified digitized divisions.

The instrument does not corresponds the assigned accuracy class if $\Delta A_{max} \ge \Delta_{пов} + \Delta_{зр}$.

The conclusion about the conformity of the instrument to the assigned accuracy class cannot be made if $\Delta_{пов} - \Delta_{зр} < \Delta A_{max} < \Delta_{пов} + \Delta_{зр}$.

Test questions

1. What are the requirements for certifiable instruments?
2. What is the main and additional measurement error?
3. How are corrections to instruments tested determined?
4. What characterizes the accuracy class of the instrument?
5. What are the errors that determine the accuracy class of the instrument?
6. What factors affect the accuracy of measurements?

7. Why can the measurements of an exemplary instrument obtained by increasing and decreasing the measured value be different?
8. What instruments are required to determine the conditions for checking the devices?
9. What are the normal operating conditions of the devices?
10. What is the purpose of resistors in circuits and how are they selected?

LABORATORY WORK MFEM - 2

POWER MEASUREMENT IN THREE-PHASE CIRCUITS

Objective: to learn how to measure active and reactive power in three-phase circuits.

Program of operation

1. Assembling a circuit for measuring active power.
2. Measurement of active power.
3. Assembling a circuit for measuring reactive power.
4. Measurement of reactive power.
5. Calculation of measurement errors.

Work stages

Stage1. Assembling a circuit for measuring active power

To measure the active power in three-phase circuits, various wattmeters switching on schemes are used, which are caused by the features of connecting the load in a three-phase circuit (a wye or delta connection, three-wire and four-wire circuits, symmetrical and asymmetric loads).

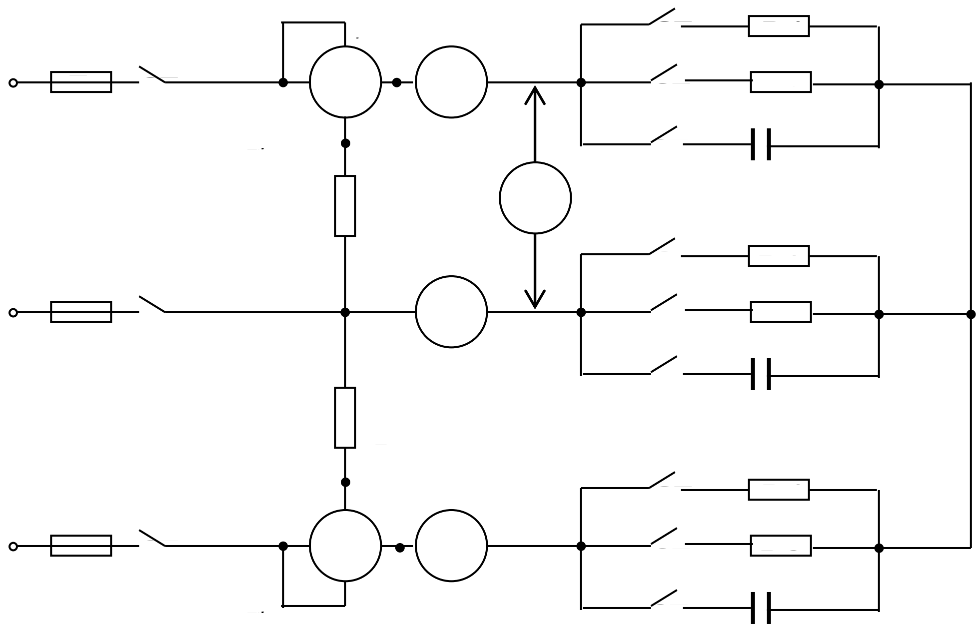

Figure1. – Scheme for measuring active power in a three-wire three-phase network

Measurement of active power in four-wire circuits is carried out using three wattmeters; to measure power in three-wire circuits with a symmetrical load, one wattmeter is enough, for an asymmetric one - two. In laboratory work to measure the active power in a three-wire circuit the method of two wattmeters is used.

The connection scheme of two wattmeters, which is shown in Fig. 1, allows measurements of active power at a symmetric and asymmetric load.

Assemble the electrical circuit according to the scheme shown in Fig. 1, given that: 1) with load resistance $R_{1,2}$ = 400; 600; 800 Ohm they are connected by a delta; 2) ammeters must measure linear currents; 3) set the limits of the wattmeter for voltage to the position U_H = 300 V, if the wattmeter limit for voltage is 150 V, then to expand the voltage measurement range, it is necessary to switch on the additional resistance in series with the voltage winding of each wattmeter (the one division value on scale of the wattmeter will change).

<u>Stage 2.</u> Active power measurement.

Measure the active power of a three-wire circuit under symmetrical and asymmetrical non-uniform load. Asymmetry should be performed by switching on the load into phase having different resistance values $R_{1,2}$. The instrument readings and load resistance values writing down in Table. 1.

Make sure that the change in reactive load does not affect to the wattmeters readings sum!

Table 1.

Measured and calculated values

<table>
<tr><td colspan="2" rowspan="3">Load</td><td colspan="6">Measured</td><td colspan="5">Calculated</td></tr>
<tr><td>U_L</td><td>I_1</td><td>I_2</td><td>I_3</td><td>W_1</td><td>W_2</td><td>$P=W_1+W_2$</td><td>ΔP_m</td><td>ΔP_b</td><td>δ_{Pm}</td><td>δ_{Pb}</td></tr>
<tr><td>V</td><td>A</td><td>A</td><td>A</td><td>W</td><td>W</td><td>W</td><td>W</td><td>W</td><td>%</td><td>%</td></tr>
<tr><td rowspan="3">Symmetrical</td><td>R</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>C</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>R, C</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Asymmetrical</td><td>R</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>R, C</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

<u>Stage 3.</u> <u>Assembling a circuit for measuring reactive power.</u>

Assemble a circuit according to the scheme shown in Fig. 2, for measuring reactive power. For this purpose it is necessary to change only the scheme of connecting the parallel windings of wattmeters. The resistance $R_Д$ must be equal to the resistance of the parallel windings of both wattmeters.

<u>Stage 4.</u> <u>Reactive power measurement.</u>

Measure the reactive power of a three-wire circuit at symmetric, asymmetric loading. The obtained readings of the devices are writing down in table 2.

Note: when conducting research, observe how the readings of the wattmeters and their sum change when the active resistance of the phases changes.

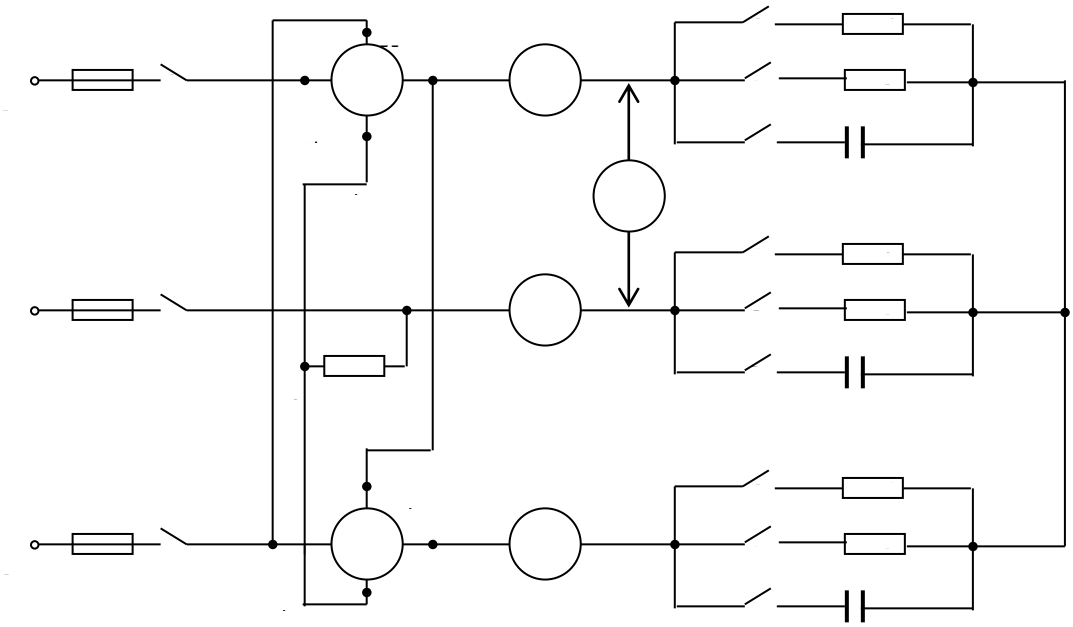

Figure1. – Scheme for measuring reactive power in a three-wire three-phase network

Table 2.

