

MINISTRY OF EDUCATION AND SCIENCE OF
UKRAINE NATIONAL TECHNICAL UNIVERSITY
"KHARKIV POLYTECHNIC INSTITUTE"

METHODOLOGICAL INSTRUCTIONS

to perform laboratory work

on the discipline "Fundamentals of relay protection and automation of power systems"
for 4th year students of the educational qualification level "Bachelor" in specialty G3 –
«Electrical engineering»

TABLE OF CONTENTS

RULES OF WORK IN THE LABORATORY OF RELAY PROTECTION AND AUTOMATION	7
1.1 Purpose of work.....	8
1.2 Basic information about electromagnetic relays and terminology used.....	8
1.3 Designs of electromagnetic relays and the main relations characterizing their operation	9
1.4 Purpose, design features, characteristics and parameters of the relays studied in this paper	11
Current relay type PT-40.....	11
Minimum voltage relay type PH-54.....	12
Time relay type RV-248.....	12
Intermediate relays of RP-251 and RP-252 types.	13
1.5 The procedure for performing laboratory work.....	14
General instructions:	14
Study of current relay type PT-40.....	14
Study of the time relay of the RV-248 type.....	19
Analyze the results of the research.	21
1.6 Preparation of report	23
1.7 Recommended sources of information	23
LABORATORY WORK RS-2 STUDY OF MAXIMUM CURRENT PROTECTION ELEMENTS WITH INDEPENDENT TIME DELAY	24
2.1 Purpose of work.....	24
2.2 Procedure for performing work	24
Describe the principle of operation of maximum current protection and the characteristics of current and time relays.	24
Investigate the overcurrent relay	26
Investigate the time relay.	27
2.3 Preparation of report	28
2.4 Control questions	29
2.5 Recommended sources of information	29
LABORATORY WORK RS-3 STUDY OF ELEMENTS OF PROTECTION WITH LIMITED TIME DELAY	30
3.1 Purpose of work.....	30

3.2 Procedure for performing work	30
Describe the principle of operation and characteristics of the maximum current relay of the RT-80 series.....	30
Investigate the maximum current relay of induction type.....	31
3.3 Research procedure relay.....	31
3.4 Preparation of report	33
3.5 Control questions	33
3.6 Recommended sources of information	33
LABORATORY WORK RS-4 STUDY OF THE OPERATION OF ADJACENT CURRENT PROTECTORS WITH DEPENDENT TIME DELAY	34
4.1 Purpose of work.....	34
4.2 Procedure for performing work	34
Describe the principle of matching adjacent maximum overcurrent protections with a dependent time delay.....	34
Describe the laboratory installation of a model of protected electrical installations.....	35
Investigate the operation of adjacent protections with limited time-dependent characteristics:	36
Set the calculated multiplicity of the line and feeder protection trip current on relays KA1 and KA2 (with the electromagnetic relay screw).....	37
4.3 Contents of report	37
4.4 Control questions	38
4.5 Recommended sources of information	38
LABORATORY WORK RS-5 STUDY OF RELAYS POWER.....	39
5.1 Purpose of work.....	39
5.2 Procedure for performing work	39
Describe the principle of operation and characteristics of power relays.....	39
To study the power directional relay of the RBM-171 type	40
5.3 Preparation of report	41
5.4 Control questions	41
5.5 Recommended sources of information	41
LABORATORY WORK RS-6 STUDY OF CURRENT-DIRECTED LINE PROTECTION	43

6.1 Purpose of work.....	43
6.2 Procedure for performing work.....	43
Describe the principle of operation of maximum current directional protection and the diagram of the laboratory setup (Fig. 6.1).	43
Investigate the current-directed protection of lines.	46
6.3 Preparation of report	46
6.4 Control questions	47
6.5 Recommended sources of information	47
LABORATORY WORK RS-7 STUDY OF CURRENT DIFFERENTIAL RELAYS.....	48
7.1 Purpose of work.....	48
7.2 Procedure for performing work.....	48
Investigate the differential relay of the RNT- 565 type	49
7.3 Research procedure relay.....	51
7.4 Preparation of report	52
7.5 Control questions	52
7.6 Recommended sources of information	52
LABORATORY WORK RS-8 STUDY OF DIFFERENTIAL PROTECTION OF A TWO-WINDING TRANSFORMER.....	53
8.1 Purpose of work.....	53
8.2 Procedure for performing work.....	53
8.3 Procedure for researching differential protection.....	55
8.4 Preparation of report	58
8.5 Control questions	58
8.6 Recommended sources of information	59

INTRODUCTION

When designing and operating any electric power system (EPS), one has to take into account the possibility of damage and abnormal operating conditions. Damage and abnormal operating conditions can lead to accidents in the system, which are accompanied by a certain shortage of electricity supply to consumers, unacceptable deterioration in its quality and destruction of the main equipment of power systems. In most cases, the development of these accidents can be stopped by quickly disconnecting the damaged section of the electrical installation or network using special automatic devices called "relay protection" (RP), which act to disconnect high-voltage circuit breakers.

Ensuring the uninterrupted operation of the EPS consumer is inextricably linked to improving the technical level and reliability of relay protection and automation devices (RPA).

The main requirements for reclosers are reliability, speed of operation, selectivity and sensitivity of relay protection. According to the PUE, RP devices must provide the shortest possible short-circuit SC tripping time in order to maintain uninterrupted operation of the undamaged part of the power system (ensuring stable operation of the electrical system and consumer electrical installations, the possibility of restoring normal operation through the successful operation of the automatic recloser and standby transfer switch (ATS), self-starting of electric motors, etc. However, the response speed of the software should not reduce the sensitivity to damage and violate the selectivity of the action, so that in case of damage to any element of the electrical installation (EI), only the damaged element is disconnected.