Measured and calculated values

Load		Measured						Calculated				
		$V_л$	I_1	I_2	I_3	P_1	P_2	$Q = \sqrt{3}(P_1 + P_2)$	ΔQ_m	ΔQ_b	δ_{Qm}	δ_{Qb}
		V	A	A	A	W	W	var	var	var	%	%
Symmetrical	R											
	C											
	R, C											
Asymmetrical	C											
	R, C											

<u>Stage 5</u>. <u>Calculation of measurement errors.</u>

Certificate data of measuring instruments to write down to table 3. According to the formulas given in the Methodical instructions, calculate the absolute and relative error of measurements of active and reactive power.

The report must contain

1. Number, name, objective and the laboratory work program.
2. Schemes of electrical circuits for measuring active and reactive powers (Fig. 1 and 2).
3. Completed tables 1, 2, 3.
4. Calculation of active and reactive powers.
5. Calculation of measurement errors.

Table 3.

Technical data of measuring instruments

Purpose of the device	Factory number	System	Measurement range	Value of division	Accuracy class
Voltmeter (PV_1)					
Wattmeter (PW_1)					
Wattmeter (PW_2)					
Ammeter (PA_1)					
Ammeter (PA_2)					
Ammeter (PA_3)					

Methodical instructions

Stage 2. Wattmeter readings can be positive or negative, depending on the angle of shift between currents and voltages, so the wattmeter readings should be summed algebraically. When switching on reactive load, the total wattmeter reading should not change, as only the reactive power is changed, the active power remains unchanged.

Stage 4. When measuring the reactive power of a three-phase circle with using two wattmeters, the parallel windings of these wattmeters join together with the resistance create a Y-connection. It is necessary to observe the conditions:

$$R_{U1} = R_{U2} = R_0,$$

where R_{U1}, R_{U2} are resistances of the wattmeters parallel windings.

Stage 4. The calculation of errors in indirect measurements is fulfilled by differentiating the function in partial derivatives of each of the direct measurements parameters [4]. The calculation formulas for estimating the error of active power measurement are given below. Calculate the error of measuring reactive power independently.

The total active power of a three-phase circuit consists of the sum of the readings of two wattmeters switched on according to the scheme Fig. 1:

$$P = W_1 + W_2.$$

The absolute errors of the wattmeter readings are calculated as follows
- for devices with an accuracy class that corresponds to the reduced error:

$$\Delta P_1 = \pm \frac{\gamma_1 \cdot P_{H1}}{100}; \qquad \Delta P_2 = \pm \frac{\gamma_2 \cdot P_{H2}}{100};$$

- for devices with an accuracy class corresponding to a relative error:

$$\Delta P_1 = \pm \frac{\delta_1 \cdot W_1}{100}; \qquad \Delta P_2 = \pm \frac{\delta_2 \cdot W_2}{100}.$$

Maximum absolute measurement error

$$\Delta P_m = |\Delta P_1| + |\Delta P_2|;$$

probable absolute error

$$\Delta P_b = \sqrt{(\Delta P_1)^2 + (\Delta P_2)^2}.$$

Maximum relative measurement error:

$$\delta P_m = \frac{\Delta P_m}{P} 100\%,$$

the probable relative error is calculated as follows

$$\delta P_b = \frac{\Delta P_b}{W_1 + W_2} 100\% = \sqrt{(\frac{\Delta P_1}{P})^2 + (\frac{\Delta P_2}{P})^2}, \%.$$

Test questions

Under what condition are the readings of one of the wattmeters in the scheme of fig. 1 at total symmetry of the circle:

a) equal to zero;

b) is negative?

1. What is equal the difference of the wattmeter readings of the scheme in Fig. 1 at symmetrical circle?
2. What is the purpose of the resistance in the scheme of Fig. 2 and how to calculate it?
3. How to measure active and reactive power in a three-wire symmetric circle with one wattmeter?
4. How to determine the value of dividing the wattmeter?
5. Record the expressions of the wattmeter readings in the scheme of Fig. 1 for an asymmetrical and symmetric three-phase circle.
6. What are the conditions for applying the two wattmeters circuit in Fig. 1 and 2?
7. How to calculate Rd for wattmeters in the scheme of Fig. 1?
8. By what metrological characteristics is the wattmeter selected?

LABORATORY WORK MFEM – 3

DIRECT, INDIRECT AND MULTIPLE MEASUREMENTS ACCURACY ASSESSMENT

Objective: get the learning of determine the errors when performing measurements of electrical parameters by direct and indirect methods and by multiple observations.

Program of operation

1. Assembling the electrical circuit; performing direct measurements of current, voltage, and active power. Determining of direct errors measurements and record the measurement result.
2. Determining of the value measured by the indirect method, calculating of errors and recording the result of the indirect measurement.
3. Performing measurements with multiple observations, processing and recording the result.

Work stages

Stage 1. Assemble the electrical circuit; perform direct measurements of current, voltage, and active power. Determine of direct errors measurements and record the measurement result.

Assemble the electrical circuit in accordance with Fig. 1 and perform direct measurements of curren I, voltage U and power P.

The parameters of the inductor –the active resistance and inductance are indicated on the diagram, respectively R_K and L.

The readings of the devices are to write down in the table 1 (one measurement of three parameters is carried out - current, voltage and power). When conducting experimental studies, it is necessary to record the parameters of measuring instruments - accuracy class and measurement limit.

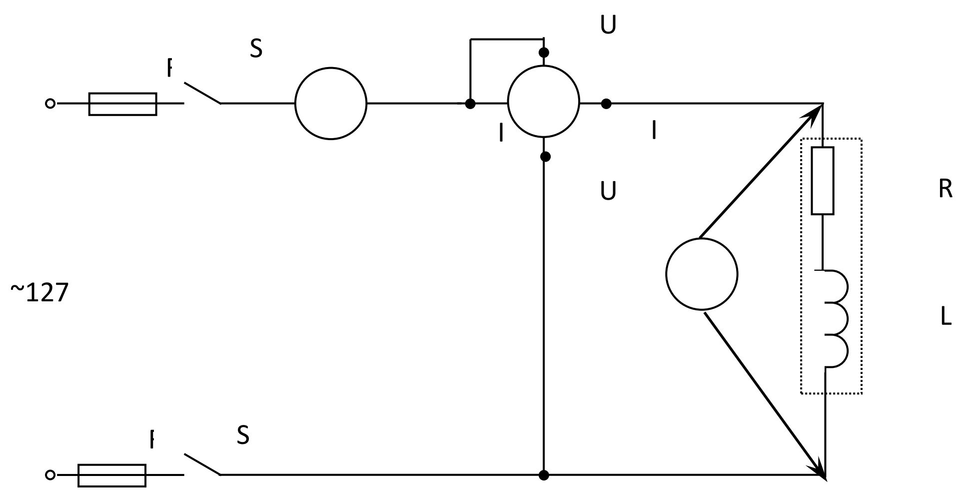

Figure 1. – Experiment circuit

Based on the data obtained, determine the absolute errors and record the results of direct measurements of the table 1 taking into account the requirements for the presentation of measurement results in accordance with the standard.

Table 1.

Instrument readings and measurement error

Instruments reading			Measurement errors			Measurement results		
I, A	U, V	P, W	ΔI, A	ΔU, V	ΔP, W	I±ΔI, A	U±ΔU, V	P±ΔP, W

Stage 2. Determination of the value measured by the indirect method, calculation of the error and recording of the result of the indirect measurement

From the results of direct measurements, calculate the apparent power S and impedance Z of the coil, as well as the power factor of the circuit $cos\varphi$. Determine the errors and results of indirect measurements. The obtained values to write dawn in table 2.

At the direction of the lecturer, for indirect measurements, the following can be set: resistance R and reactance X_L, coil inductance L, reactive power Q, consumed by the coil.

Table 2.

Calculated values and measurement error

Calculated values			Measurement errors			Measurement results		
S, VA	Z, Ohm	$cos\varphi$	ΔS, VA	ΔZ, Ohm	$\Delta cos\varphi$	S±ΔS	Z±ΔZ	$cos\varphi \pm \Delta cos\varphi$

Stage 3. Fulfilling measurements with multiple observations, process and record the result.

Using a multimeter, measure the values of ten ohmic resistors resistances selected from one technological batch. The results of multiple measurements as well as calculation results and measurement results write down in table. 3. (When preparing a report for laboratory work, note that the first column will contain ten rows).

Based on the results of multiple measurements are construct graphs of the histogram and the theoretical probability density function of the measured value.

Table 3.

Measurement parameters and measurement result

Observation results	Measurement parameters				Measurement result
R_i, Ohm	σ, Ohm	σ_n, Ohm	ε, Ohm	ΔR, Ohm	$R \pm \Delta R$, P=

The report must contain.

1. Number, name, objective and program of laboratory work.
2. The scheme of the test circle (Fig. 1).
3. Tables 1, 2 and 3 with have been recorded measurement results.
4. Graph with histogram and probability density function of measured ohmic resistor resistance.
5. Conclusions.

Methodical instructions

Stage 1. The absolute error ΔX s determined based on the accuracy class of the instrument. It is known that for most electromechanical instruments, the accuracy class is determined by the basic and reduced error: $\gamma = \frac{\Delta X}{X_H} \cdot 100\%$, where X_H is the normalized value of the measured quantity (in this case, the measurement limit of the given instrument is chosen as the normative value); ΔX is an absolute measurement error.

If the accuracy class of an instrument is circled, it means that it corresponds to its basic relative error, that is $\delta = \frac{\Delta X}{X} \cdot 100\%$, where X is the value of the measured quantity.

The calculation $\Delta I, \Delta U, \Delta P$ is made using the formulas above. The result of the calculation of the absolute error must have no more than two significant figures. The recording of direct measurement format has as follows: $X_n = X \pm \Delta X$, where X is instrument readings (the number must have the same quantity for digit positions as in the absolute error).

Stage 2. 2. The maximum value of the indirect measurement error is calculated by the formula:

$$\Delta Y_m = \left|\frac{\partial Y}{\partial x_1}\Delta x_1\right| + \left|\frac{\partial Y}{\partial x_2}\Delta x_2\right| + \ldots + \left|\frac{\partial Y}{\partial x_n}\Delta x_n\right|,$$

where $Y = f(x_1, x_2, \ldots x_n)$ is known dependence on which the result of indirect measurement of physical quantity is calculated Y;

$x_1, x_2, \ldots x_n$ are values of physical quantities, determined by the results of direct measurements;

$\Delta x_1, \Delta x_2, \ldots \Delta x_n$ are the values of absolute errors;

$\frac{\partial Y}{\partial x_1}, \frac{\partial Y}{\partial x_2}, \ldots \frac{\partial Y}{\partial x_n}$ are partial derivative functions of Y on arguments $x_1, x_2, \ldots x_n$.

Since the magnitudes of absolute errors are random variables, it is therefore recommended to calculate the probable error (root mean square) by the following formula to calculate the accuracy of indirect measurements:

$$\Delta Y = \sqrt{\sum_{i=1}^{n}\left(\frac{\partial Y}{\partial x_i}\Delta x_i\right)^2}.$$

The relative error of the indirect measurement result is determined by the formula:

$$\delta = \frac{\Delta Y}{Y} \cdot 100\%,$$

where Y is the calculated function value.

Example. Calculate absolute and relative error when determining apparent power S on readings of ammeter and voltmeter.

The apparent power is equal $S = IU$. Defining first-order partial derivatives of S with respect to I and U we are obtain: $\frac{\partial S}{\partial U} = I$; $\frac{\partial S}{\partial I} = U$. Probable value of absolute ΔS

and relative δS errors: $\Delta S = \sqrt{(I \cdot \Delta U)^2 + (U \cdot \Delta I)^2}$, $\delta S = \frac{\Delta S}{S} = \sqrt{\left(\frac{\Delta U}{U}\right)^2 + \left(\frac{\Delta I}{I}\right)^2} = \sqrt{\delta U^2 + \delta I^2}$.

The result of the indirect measurement is recorded in the same form as the direct measurement: $S_H = S \pm \Delta S$.

Stage 3. When processing the results of multiple measurements, we accept the hypothesis of distribution normal law of measured random variables and their errors variations.

In accordance with the regulatory requirements, the procedure for processing the results of measurements with multiple observations is the following:

1. Calculate the most likely value of the value we are looking for:

$$\overline{R} = \frac{1}{n} \cdot \sum_{i=1}^{n} R_i ,$$

where n is the total number of measurements; R_i is the value of the measured quantity (resistance) when performing the i-th measurement, Ohm.

2. Calculate the root mean square deviation of the observation results:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(R_i - \overline{R}\right)^2}{n-1}} = \sqrt{\frac{\sum_{i=1}^{n} \Delta R_i^2}{n-1}} ,$$

where $\Delta R_i = R_i - \overline{R}$ is absolute error of i-th measurement, Ohm.

3. If is suspicion a non-normality (inconsistency with the normal law of distribution of random variables) of an observation result that is significantly different from the others in the experimental sample is suspected, it is necessary to calculate the non-normality index V_k for that result and compare it with the table value β or the given sample size (Table 4). If suspicion is confirmed, this oversight result should be excluded from the sample, and the values $\overline{R}$ and σ recalculated taking into account the reduced sample size

Table 4.

β value at confidence probability P=0.95

n	5	6	7	8	9	10	12	14	16	18	20	25
β	1.67	1.82	1.94	2.03	2.11	2.18	2.29	2.37	2.44	2.5	2.56	2.65

The index of non-normality of the observation result is determined by the formula:

$$V_k = \left| \frac{R_k - \overline{R}}{\sigma} \right| .$$

The criterion of non-normality is the condition $V_k > \beta$, that is, if this inequality is valid, the result R_k from the experimental sample must be excluded and the calculation according to subsections 1, 2 re-performed.

4. Calculate the coefficient of variation: $\upsilon = \sigma / \overline{R}$.
5. Calculate the rms value of the arithmetic mean (deviation of the measurement result):

$$\sigma_n = \frac{\sigma}{\sqrt{n}}.$$

6. Calculate the confidence limits of the probable component of the measurement result error $\varepsilon = t_p \cdot \sigma_n$, where t_p is the confidence factor (Student's t test), which is determined by Table. 5 depending on the value of the confidence probability P and the number $K = n - 1$.

Table 5.

The confidence factor t_p (when confidence probability P=0.95)

К	4	5	6	7	8	9	11	13	15	17	19	24
t_p	2.78	2.57	2.45	2.37	2.31	2.26	2.2	2.16	2.13	2.11	2.09	2.06

When performing laboratory work, it is recommended to ignore the systematic error, for that reason the confidence limits of the measurement result total error coincide with the confidence limits of the probable component, that is $\Delta R = \varepsilon$, and the result of multiple measurements is presented in the form:

$$R = \overline{R} \mp \Delta R; \quad P = 0.95.$$

Graph plotting. The histogram plotting (a stepwise curve characterizing the probability distribution of the error random component) begins with determining the number of intervals on which the variation range of the random variable is distributed $N = 3.32 \cdot \lg(n) + 1$. The resulting value N is rounded to the integer value.

On the histogram along the abscissa axis, the resistances values in, Ohm is denoted and along the ordinate axis - hit frequencies within each interval. The entire range of changes R from R_{min} to R_{max} is divided into N intervals and the quantities P_j of hit values into each of the intervals $P_j = \frac{N_j}{n}$, are calculated, where N_j is the total number of hits of a random variable R in j-th interval. The histogram is a graphical expression of the dependence $P_j = f(R)$ (Fig.2).

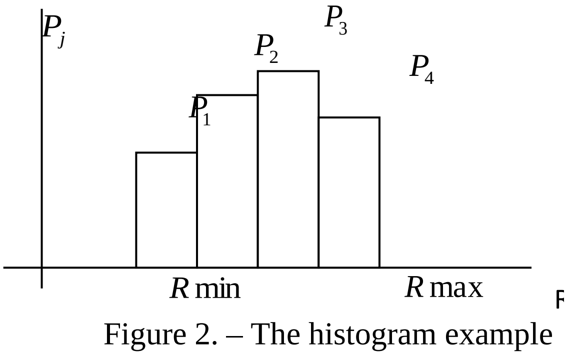

Figure 2. – The histogram example

The random density probability function for a normal distribution law has the form:

$$P(R) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(R - \overline{R})^2}{2\sigma^2}}$$

and can be graphically constructed with known $\overline{R}$ and σ parameters if given some R_i values. Both graphs (histogram and theoretical probability density function) should be shown in the same figure.