RULES OF WORK IN THE LABORATORY OF RELAY PROTECTION AND AUTOMATION

Students are allowed to work after receiving safety instructions and studying the approved "Safety Instructions for Students in Laboratory Work", with a note in the instruction log against signature.

The following rules must be followed in the laboratory:

- work only at specially equipped stands;
- Do not touch heating batteries, pipes, grounded frames, cabinetry, appliances and devices that may be energized at the same time;
- insulate live parts and drives of the systems from possible contact during operation.

It is prohibited during laboratory work:

- make connections in live electrical circuits;
- work without a pre-designed circuit and preparation of wires for it;
- use defective tools, devices and equipment;
- leave the circuits on after finishing work;
- clutter up the workplace with unnecessary things;
- energize the circuit without first checking it with the teacher;
- leave the live circuit unattended. If an accident occurs, you must:
 - disconnect the voltage from the circuit (disconnect the automatic machines on the stand power panel, disconnect the input switch in the power cabinet);
 - provide first aid to the victim;
 - report the incident to the teacher;
 - if necessary, call an ambulance (phone 103).

LABORATORY WORK RS-1 STUDY OF THE CHARACTERISTICS OF ELECTROMAGNETIC RELAYS OF CURRENT, VOLTAGE, TIME AND INTERMEDIATE RELAYS

1.1 Purpose of work

The aim of the work is to consolidate and deepen knowledge in the field of the element base of relay protection and automation (RPA) devices of electric power systems and power supply systems.

Study of the main characteristics and parameters of electromagnetic relay.

In the course of performing work the student should familiarize themselves with the principle of relay operation, design, and adjustment of relay settings and learn to experimentally determine the main characteristics and parameters of electromagnetic relays.

The scope of the research is set by the teacher.

1.2 Basic information about electromagnetic relays and terminology used

Reliable and cost-effective operation of electric power and power supply systems is possible only with their automatic control. For this purpose, a set of automatic devices is used, among which the first place is occupied by relay protection devices, including relays for various purposes.

The term relay is generally understood to mean an automatically acting device designed to produce an abrupt change in electrical control or signaling circuits at a given value of an influencing quantity characterizing certain external phenomena. Relays used for relay protection and automation of electrical systems mainly have electrical quantities and are therefore called electrical relays.

By purpose relays are divided into measuring and logic relays. Relays, are intended for trigger with certain accuracy at in advance Relays that respond to a certain level of an influencing variable within a continuous range of its change are called measuring relays. Such relays include, for example, current and voltage relays that respond, respectively, to the current and voltage in the controlled circuit, as well as power, frequency, resistance, and other relays.

In addition to measuring relays, logic relays designed to operate with a discrete change in the influencing variable are widely used in relay protection devices. These relays include, for example, intermediate relays designed to extend the functions of other relays, time relays designed to operate with an adjustable time delay that has a specified error.

According to the element base on which electrical relays are realized, they can be divided into electromechanical, semiconductor and microprocessor relays.

Nowadays, due to the introduction of integrated microelectronics in the relay structure, relays based on semiconductor and microprocessor bases are becoming more and more widely used. However, electromechanical relays are still the main elements of reclosers and will obviously continue to be used to implement the simplest protections in power supply system's when there is no need to use semiconductor and microprocessor-based protections. It should be borne in mind that electromechanical relays have both significant advantages, such as high reliability, long service life, and disadvantages, the main ones being: high power consumption

from measuring primary transformers; presence of moving elements in linear systems and contacts that determine the corresponding operating requirements and affect the reliability of protection functioning, relatively large relay operation errors. Therefore, the study of these relays, their characteristics and parameters are necessary for specialists dealing with the protection and automation of electrical installations, networks and systems.

Electromechanical relays include electromagnetic relays, which are the subject of this. The principle of operation of electromagnetic relay is based on the influence of magnetic fields of fixed windings on a moving ferromagnetic element (armature).

Relay operation means that the relay performs its intended function, for example: closing the current relay contacts when the current in the relay winding exceeds a specified threshold value of the influencing value, called *the setpoint*; closing the time relay contacts with a time delay after the voltage is applied to its winding, determined by the clock mechanism.

All relays are characterized by a number of parameters, in particular, the following: relay trip parameter is the threshold value of the influencing value when triggered; relay return parameter is the threshold value of the influencing value at which the relay returns to its initial (de-energized) state; relay response time is the time from the moment the influencing value appears in a certain multiple with respect to the trip parameter until its contacts close (open). The delay when the contacts close (open) is called the time delay.

The ratio of the return parameter to the actuation parameter of the relay is called the relay return factor. For maximum relays (triggered by an increase in the influencing value), the return ratio is always less than one, for minimum relays (triggered by a decrease in the influencing value) - more than one.

The relay operation parameters do not always coincide with the relay setpoint. The deviation of the relay response parameter from the setpoint is called the relay response error.

1.3 Designs of electromagnetic relays and the main relations characterizing their operation

The following electromechanical systems are commonly used to build electromagnetic relays: with a retractable armature; with a rotary armature; with a transverse armature movement.

Such relays are based on the attraction of a steel moving armature to an electromagnet, the winding of which is subject to current I_r . When the current flows through the relay winding, a magnetic flux Φ occurs, which closes through the magnetic circuit of the electromagnet air gap and armature. At this is created electromagnetic force F_{em} , which seeks to attract the relay armature to the electromagnet, overcoming the opposing force of the spring - which will cause the relay to act

$$F_{em} = 0,5 \cdot I_r^2 \cdot W_r^2 \cdot \left(\frac{d\lambda}{dl} \right) \quad (1.1)$$

where λ is the magnetic conductivity;

l - is the length of the power magnetic line;

W_r - number of turns in the relay winding.