Test questions

1. Explain the concepts of confidence interval and confidence probability.
2. Under what conditions is the measurement result considered non-normal?
3. How is the law of the normal probability distribution written down analytically?
4. How to correctly record the result of measurements: a) of one supervision; b) multiple observations?
5. What measurement methods do you know?
6. How to determine the most likely value of the observation result?
7. Could the accuracy of the indirect measurement be greater than when directly measured by the same quantity?
8. Derive the dependence for measuring the error of the indirect measurement for the next quantities $L, R_k, sin\varphi, tg\varphi$.
9. What factors influence the errors of indirect measurements?
10. How to determine the error of single measurements?
11. What does a next lable of the accuracy class of devices mean: 1.5 ; 1.0; 2.5; 0.02/0.01?
12. How to determine the scale division value (it sensitiveness) of a wattmeter (wattmeter constant)?
13. When do additional errors appear?
14. When does the methodological error (interaction) appear?

LABORATORY WORK MFEM – 4

VOLTAGE TRANSFORMER MEASUREMENT ERRORS STUDY

Objective: get the learning to measure voltage errors and angular errors of voltage measuring transformers.

Program of operation

1. Assembly of the circuit for checking the voltage transformer.
2. Determination of voltage transformer errors.
3. Determination of angular error.

Work stages

Stage 1. Assembly of the circuit for checking the voltage transformer (TV)

Assemble the electrical circuit in accordance with the diagram shown in Fig.1. Two transformers TV_0 and TV_1 are switched on via an automatic switch. In the given scheme through AX is marked the primary circuit TV_0, through $A'X'$ - respectively the primary circuit of the voltage transformer TV_1. Little letters indicate the terminals of the secondary circuit of the transformer TV_0, $a'x'$ - the transformer TV_1.

Analyze the proposed connection diagrams of two voltage transformers: the first of them (TV_0) operates in open circuit mode; the second (TV_1) is connected to the load

R. In addition, an ammeter A is connected to the secondary circuit of the transforme TV_1 ввімкнено. Select a rheostat with $R_H \approx$ 150 (Ohm) and $I = 1{,}5 \div 2$ A as the load in the secondary winding.

For the laboratory work is recommended to choose the following instruments: ammeter with a scale I_H = 2.5 A; voltmeters with U_H = 3, 150, 300 V.

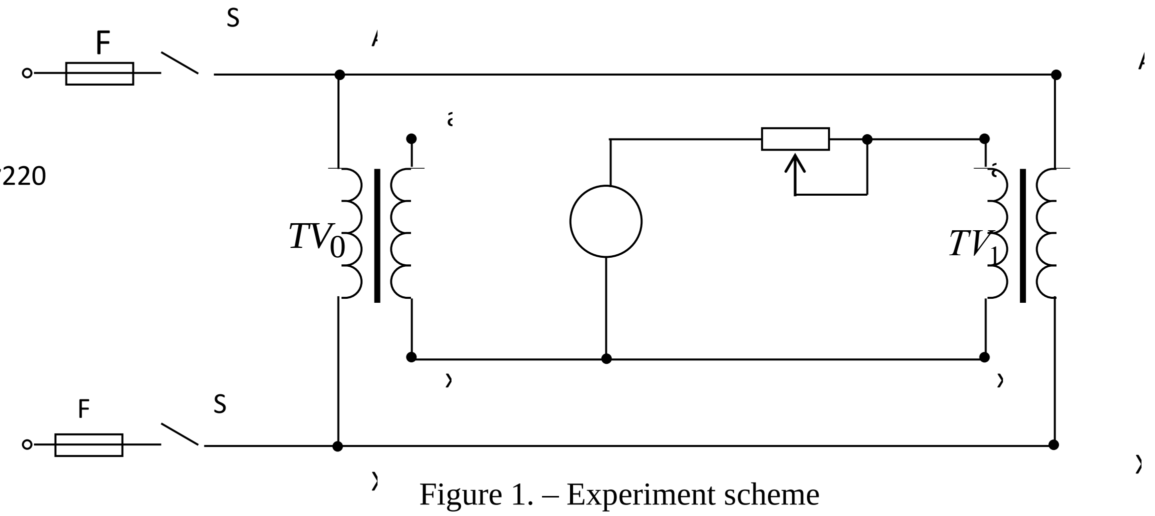

Figure 1. – Experiment scheme

Stage 2. Performing measurements

After the tutor has checked the circle, turn it on and perform the following measurements. Using a rheostat, change the current in the secondary circuit of the transformer TV_1 in approximately the next range $0{,}5 \div 2$ A. Perform measurements at points $4 \div 6$ and enter the values in the Table 1.

At each point it is necessary to measure and record the value of the voltage U_{ax} on the secondary winding (the transformer is open circuit mode, so this value should remain approximately constant and equal to 100 V); the value of the voltage $U_{a'x'}$ on the secondary winding TV_1 (since this transformer is turned on for load, the voltage on the secondary winding will gradually decrease with increasing current); and the value of the voltage difference TV_1.

Note that the voltage value $U_{aa'}$ will be small (approximately 3V), so it is impossible to use voltmeters of the electromechanical system to measure it. It is recommended to use multi-limit electronic or digital voltmeters, selecting the appropriate measurement limit.

Table 1

Measured and calculated values

Sequential number	Measured				Calculated		
	U_{ax}	$U_{a'x'}$	$U_{aa'}$	I	f_U	δ_U	$\delta_U^{/}$
	V	V	V	V	%	degrees	degrees
1							
2							
3							
…							
n							

Stage 3. Processing of measurement results

The values of the voltage error and the angular error of the transformer calculated during the processing of the measurement results should be entered in table 1.

The report must contain

1. Name, objective and program of operation.
2. The scheme of the experimental circle (Fig. 1).
3. Table 1 with the results of measurements and calculations.
4. Formulas with calculations.
5. Phasor diagram.
6. Conclusions.

Methodical instructions

When performing calculations, it is necessary to find the value f_U,% - the allowable error of the voltage transformation coefficient, or simply the error of the voltage transformer. It depends on the metrological characteristics of the transformer, namely, the accuracy class, which is determined by the load parameters

The voltage error is calculated as follows:

1) find the coefficient of transformation at open circuit mode

$$k_{mp\ x.x} = \frac{U_{AX}}{U_{ax}},$$

where U_{AX}=220 V – rated voltage on the primary winding of the voltage transformer TV_0.

2) find the transformation factor for a transformer TV_1, that has the same parameters as the transformer TV_0, but is switched on load:

$$k_{mp} = \frac{U_{A'X'}}{U_{a'x'}}.$$

Note that the values k_{mp} will be different at different loads in the secondary circuit of the voltage transformer.

3) For each mode (the mode means the operation of the transformer at a certain value of the load) to calculate the value of the allowable error of the voltage conversion factor:

$$f_U = \frac{|k_{òð} - k_{òð\ õ.õ.}|}{k_{òð\ õ.õ.}} \cdot 100\%.$$

To perform laboratory tests, transformers with an accuracy class of 0.2 when S_H=15 *VA* are used, ie with an error of the transformation coefficient $f_U^{ном} = 0,2\%$. If for any mode of research the estimated error does not exceed this value, then the voltage transformer corresponds to the accuracy class.

The angular error of the voltage transformer, which is determined by the load connected to its secondary circuit is calculated as follows:

$$\delta_U = arctg\frac{U_{aa'}}{U_{a'x'}}.$$

The total angular error of the transformer is determined by the sum:

$$\delta_{U'} = \delta_U + \delta_{U_0},$$

where δ_{U_0} - angular error in the open circuit mode, which is determined by the design parameters of the real transformer (measured in minutes). For the perfect transformer $\delta_{U_0} = 0$.

For a real transformer δ_{U_0} is a tabular value. Values are recommended for calculations in this laboratory work $\delta_{U_0} = 10'$.

The phasor diagram is constructing according to the measured values of current and voltage by the method of serifs. The size of the angular error can be found according to the cosine theorem.