Expression (1.1) is common to all electromagnetic relay designs. For a relay with a rotary armature, where the angular displacement λ is used, it is customary to consider the torque M_{emt} (rather than the force F_{em} , an expression that follows from the Lagrange equations, which are equations of system dynamics

$$M_{emt} = \frac{dM_{emt}}{d\alpha} \quad (1.2)$$

where M_{emt} is the electromagnetic energy of the field at the moment of time t .

The magnetic field energy of, for example, a current measuring relay with a current in the winding i_r (instantaneous value) is defined as

$$W_{emt} = 0.5 \cdot i_r^2 \cdot L \quad (1.3)$$

where L is the self-induction coefficient.

Given that the current i_r , which comes, in particular, from the primary current measuring transformer, which is the current source, does not depend on the parameters of the electromagnet and the position of the armature, which is characterized by its angle of rotation α , the torque is defined as

$$M_{emt} = \frac{0.5 \cdot i_r^2 dL}{d\alpha} \quad (1.4)$$

It follows from (1.4) that the direction of the torque does not depend on the sign of the current i_r . Therefore, electromagnetic systems can be used both on direct and alternating current.

The value of M_{emt} assuming that the current i_p is sinusoidal is equal to

$$M_{emt} = \frac{0.5 \cdot I_{mr}^2 \cdot \sin^2 \omega t dL}{d\alpha} = \frac{k_1 \cdot I_r^2 dL}{d\alpha} = \frac{k_1 \cdot I_r^2 \cdot \cos 2\omega t dL}{d\alpha} \quad (1.5)$$

The first term of equation (1.5) is time independent and gives the average value of M_{em} , over the period, the second term is the harmonic component of the doubled frequency. As a result, the armature of the AC relay is affected by M_{emt} , which varies in time from zero to the maximum value with a doubled frequency. As a result, armature oscillations (vibration) occur in the relay, since at some points in time the rotational torque becomes less than the counter torque, as rule, created by the spring. To eliminate vibration, it is necessary that the resulting torque, or in general the resulting magnetic force $F_{em\Sigma}$, when the current changes over time, remains at all times greater than the counteracting force F_{co} . This is usually achieved by dividing the magnetic flux into two fluxes by means of a short-circuited coil called a screen, which is a copper short-

circuited coil w_{sc} mounted on a part of the core pole (Fig. 1.1). Due to this, the magnetic flux Φ , which created by the current I_r , which passes through the relay winding, is split into two flows Φ_1 and Φ_2 shifted by the angle ψ (Fig. 1.1 b).

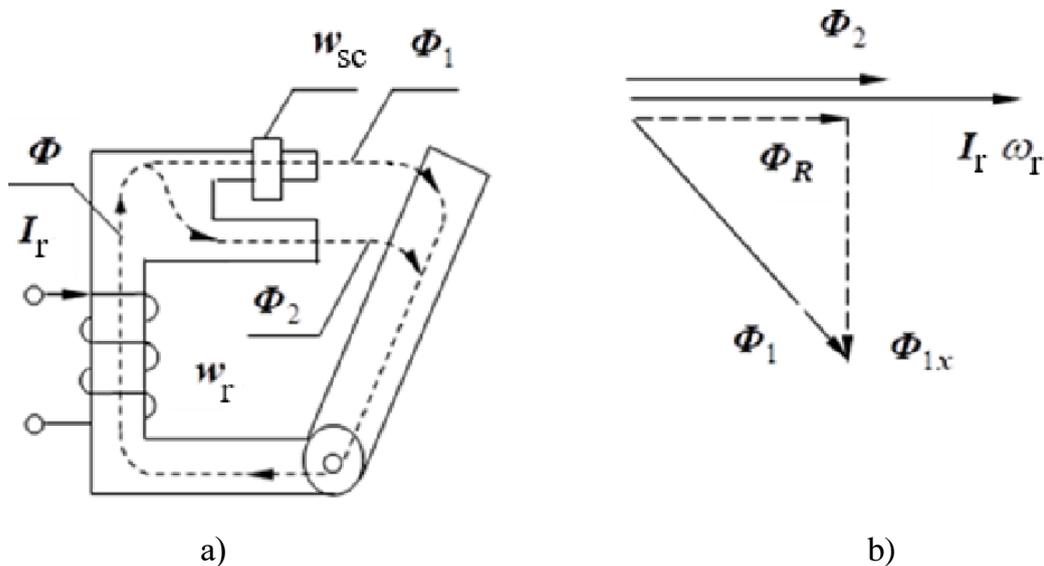


Figure 1.1 - Electromagnetic relay with rotary armature and short-circuited coil
(screen)

As a result, the resulting electromagnetic force $F_{em\Sigma}$ generated by two by sinusoidal magnetic fluxes Φ_1 and Φ_2 shifted in phase will have insignificant fluctuations and will always exceed the opposing force F_{co} .

1.4 Purpose, design features, characteristics and parameters of the relays studied in this paper

Current relay type PT-40

Maximum current relays of the PT-40 type are used in relay protection devices as measuring relays that respond to an increase in current in the controlled circuit.

The RT-40 current relay uses a U-shaped magnetic system with transverse armature movement. On the poles of the magnetic circuit are located two coils (relay windings) that can be connected in series or in parallel. The moving system of the relay consists of an L-shaped steel armature, a movable contact and a mechanical armature vibration damper, which is a small hollow cylinder mounted on the same axis as the armature and filled with sand. When the relay is triggered, the sand absorbs the energy of the armature's impact on the relay's limiting stops, which prevents it from rebounding and vibration of the contacts.

As the current passes through the windings of the relay I_r , the electromagnet tends to pull the armature toward the poles, i.e., to turn it along with the axis clockwise. This is prevented by a coil spring. As the current increases, the electromagnetic torque increases and when it exceeds the counteracting torque of the spring, the armature is pulled under the poles and turns the axis with the moving contact bridge, which closes the fixed contacts. The moment of contact closure

is called the moment of operation of the relay. The smallest current, at which the relay operates, is called current I_{op} , and the highest current at which the relay returns to its initial position is the return current I_{ret} .