Test questions

1. According to which parameter is the load resistance selected a) for voltage transformers; b) for current transformers?
2. Explain the occurrence of angular and amplitude error for transformers.
3. Qualitatively construct a phasor diagram for current and voltage transformers.
4. The readings of which measuring instruments are affected by the specified errors of transformers: angular, amplitude, angular and amplitude?
5. What affects the accuracy class of measuring transformers?
6. Does the length of the conductor from the device to current and voltage transformers affect the accuracy of measurements?
7. How to calculate the number of devices that can be included in the secondary winding of current and voltage transformers?
8. Specify the purpose of current and voltage transformers.
9. Is it necessary to ground the secondary winding of transformers?

LABORATORY WORK MFEM – 5

ELECTRICAL PARAMETERS MEASUREMENT BY CATHODE-RAY OSCILLOSCOPE

Objective: get the learning to use different methods and technical approaches to measure electrical quantities that change periodically using a cathode-ray oscilloscope.

Program of operation

1. Acquaintance with the basic constructive elements, the principle of action and rules of work with the oscilloscope.
2. Measurement of time and amplitude parameters of a sinusoidal signal: frequency, period, phase shift angle, amplitude and current value.
3. Measurement of the constant component of the signal.
4. Calculation of measurement results.

Work stages

<u>Stage 1.</u> <u>Acquaintance with the basic constructive elements, the principle of action and rules of work with the oscilloscope.</u>

According to the lecture note, literature sources and guidelines need to study the assignment and principle of operation of the oscilloscope main structural elements.

<u>Stage 2.</u> <u>Measurement of frequency, period, phase shift angle, amplitude and current value of sinusoidal signal.</u>

To measure the time and amplitude parameters of the periodic signal to assemble an electrical circuit according to the scheme shown in Fig.1. The electrical circuit is connected to the input of the sound signal generator (SSG). SSG allows you to get a sinusoidal signal, the parameters of which can be adjusted.

To measure the characteristics of a sinusoidal signal, the following sequence of steps must be performed:

1) apply the measuring voltage to the socket “⊸ $1\,M\Omega,\quad 30\,pF$”;

2) set the appropriate channel with the amplifier mode switch;

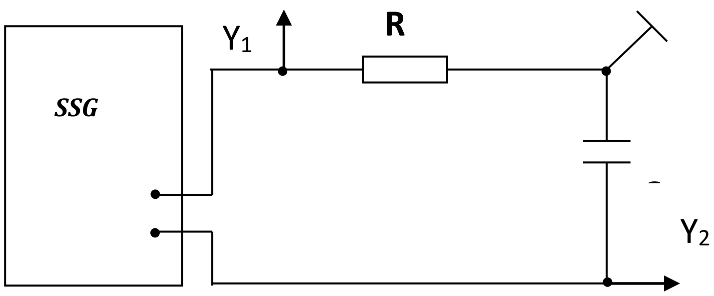

Figure1. – Experiment scheme

3) set the switch “$V\,/\,\partial e\textit{л}$” to such an position that the image amplitude is 5 cells;

4) Set the channel and sync switches “~”, “~” to position “≃”;

5) according to the channel “Y”, to which the signal is sent, turn on synchronization “Internal” **I** or **II**;

6) set the "Level" knob to the middle position; the “Stabilization” knob slowly need to move from the leftmost position to the right until a steady image appears;
7) use the “Level” knob to set a steady image;
8) set the knob ”↕” so that the minimum signal level coincides with one of the bottom lines and the maximum is within the screen.

For example, we obtained the image shown in Fig. 2.

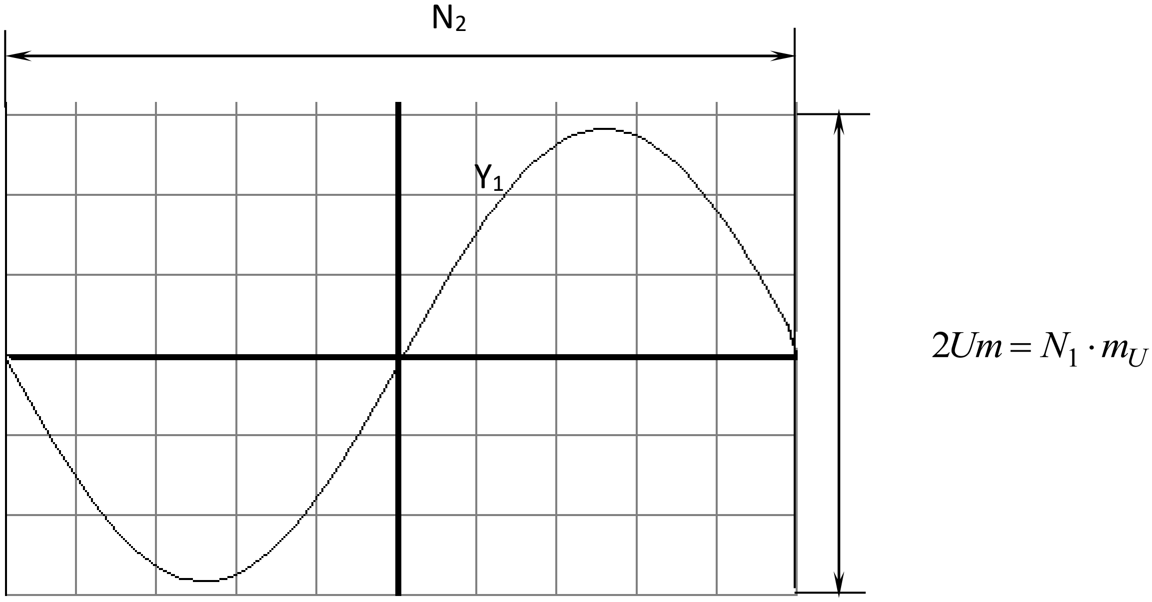

Figure 2. – Waveform on the oscilloscope screen

Signal period $T = N_2 \cdot m_S$, where N_2 - the number of cells corresponding to the signal period on the oscilloscope screen; m_S - scale time multiplier, “c/cell”. Signal frequency $f = \frac{1}{T}$.

Signal amplitude $U_m = \frac{N_1 \cdot m_U}{2}$, where N_1 - the number of cells corresponding to the scope of the sinusoidal signal; m_U - scale voltage multiplier, “V/cell”.

The effective value of the sinusoidal signal:

$$U = \frac{U_m}{\sqrt{2}}.$$

The oscillogram of the voltage at the active resistance in shape coincides with the oscillogram of the current in this circuit $u_R=iR$. Based on this, we can calculate the amplitude parameters of the current according to Ohm's law $I_m = U_m / R$.

In the absence of active resistance for current measurement in a circle it is in addition necessary to include a non-reactive shunt and to measure the corresponding voltage through it.

A two-channel oscilloscope can be used to determine the phase between two sinusoidal signals of the same frequency. In this case:

1) the channel switches “~”, “≃” set in the same position;
2) set the amplifier mode switch to position “…”;

3) apply a reference signal to the input of channel I, and the comparator - to the input of channel II;

Be careful when connecting the ends of the measuring cable to the circuit. Its pins "⊥1", "⊥2" must be connected to one point, otherwise they will short circuit of elements.

4) by pressing the knob button ∏ invert channel II signal;
5) set by the switch "V / cell" of each of the channels close in size (about 5 cells in amplitude);
6) use the "Level" knob to set a steady image of the signals;
7) set the "Time / cell" switch to the scanning-line frequency, which provides 1, 2 periods of signals on the screen;
8) place the waveforms of the signals Y_1 and Y_2 symmetrically about the horizontal axis using the knob handle "↕";
9) measure the reference signal period 1 (Fig. 3);

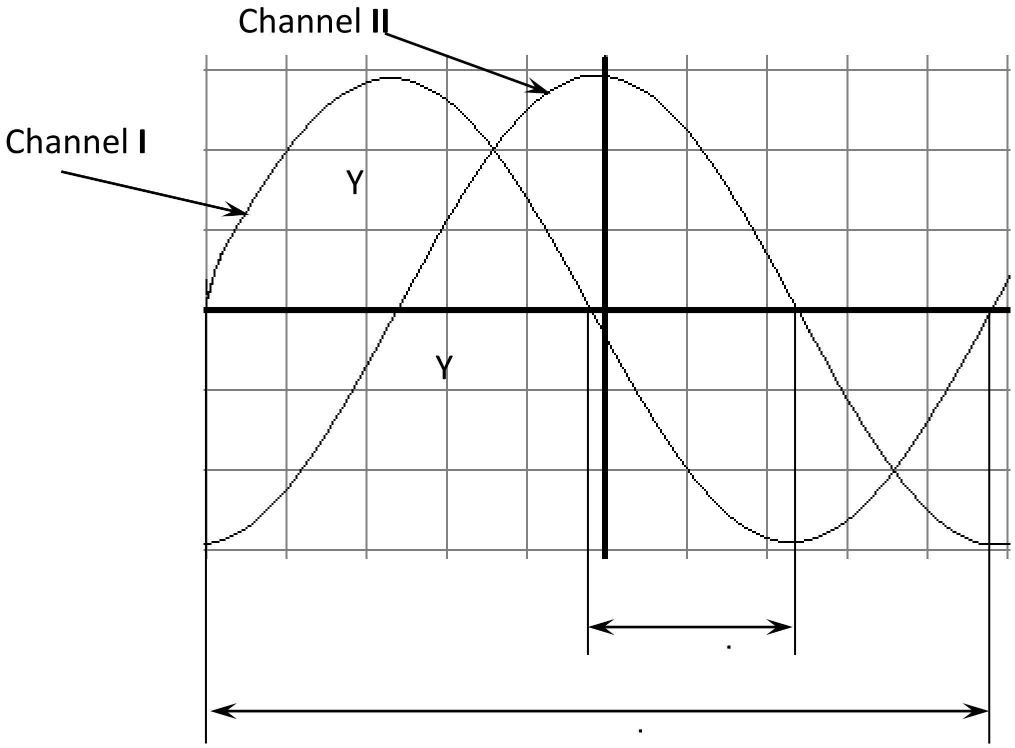

Figure 3. – Waveform on the oscilloscope screen

10) measure the horizontal difference between the signal points;
11) phase shift is calculated by the formula

$$\varphi = \frac{360}{t_1} t_x .$$

Stage 3. Measurement of the constant component of the signal.

To measure the constant component of the signal to assemble an electrical circuit according to the scheme shown in Fig. 4, and perform the following sequence of actions:

a) by switching the corresponding control knobs of the oscilloscope to provide a stable image of the test signal on the screen;

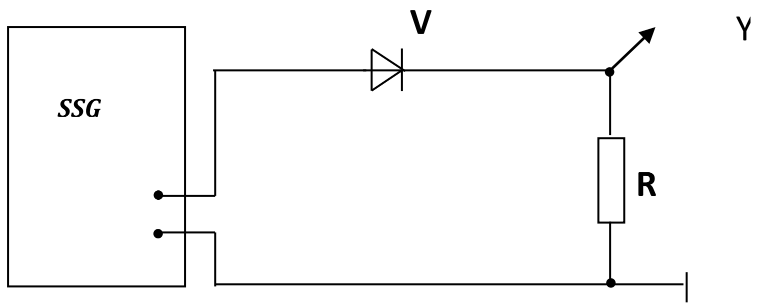

Figure4. – Experiment scheme

b) set the knob switch "~", "≃" to position "~", and an image similar to the one shown in Fig. 1 will be obtained on the oscilloscope screen. 5, curve1;

c) set the knob switch "~", "≃" to position "≃", at that the image of the signal will shift to its constant component (similar to Fig. 5, curve 2);

d) the constant component of the signal is calculated by the following formula:

$$U_0 = l_3 \cdot m_U .$$

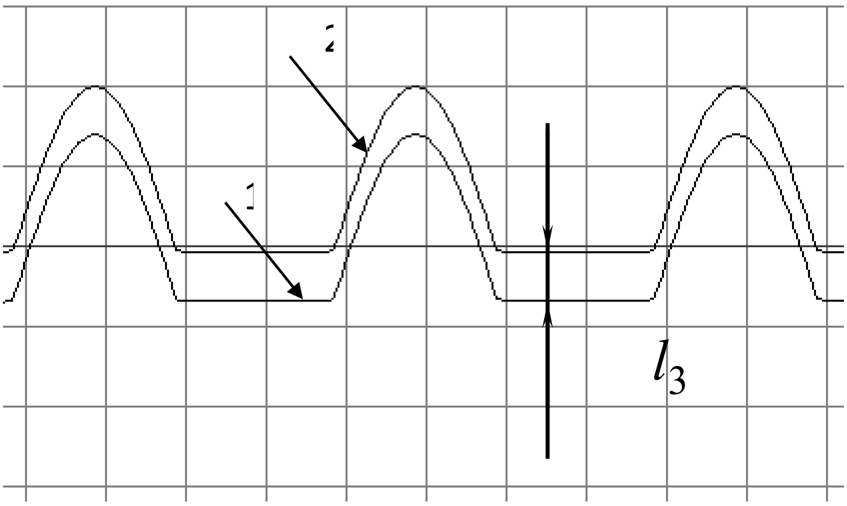

Figure 5. – Waveform on the oscilloscope screen

Stage 4. Calculation of measurement results.

According to the above methods, the results of observations of the measured parameters of electrical signals need to obtain. To record the measurement result, it is necessary to determine the absolute error.

The report must contain

1. Name, objective and program of operation.
2. Schemes of experimental circles (Fig. 1-4).
3. Experimental oscillograms with certain scales in voltage and time.
4. Formulas with calculations.
5. Recording the results of measuring the parameters of electrical quantities.

6. Conclusions, which should include a comparison of measurement errors of oscilloscopes with other types of devices for measuring the parameters of electrical signals.

Methodical instructions

The principle of operation of the oscilloscope to study independently according to the recommended literature. Particular attention should be paid to familiarizing yourself with the purpose of the oscilloscope units.

The oscilloscope beam control circuit produces rectangular pulses that are fed to the blocking plates and used to dampen the electron oscilloscope beam during reverse scanning.

Oscilloscope control knobs:

Knob handle "*" – adjusts the brightness of the image.

Knob handle "Θ" – adjusts the sharpness (focus) of the image.

Knob handle "☼" – adjusts the brightness of the scale illumination on the oscilloscope screen.

Vertical deflection control knobs:

Switch "V/cell" – sets the calibrated channel deflection coefficients.

Knob handle "↕" – adjusts the position of the beam vertically.

Knob handle "↔" – adjusts the position of the beam horizontally.

Input amplifier mode selector switch (channel Y):

"~" – at the input of the amplifier the test signal is fed through a separating capacitor, ie only the variable component of the signal is measured;

"≃ " – at the input of the amplifier test signal is supplied together with a constant component.

Amplifier mode switch (for single beam oscilloscope with commutation switch):

"**I**" – a channel signal is observed on the oscilloscope screen I.

"**II**" – a channel signal is observed on the oscilloscope screen II.

"…" – the oscilloscope screen displays signals from both channels.

"→→" – on the oscilloscope screen, the image of both signals appears at the end of each direct scan.

I + **II** – on the oscilloscope screen we have an image of the sum of both signals.

Polarity switch (inversion) channel **II**:

"+" – the phase of the signal does not change;

"-" - the phase of the signal changes to 180^0.

Synchronization control knobs:

Knob handle "Level" - selects the level of the test signal at which the scan is started;

Knob handle "Stability" - stabilizes the beginning of the signal scan.

Synchronization type switch:

"Internal", (+), (-) - internal signal synchronization.

"External" – the scan is synchronized with an external signal.

"Automatic" - a scan in the study of periodic signals;

"Pending" - the scan is turned on by the leading edge of the test signal.

Scan control knobs:

"Time / cell" switch - sets the calibrated sweep ratio at the extreme right position of the “Smoothly” knob (before locking);

The “Smoothly” knob provides smooth adjustment of the sweep ratio with an overlap of 2.5 times in each position of the “Time / cell” switch.

Preparing the oscilloscope for work.

Set the controls on the oscilloscope panel to the following positions:
the handle “*” – is turn on the far right;
the handle “Θ” – is turn on the middle position;
the switch “V /cell” – is turn on the maximum value;
the handle “↕” – is turn on the middle position;
the switch “~”, “≃” – in position “≃”;
the polarity switch – in position “+”;
the switch “Time/cell” – in position “1 mS”;
the handle “Automatic”, “Pending” - in position “Automatic.”;
synchronization type switch – “Internal”;
the handle “Level” – is turn on the far right;
the handle “↔” – is turn on the middle position;
the handle “↔” – for a single-beam oscilloscope - in the far right.