The ratio of these currents is called the return coefficient k_{ret} and is defined as

$$k_{ret} = \frac{I_{ret}}{I_{op}} \quad (1.6)$$

It should be noted that after the armature starts to move, with a decrease in the air gap between the armature and the electromagnet pole, the force of attraction increases, which ensures reliable holding of the relay armature, but reduces the return coefficient k_{ret} , to increase which mechanical stops are placed, which limit the minimum gap.

The trip setpoints of RT-40 current relays are regulated by turning the setpoint pointer, which changes the tension of the coil spring and, accordingly, its counteracting torque, and by changing the connection of the relay winding coils (sequentially or in parallel), which changes the limits of the setting scale by half. The return coefficient of such relays at all settings is not less than 0.8.

Current relays of the RT-40 type have a so-called independent response characteristic, i.e., the response time of the relay t_{op} practically does not depend on the multiplicity of the current in the relay winding I_r to the response current I_{op} .

The response time of these relays is not more than 0.1 s at a current of $1.2 \cdot I_{op}$, and not more than 0.03 s at a current of $3 \cdot I_{op}$.

Minimum voltage relay type PH-54

The minimum voltage relay is designed for use in relay protection and emergency automation circuits as a measuring relay that responds to a voltage drop in the controlled AC circuit.

The design of the relay is similar to the design of the RT-40 relay. Only the vibration damping drum of the RT-40 relay has been removed. In order to reduce power consumption and vibration of the moving system, the relay winding of two coils connected in series is connected to the controlled circuit through a rectifier bridge and additional resistors.

The trip voltage U_{op} of these relays is the voltage at which the is released (i.e., it is in the de-energized state), and the return voltage U_{ret} is the voltage at which the anchor the relay is attracted to the poles of the electromagnet. Return coefficient k_{ret} minimum voltage relay equal to the ratio of return voltage U_{ret} to the trip voltage U_{op} , in this case always greater than one.

$$k_{ret} = \frac{U_{ret}}{U_{op}} > 1. \quad (1.7)$$

But not more than 1.25 for this type of relay.

Time relay type RV-248

The RV-248 relay is used in relay protection and emergency automation circuits based on AC operating current to create a time delay when triggered and to ensure the specified sequence of operation of circuit elements.

The time delay is created by the 2104P series clock mechanism specially designed for this purpose. When the relay winding is de-energized, the clock is in the wound state. When voltage is applied to the relay winding, the electromagnet anchor retracts and releases the clockwork lever. Under the action of the operating spring, the output shaft of the mechanism, together with the moving contacts (contact crosshead), begins to rotate at a certain speed. Therefore, the time delay from the start of the relay operation to the contact closure is determined by the distance between the initial position of the moving contact traverse and the fixed contacts (briefly closing after a given time delay), which can be moved along the relay scale to change the settings. The time delay of the moving contact can be shorter than the time delay of the end contacts. In addition to contacts with adjustable time delay, time relays have instantaneous switching contacts. Switching of momentary contacts occurs when the armature is retracted.

These relays have a strong return spring designed to wind the clockwork (to bring up the mainspring), so the electromagnet winding consumes considerable power to hold (compress) the return spring and can be connected to a voltage source only for a short time. In cases where the relay winding needs to be energized for a long time, an additional resistor is introduced in series with the winding after the armature is retracted, for which a momentary contact is used.

The relay winding is designed for a rated voltage of 220 VAC. The setting range is 1.0 - 20 seconds.

Intermediate relays of RP-251 and RP-252 types.

Intermediate relays of types RP-251 and RP-252 are designed for use in DC circuits of protection and automation circuits in cases where a slowdown is required when tripping (relay RP-251) or returning (relay RP-252).

The design and internal connection schemes of these relays are identical except for the location of copper damping washers that provide deceleration of the relay during operation and return.

The relays consist of: a branched magnetic circuit with a winding and copper damping washers on the middle core; a steel armature fixed to the magnetic circuit with a bracket; a contact system consisting of a block with fixed contacts and movable contacts fixed to the stem; and a return spring.

The relays are available with closing contacts, but by rearranging the contact squares and springs, any contact can be turned from a closing contact to an opening contact.

When voltage is applied to the relay winding, the armature, attracted to the core of the magnetic circuit, rests against the protruding part of the rod and moves it together with the moving contacts, which closes and opens the corresponding contacts. In the RP-251 relay, copper damping washers are placed on the magnetic circuit closer to the relay base to the relay coil and provide a slowdown of the relay action when it is triggered. The magnetic flux induced by the self-induction currents in the copper massive washers when the relay winding is energized counteracts the rapid increase of the magnetic flux in the core of the magnetic circuit,

thereby ensuring the slowdown of the relay action when the relay trips.

Unlike the RP-251 relay, the RP-252 relay has damping washers placed on the core next to the working gap, thus, the magnetic flux induced by self-induction currents in the washers, at the moment of disconnection of the relay winding (voltage release), with the armature pulled in, almost completely passes

through the working gap. The solenoid coil has a solid copper frame, which creates an additional return slowdown, and is located on the base of the core near the relay base.

The deceleration time can be adjusted by changing the number of damping washers or by changing the final operating gap of the relay. The actuation deceleration time (relay RP-251) varies in the range of 0.074-0.14 seconds, and the return deceleration time (relay RP-252) - in the range of 0.5-1.4 seconds.

1.5 The procedure for performing laboratory work

General instructions:

- carefully study these guidelines;
- familiarize yourself with the laboratory bench and equipment necessary for this work;
- study the designs of the relays studied in this work;
- understand the operation of the schemes provided in the work instructions.
- to realize the procedure for performing work;
- Prepare forms of tables for recording the experimental characteristics of the relays under study.

Make all connections carefully with the DC and AC power supplies of the laboratory stand turned off.

After finishing the work, disconnect the power supply of the laboratory bench and connect all wires from the devices and equipment used in this work.

Study of current relay type PT-40

1. Determine the operating current I_{sp} , the return current I_{pw} of the relay and its return ratio K_{pw} .

The equipment and devices required for the research include: a current relay of the RT-40 type (KA1); a variac (a transformer that regulates the current on its secondary winding) (TL1); a rheostat (10 A; 10 Ohm) (R1); astatic ammeter, class 0.5 (with measuring limits of 5 and 10 A) (RA); indicator lamp (HL). The test scheme is shown in Fig. 1.2.

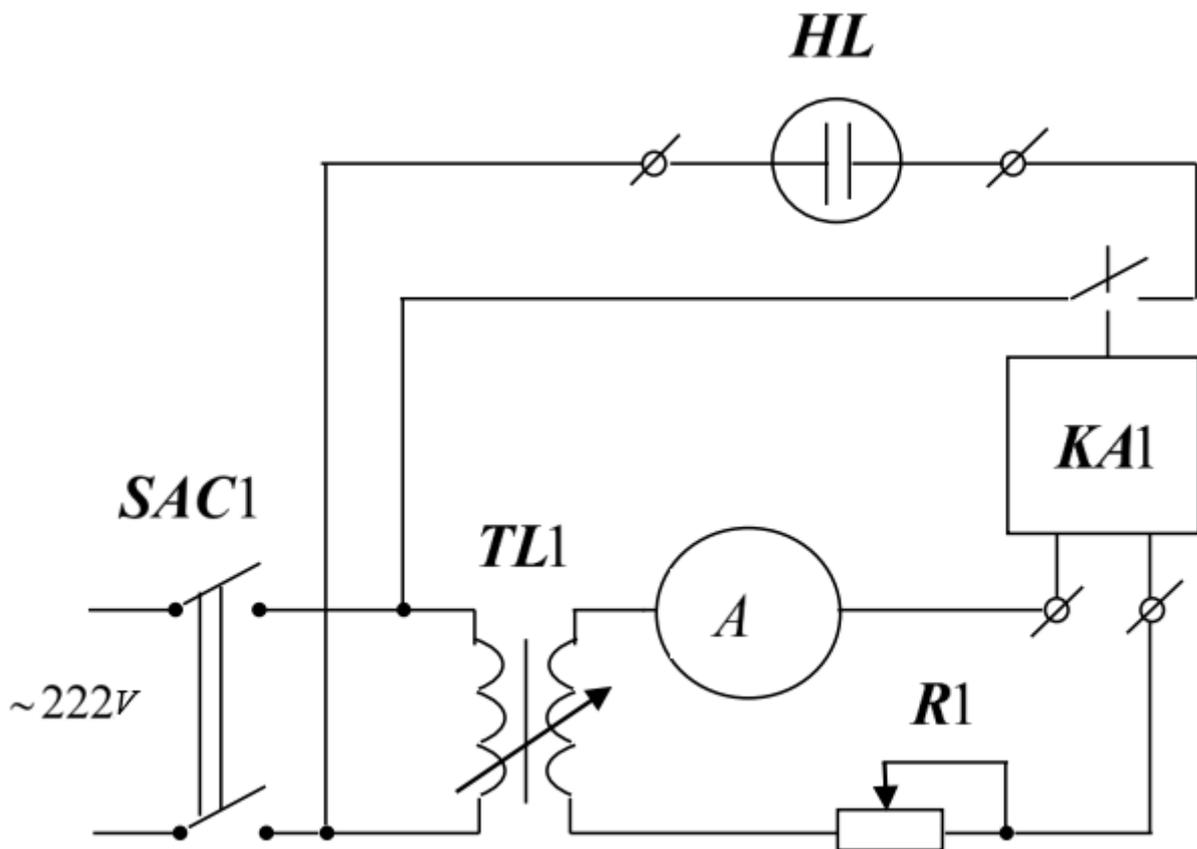


Figure 1.2 - Electrical circuit for determining the trip current and return current of the overcurrent relay

Assemble the circuit to determine the tripping current and the relay return current in accordance with Fig. 1.2.

Set the relay's setpoint scale to the value set by the teacher.

Turn on the AC power supply (SAC1) of the laboratory bench. Smoothly moving the slider of the variator and increasing the current in the relay winding, determine the ammeter reading, at the moment of relay operation, the current of the relay RT-40 I_{op} . The moment of operation of the relay corresponds to the moment the indicator lamp lights up, which is switched on through the relay contacts is being investigated.

The return current of the relay I_{ret} is determined by the ammeter readings when the current in the relay winding gradually decreases at the moment of extinguishing the indicator light. lamps, when moving system relay returns in original position (corresponding to the de-energized relay).

The rheostat in the circuit in Fig. 1.2 is used to change the range of current control by the variator.

Repeat the experiments to determine the tripping current and return current of the relay 3-5 times and calculate the average value of $I_{op,avg}$ and $I_{ret,avg}$.

Based on the results of these measurements and calculations using formula 1.6 Determine the relay return coefficient at a given setpoint.

Turn off the power supply of the laboratory bench.

Without changing the position of the setpoint pointer on the relay setpoint scale, switch the relay windings from series to parallel connection.

Repeat the experiments to determine the tripping current, return current, and return coefficient when the RT-40 relay windings are connected in parallel similarly to the experiments described above when the relay windings are connected in series.