Connect the oscilloscope to the power supply and turn it on. After 2-3 minutes, adjust the sharpness, focus of the beam, moving it to the working area of the screen. After 10-15 minutes, check and perform (with the “Balance” handle) balancing the amplifier. The beam on the oscilloscope screen, when properly balanced, must not move when the position of the “V/cell” switch is changed. Calculate, knowing the scale along the y-axis, the maximum value of voltage that can be applied to the input of the oscilloscope. After performing the operations, you can apply the test signal to the input of the oscilloscope.

Calculation of measurement results. The results of measuring the parameters of electrical signals must be recorded in accordance with the requirements of state standards. To present the measurement result, it is necessary to calculate the absolute error based on data on the accuracy class of the oscilloscope.

Oscilloscopes are 1, 2, 3 and 4 accuracy classes, which correspond to the values of relative errors given in table1.

Table 1.

Oscilloscopes accuracy classes

Accuracy class	1	2	3	4
Relative error, %	2	6	10	12

Test questions

1. Name the methods of measuring frequency electron beam oscilloscope.
2. How can you use an oscilloscope to measure the value of current?
3. Is it possible to stop the constant movement of the image horizontally with the help of the oscilloscope knobs? How to do it?
4. Name the types of image synchronization.
5. How to expand the measurement limit of the voltage oscilloscope?
6. What is the purpose of the scan generator?

7. How to check the calibration of the amplifier channels and scan?
8. What is the purpose of the closed and open input of the oscilloscope?

LABORATORY WORK MFEM – 6

STUDY OF MEASUREMENT ERRORS OF ELECTRONIC AND DIGITAL DEVICES

Objective: determination of absolute errors and presentation of the measurement result when using electronic and digital devices.

Program of operation

1. Preparation for laboratory work.
2. Familiarity with the metrological characteristics of the voltmeter universal digital B7-38, multimeter BP-11A and millivoltmeter B3-38.
3. Measurement of voltage and resistance using a voltmeter B7-38.
4. Measurement of electrical quantities with a BP-11A multimeter.
5. Voltage measurement with a millivoltmeter B3-38A.
6. Estimation of errors in measuring electrical quantities by electronic and digital devices. Conclusions.

Work stages

Stage 1. According to literature sources and lecture notes need to study the principle of operation and operation of electronic devices.

Stage 2. With the help of data sheets to get acquainted with the work and technical characteristics of the devices B7-38, BP-11A, B3-38.

Stage 3. Measurement of voltage and resistance using a voltmeter B7-38

To measure electrical values with a voltmeter B7-38 it is necessary to connect it to a power supply with a voltage of 220 V. After warming up the device for 2-3 minutes, it is ready to work.

Use a voltmeter to measure the effective value of the sinusoidal voltage. Use a signal generator as a source of electrical signals studied in this and subsequent stages of laboratory work. The generator allows you to smoothly and discretely change the voltage signal level and frequency.

To perform measurements, it is necessary to set the parameters of the electrical signal from the ranges specified in table 1 (arbitrarily choose any voltage value from the specified range), and enter the measurement results in accordance with the same table.

Table 1.

Result of measurement

Parameter	0,2<U<2 V f=50 Hz	2<U<20 V f=20 kHz
U_x, V		
δU, %		
Result of measurement	$U = U_x \pm \Delta U$	$U = U_x \pm \Delta U$

The device B7-38 allows to measure resistance to a direct current within $10^{-5} \ldots 2*10^4$ Ohm. To evaluate the measurement results, measure the resistances within the limits specified in table. 2. Enter the results of calculations in the same table. To perform the study, use the resistance store included in the set of the laboratory stand.

Таблиця 2.

Result of measurement

Parameter	R<200 Ohm	200 Ohm < R < 30 kOhm
R_x, кOhm		
δR, кOhm		
Result of measurement	$R = R_x \pm \Delta R$	$R = R_x \pm \Delta R$

Stage 4. Measurement of electrical quantities with a multimeter BP-11A.

The BP-11A device allows to measure voltage, resistance and frequency in rather wide limits. For metrological evaluation of the measurement result at different measurement limits to measure electrical quantities in accordance with the requirements of Tables 3-5.

When measuring voltage and frequency, the device is connected to the output of the signal generator. The optimal voltage when measuring the frequency corresponds to 4 ... 5 V. The results of observations should have numbers in all four of bit positions.

Table 3.

Result of measurement

Parameter	0,2<U<2 B f=50 Hz	2<U<20 V f=20 kHz
U_x, V		
ΔU, %		
Result of measurement	$U = U_x \pm \Delta U$	$U = U_x \pm \Delta U$

Table 4.

Result of measurement

Parameter	R<2 kOhm	2 kOhm < R < 20 kOhm
R_x, кOhm		
ΔR, кOhm		
Result of measurement	$R = R_x \pm \Delta R$	$R = R_x \pm \Delta R$

Table 5.

Result of measurement

Параметр	0,2 kГц < f < 2 kГц	2 kГц < f < 20 kГц
f_x, кГц		
Δf, кГц		
Result of measurement	$f = f_x \pm \Delta f$	$f = f_x \pm \Delta f$

<u>Stage 5</u>. <u>Voltage measurement with a millivoltmeter B3-38A</u>

When measuring the voltage with a millivoltmeter B3-38A it is necessary to turn it on to a power supply with a voltage of 220 V. After warming up the device for 2-3 minutes, it is ready to work.

For metrological evaluation of measurement results using the device B3-38A to measure voltage at different measurement limits. The results of observations and calculations are entered in table 6.

Таблиця 6.

Result of measurement

Parameter	10 mB < U < 30 mB f=10 kHz	3<U<10 B f=10 kHz
U_x, V		
ΔU, %		
Result of measurement	$U = U_x \pm \Delta U$	$U = U_x \pm \Delta U$

<u>Stage 6.</u> Estimation of errors in measuring electrical quantities by electronic devices.

The report must contain

1. Name and objective of the work.
2. Program of operation.
3. Completed Tables 1-6.
4. The results of error calculations and measurement results.
5. Conclusions on the accuracy of measurements by electronic and digital devices.

Methodical instructions

The measurement result in accordance with the requirements of the State Standards of Ukraine is presented in the form:

$$X = X_1 \pm \Delta X \text{ ,} \tag{1}$$

where X_1 - the result of observation of the measured value; ΔX - the absolute error of measurement.

For example, the results of measurement observations R and U respectively are equal to 537.6 Ohm; 3.26 V. Calculated values of absolute errors are ΔR=19.7 Ohm;

ΔU =0.0367 V. When recording the measurement result in accordance with regulatory requirements, the absolute errors must be rounded to 2 high-order digits. That is ΔR =20 Ohm; ΔU =0.037 V.

The results of observations substituting in formula (1) should be rounded and recorded in accordance with the values of the smallest digit of absolute error:

$$R = 540 \pm 20 \text{ Ohm}; \quad (2)$$

$$U = 3.260 \pm 0.037 \text{ V}. \quad (3)$$

After the point as a result of observations there should be as many digits as there are digits after the point in the absolute error.

The procedure for calculating the absolute errors when measuring with a voltmeter B7-38 is given in the extract from the passport data of the device (Annex 1, Table 7). The calculation of the measurement results of the device B7-38 enter in Tables 1, 2.

Formulas for calculating the absolute errors when measuring with a multimeter BP-11A are given in the extract from the passport characteristics (Annex 2, Table 8). The calculation of the results of measurements with a multimeter BP-11A to enter in Tables 3, 4, 5.

The procedure for calculating the absolute errors of the millivoltmeter B3-38A is given in Annex 3 (Table 9). The calculation of measurement results should be entered in tables 6.

Based on the results of calculations to draw conclusions about the regularity of changes in the value of errors when measuring electronic and digital devices.

Test questions

1. Indicate the fundamental differences between analog electromechanical and electronic measuring instruments.
2. Indicate the fundamental differences between analog electromechanical and digital measuring instruments.
3. Describe the general principle of operation of digital measuring instruments.
4. Explain the essence of sampling and quantization procedures performed by digital measuring instruments.
5. Explain the difference between the additive and multiplicative components of the error of digital devices.

Appendix 1

Table 7.