Based on the results of the changes, calculate the error of the relay δ . To do this, determine the deviation of the relay operating current in individual experiments I_{opi} from its calculated average value $I_{op,avg}$.

$$\Delta = I_{opi} - I_{op,avg} \quad (1.8)$$

The maximum error of the relay is defined as

$$\delta_{max} = \frac{\Delta^{max}}{I_{op,avg}} \cdot 100\% \quad (1.9)$$

Based on the results of experimental studies and calculations, fill in Table 1.1 and analyze the results of the research.

Table 1.1 - Measurement and calculation results

№ Experience.	Relay operation setpoint, A	Triggering current		Return current			The error of detection	
		I_{opi} , A	$I_{op,avg}$, A	I_{reti} , A	$I_{ret,avg}$, A	k_{ret}	Δ , A	δ_{max} , %
1								
2								
3								

2. To experimentally determine the characteristic of the dependence of the relay response time on the current multiplicity in its winding.

The equipment and instruments required for the study include: current relay type RT-40 (KA1); variac (TL1); rheostat (10 A, 10 Ohm) (R1); astatic ammeter class 0.5 (with measuring limits of 5 and 10 A) (pA); electric stopwatch type 53 L (CT).

Table 1.2 - Research results

№ Experience.	Current multiplicity in the relay winding I_{op} , A	Relay response time	
		t_{opi} , S	t_{opi} , S
1	1,2		
2	1,5		
3	2,0		
4	2,5		

Analyze the results of the research and compare the data obtained with the technical characteristics of the relay given in these guidelines.

Investigation of the minimum voltage relay type PH-54

The equipment and devices required for the research include: voltage relay type PH-54/160 (KV1); laboratory autotransformer (LATR) (TL1); astatic voltmeter class 0.5 (with measurement limits of 150 and 300 V) (PV), indicator lamp (HL).

The research data include the experimental determination of the trip voltages U_{sp} and return voltages U_{rel} of the relay type PH-54/160, as well as the determination of its return coefficient K_{rel} .

The research scheme is shown in Fig. 1.4.

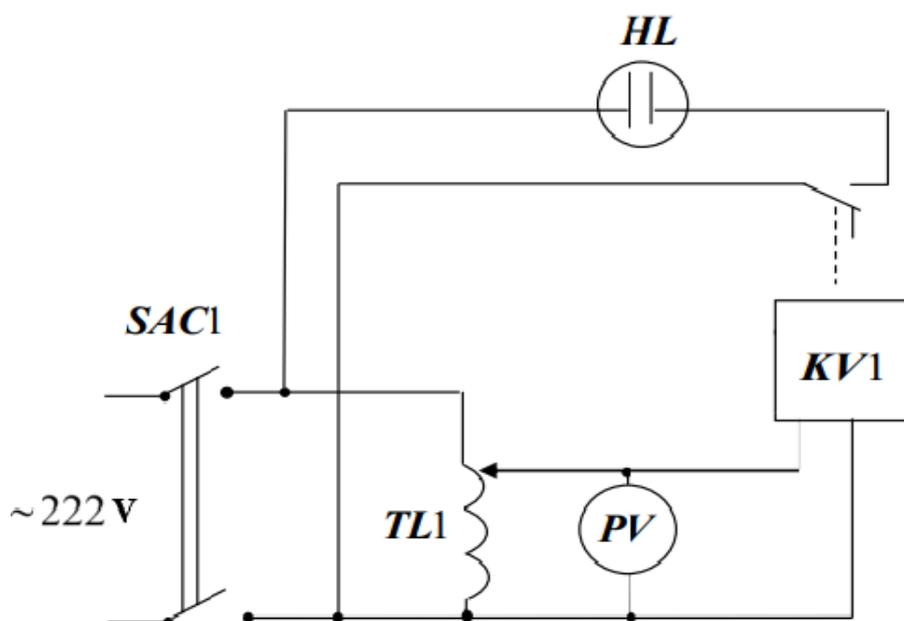


Figure 1.4 - Schematic for determining the trip voltage and return voltage of the minimum voltage relay

Assemble the circuit for experimental studies according to Fig. 1.4 Set one of the setpoints on the relay scale to one of the setpoints specified by the teacher (in this experiment, 2-3 values are).

Apply a voltage of 220 VAC to the winding of the relay under test and gradually reduce it using a LAMP to determine the relay trip voltage U_{op} . The value of the relay operating voltage is recorded according to the voltmeter readings at the moment the indicator lamp goes out, which corresponds to the moment when the relay contacts open.

The relay return voltage U_{ret} is determined by a smooth increase in the voltage on the winding of the relay under test when the indicator lamp lights up.

Based on the results of measurements carried out 5-6 times, the average values of $U_{op.avg}$ and $U_{ret.avg}$ are determined, the relay return coefficient is determined according to formula 1.7. Relay response errors are determined similarly to the current relay response errors (formulas 1.8 and 1.9).

These measurements and calculations are performed for all settings specified by the teacher.

The results of the measurements and calculations are recorded in Table 1.3.

Table 1.3 - Measurement and calculation results

№ The experie nce in	Parameter and settings	Trigger voltage		Return voltage		K_{st}	The error of detection	
		$U_{(spi)}, B$	$U_{sp, sir}, V$	$U_{побл}, B$	$U_{regiment, sir}, B$		Δ, A	$\delta_{max}, \%$
1								
2								
3								

Analyze the results and compare the experimentally obtained parameters of the RN-54/160 relay with the technical characteristics of this relay.

Study of the time relay of the RV-248 type.

In these studies, it is necessary to determine the error of the relay operation time.

The equipment required for this work includes a time relay of the RV-E48 type (KL-1) and an electric stopwatch.

The test scheme is shown in Fig. 1.5.

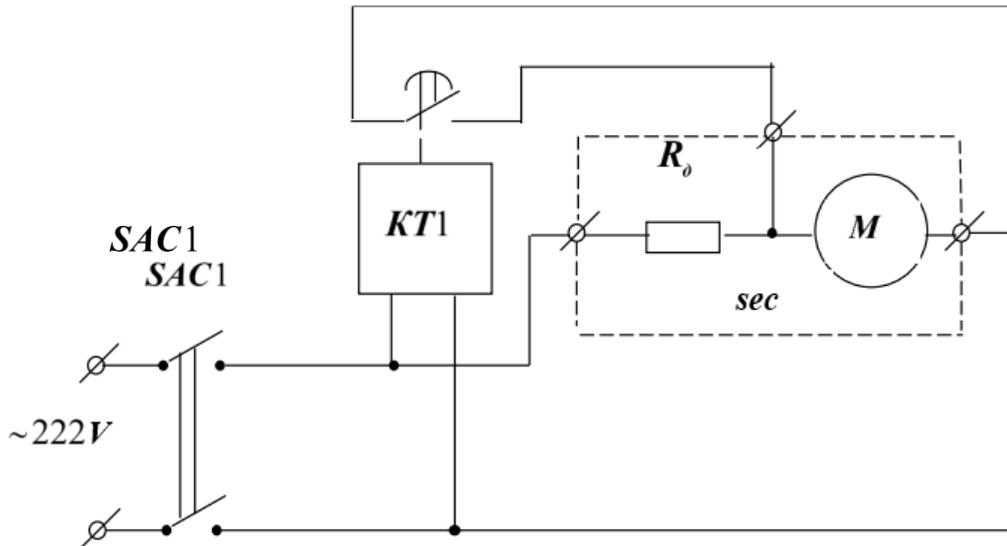


Figure 1.5 - Diagram of determining the time of operation of the AC time relay

Set the relay to the minimum trip setpoint (for end contacts) on the setpoint scale.

Using the power supply of the laboratory bench, apply an alternating voltage of 220 V to the relay winding and the electric stopwatch, having previously zeroed the electric stopwatch.

Record the readings of the electric stopwatch corresponding to the time of operation of the time relay t_{opi} in Table 5.4. Repeat the experiments to determine the time of operation of the time relay for this installation 5-6 times and calculate the average response time of $t_{op,avg}$.

Do the same for the maximum value of the relay scale trip setpoint and any (average) value of the relay scale setpoint. Summarize all the data obtained in Table 5.4.

Based on the results of measurements t_{op} and calculations of the average values of $t_{op,avg}$ at each setpoint, determine the absolute value of the error of the time relay operation (its inertial error)

$$\Delta = t_{opi} - t_{op,avg} \quad (1.10)$$

Also find the maximum error of the time relay operation

$$\delta_{max} = \frac{\Delta^{max}}{t_{op,avg}} \cdot 100\% \quad (1.11)$$

The results of the calculations according to (1.10) and (1.11) are recorded in Table 1.4.

Table 1.4 - Results of measurements and calculations

Setpoint parameter by scale	№ n/a	t_{opi}, S	$t_{op,avg}, S$	Δ, S	δ_{max}, S
Minimum.	1				
	2				
	3				
	4				
Medium	1				
	2				
	3				
	4				
Maximum	1				
	2				
	3				
	4				

Analyze the results of the research.

Investigation of intermediate relays of types RP-251, RP-252, RE-251 and RP-252

Determine the time of slowing down of the relay RE-251.

The equipment required for the work includes: intermediate relay type RP-251 (KL); electric stopwatch (CT); separate two-pole switch (SAC 1).

The scheme for conducting the tests is shown in Fig. 1.6

Using a separate two-pole switch, apply two voltages simultaneously: one 220 V AC to start the electric stopwatch, and the other 220 V DC to the relay winding under test.

The time is recorded by an electric stopwatch from the moment the voltage is applied to the winding of the RP-251 intermediate relay until its contacts closes, and is the deceleration time t_{decel} when the relay is triggered.

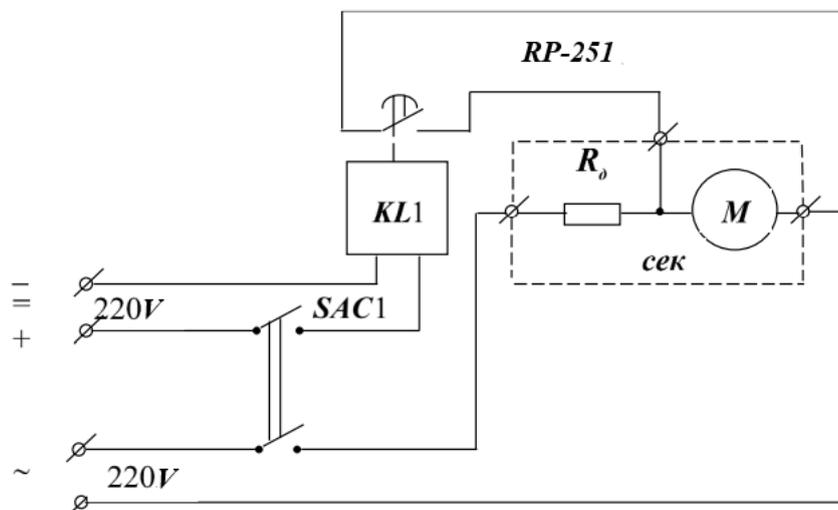


Figure 1.6 - Diagram of determining the deceleration time when intermediate relays are triggered

Repeat the experiment 3-4 times and determine the average value of t_{decel} when the relay RP-251 is triggered.

Compare the result with the passport data of this relay. Determine the deceleration time when the intermediate relay type RP- 252 is returned.

The following equipment is used for this experiment: intermediate relay type PP-252 (KL1); electric stopwatch; separate two-pole switch with opposite poles (SAC1).

The test setup is shown in Fig. 1.7.