Determination of errors when measuring with a voltmeter B7-38

Measured value	Range of measuring values, V, кOmh, mA	Range of measuring values, V, кOmh, mA	Limits of permissible error, %	Note
1	2	3	4	5
DC voltage	10^{-5}-10^{-3}	0,2; 2	$\pm(0{,}04 + 0{,}02U_n / U_x)$	

		20; 200; 1000	$\pm(0,07+0,02U_n/U_x)$	
AC voltage with a frequency of 30Hz-40Hz	10^{-5}-300	0,2; 2; 20; 200; 300	$\pm(1,5+0,1U_n/U_x)$	
AC voltage with a frequency of 40Hz-60Hz	10^{-5}-300	0,2; 2; 20; 200	$\pm(0,4+0,05U_n/U_x)$	$K\tilde{a} \le 0,5\%$
		300	$\pm(0,5+0,4U_n/U_x)$	$K\tilde{a} \le 0,8\%$
AC voltage with a frequency of 60Hz-10000Hz	10^{-5}-300	0,2; 2; 20; 200	$\pm(0,2+0,05U_n/U_x)$	$K\tilde{a} \le 0,2\%$
		300	$\pm(0,2+0,4U_n/U_x)$	$K\tilde{a} \le 0,5\%$
AC voltage with a frequency of 10kHz-20kHz	10^{-5}-200	0,2; 2	$\pm(0,2+0,1U_n/U_x)$	$K\tilde{a} \le 0,5\%$
		20; 200	$\pm(0,5+0,1U_n/U_x)$	$K\tilde{a} \le 0,5\%$
	10^{-5}-300	300	$\pm(0,5+0,6U_n/U_x)$	$K\tilde{a} \le 0,5\%$
DC resistance	10^{-5}-$2\cdot10^4$	0,2	$\pm(0,07+0,1R_n/R_x)$	
		2; 20	$\pm(0,07+0,2R_n/R_x)$	
		200	$\pm(0,07+0,2R_n/R_x)$	
		2000	$\pm(0,15+0,2R_n/R_x)$	
		$2\cdot10^4$	$\pm(0,5+0,1R_n/R_x)$	
DC value	10^{-5}-$2\cdot10^3$	0,2; 2; 20; 200; 2000	$\pm(0,25+0,02I_n/I_x)$	
AC value with frequency 30Hz-40Hz		0,2; 2; 20; 200; 2000	$\pm(1,6+0,1I_n/I_x)$	
AC value with frequency 40Hz-20kHz	10^{-5}-$2\cdot10^3$	0,2; 2; 20; 200; 2000	$\pm(0,5+0,05I_n/I_x)$	$K\tilde{a} = 0,5\%$

In the table: $K\tilde{a}$ - harmonic coefficient;

U_x, I_x, R_x - the reading of the device or the rated value of the measure (when checking) voltage, current, resistance;

U_n, I_n, R_n - limits for measuring voltage, current, resistance.

Note:

1. The common socket of the device allows a voltage of direct or alternating current not more than 500 V relative to the grounding contact.
2. The measuring range of 0.2 V, kOhm corresponds to the position of the point on the first lamp on the left.
   The measurement range of 2 V, kOhm corresponds to the position of the point on the second lamp on the left, etc.
   At the limit of 20,000 kOhm point is not indicated.
3. Current measurement is performed using an external shunt.
4. A constant voltage component when measuring AC voltage is allowed not more than 600 V.

Appendix 2.

Table 8.

Determination of absolute errors of multimeter measurements BP-11A

List of verifiable characteristics	Range of measured values	Measurement limits	The main measurement error
DC voltage	10^{-3}-10^3	2, 20, 200, 1000*	$\pm(0{,}5\%U_x + 0{,}4 çí)$
AC voltage **			
20Hz-45Hz	10^{-3}-500	2, 20, 200, 500*	$\pm(2\%U_x + 10 çí)$
45Hz-1kHz	10^{-3}-500	2, 20, 200, 500*	$\pm(1\%U_x + 10 çí)$
1kHz-10kHz	10^{-3}-200	2, 20, 200	$\pm(5\%U_x + 10 çí)$
10kHz-20kHz	10^{-3}-200	2	$\pm(5\%U_x + 10 çí)$
		20, 200	$\pm(10\%U_x + 10 çí)$
20kHz-100kHz	10^{-3}-2	2	$\pm(5\%U_x + 10 çí)$
DC resistance, kOhm	10^{-3}-$2 \cdot 10^3$	2, 20, 200, 2000	$\pm(1\%R_x + 7 çí)$
	10-$2 \cdot 10^4$	20000***	$\pm(10\%R_x + 50 çí)$
DC value, mA	10^{-3}-$1 \cdot 10^3$	2, 20, 200, 1000*	$\pm(1\%I_x + 7 çí)$
		10000*	$\pm(3\%I_x + 8 çí)$
AC VALUE**, mA, 20Hz-10kHz	10^{-3}-$10 \cdot 10^3$	1000	$\pm(2{,}5\%I_x + 12 çí)$
		10000	$\pm(5\%I_x + 12 çí)$
AC frequency, kHz	0,01-10^4	2, 20, 200, 1000*x10	$\pm(1\%F_x + 2 çí)$

Notes: 1. * The button 2000 is pressed on the switch.

2. ** Harmonious shape with curvature no more 0,5%.

3. *** The buttons 20 and 2000 are pressed on the switch.

4. U_x, R_x, F_x, I_x - device readings or rated value of the measure (when checking) voltage, resistance, frequency and current.

5. LDV – least digit value.

6. The constant component at the input of the device when measuring voltage and frequency of alternating current should not exceed 250 V and 50 V, respectively.

The range of input voltages when measuring the frequency of alternating current is 1-20 V. The limit of the allowable additional measurement error (change of readings) when changing the air temperature from $20 \pm 5^0 C$ to 10^0C or 35^0C does not exceed half the limit of the allowable main error

Appendix 3.
Table 9.

Determination of electronic voltmeter errors B3-38

<table>
<tr><td rowspan="3">Subranges</td><td colspan="4">Limits of permissible errors (limits of permissible changes of readings), %</td></tr>
<tr><td colspan="4">Operating frequency ranges, Hz</td></tr>
<tr><td>$45 - 1 \cdot 10^6$</td><td>20-45</td><td>$(1-3) \cdot 10^6$</td><td>$(3-5) \cdot 10^6$</td></tr>
<tr><td>1-300 mV</td><td rowspan="2">$\pm 2,5$</td><td rowspan="2">$\pm 4,0(\pm 4,0)$</td><td>$\pm 4,0(\pm 4,0)$</td><td rowspan="2">$\pm 6,0(\pm 6,0)$</td></tr>
<tr><td>1-300 V</td><td>$\pm 6,0(\pm 6,0)$</td></tr>
</table>

Calibration frequency 1kHz.

1. Changes in the readings of the device caused by the change of ambient temperature from normal to any temperature within the working temperature range does not exceed the limit of the main error for every 100C changes in temperature.

2. The change in the readings of the device, expressed as a percentage of the value of the upper limit of the set sub-range, when the deviation of the shape of the curve of the measured signal from sinusoidal (harmonic factor not more than 20%) does not exceed half the value of the harmonic factor in percent.

3. The deviation of the pointer from zero, caused by its own noise, does not exceed 5% of the value of the upper limit of the set sub-range of the measurement with a short-circuited input.

4. The device keeps the technical characteristics within norms, in the presence at an input of a constant component of voltage no more than 250 V.

5. The time of setting the readings of the device does not exceed 4 c.

6. The device retains the main error after exposure to five times the overload voltage, but not more than 600 V.

7. The active input resistance of the device, measured at a frequency of 45 Hz, not less than 5 MOhм on the sub-ranges with the upper limits of 1-300 V.

8. The input capacitance of the device is not more than 25 pF in the ranges with the upper limits of 1-300 mV and not more than 15 pF in the sub-ranges with the upper limits of 1-300 V. The capacity of each of the connecting cables is not more than 80 pF.

9. Operating mode setting time 15 minutes.

10. The device retains its technical characteristics when powered from an AC mains voltage (220 ± 22) V frequency $(50 \pm 0,5)$ Hz.

11. The power consumed from the network at rated voltage does not exceed 6VA.

12. The device allows continuous operation in working conditions for 8 hours.

13. The size of the device is not more 152x206x275 mm.

14. The weight of the device is not more than 3.2 kg. Weight of the device with transport container no more than 25 kg.

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CONTENT

Автор

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для студентів спеціальності
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