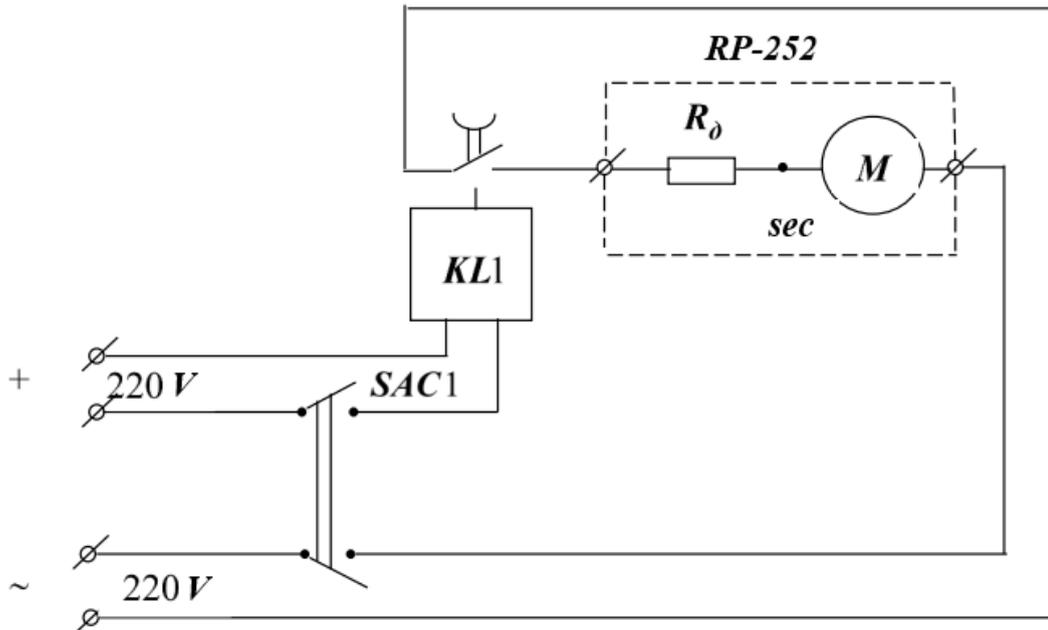


Figure 1.7 - Diagram of determining the deceleration time when the relay returns

Set a separate two-pole switch to the position when the winding circuit of the intermediate relay is closed and it is under the voltage of 220 VDC, and the AC power supply circuit of the electric stopwatch is open.

Reset the electric stopwatch to zero. Then switch the two-pole switch.

This switching will de-energize the winding of the intermediate relay and simultaneously start the electric stopwatch. The stopwatch will stop after the contacts of the relay under test are opened, i.e., it returns to its initial state.

The time recorded by the electric stopwatch is the deceleration time. t_{decel} when the relay returns.

Repeat the experiment 3-4 times and determine the average value of t_{decel} when the relay RE-252 returns.

Compare the result with the passport data of the RP-252 relay.

1.6 Preparation of report

The report on laboratory work is drawn up in accordance with the requirements of the standards of NTU "KhPI".

In report should be include electrical diagrams of all studies, results of measurements and calculations.

1.7 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.
2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.
3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.
4. Shelepeten T.M. Protective automation of electrical networks: Study guide for students of specialties 7.090602 and 8.090602 "Electrical Systems and Networks" of all forms of education. - Lviv, 2002, 157 p.
5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovich, V.F. Sokolov et al. Textbook - K.: IZMN, 1996. 288 c.

LABORATORY WORK RS-2 STUDY OF MAXIMUM CURRENT PROTECTION ELEMENTS WITH INDEPENDENT TIME DELAY

2.1 Purpose of work

The aim of the work is to consolidate and deepen theoretical knowledge on the characteristics of current relays and time relays; to acquire practical skills in the maintenance of relay protection devices.

2.2 Procedure for performing work

Describe the principle of operation of maximum current protection and the characteristics of current and time relays.

Overcurrent protection is a protection that responds to an increase in current in the protected element above a certain value. The overcurrent protection is triggered by a current relay, which operates when the current in the relay winding increases to the setpoint value. The time relay determines the protection time, which does not depend on the amount of current flowing in the protected element, so this protection is called independent time protection.

The main requirement for maximum overcurrent protection is the requirement for reliable operation in the event of damage and failure at maximum load currents and short-term impulses. Therefore, one of the main tasks when selecting trip currents is to restore protection against load currents. The tripping current of the relay I_{op} taking into account the requirements for maximum current protection, is determined from the following expression

$$I_{op} = \frac{k_{rel} \cdot k_{sch} \cdot k_{str} \cdot I_{op\ max}}{k_{ret} \cdot n_{tr}} \quad (2.1)$$

where $I_{op\ max}$ is the maximum operating current of the load;

k_{rel} - reliability factor, which takes into account the error in the value of the current protection relay, is taken equal to 1.1÷1.2;

k_{sch} is a coefficient that depends on the connection scheme of current transformers and relays;

k_{str} is the startup coefficient, which takes into account the increase in current caused by the self-starting of motors;

k_{ret} - the return coefficient of the current relay is calculated according to formula 1.6;

n_{tr} is the transformation ratio of the current transformer.

The selectivity of the overcurrent protection is achieved by means of a time delay. The time delay is calculated depending on the type of protected object and its location in the power system. To ensure the selectivity of the protection, the time durations of the maximum current protections are matched according to the step principle. The value of the degree of matching Δt should be such that in the event of a short circuit in one section, the protection of the next section does not have time to trip.

The most common current relays include: PT-40, PT-40/1D,

PT-10. The electromagnetic relay PT-40 is a modernized analog of the relay type ET-

520. The modernization consisted of reducing the magnetic circuit cross-section and increasing the joint stroke of the contacts to reduce vibration and increase the reliability of contact closure at high multiples of short-circuit current in relation to the rated current of current transformers. The relay has a scale of divisions in amperes for series connection of coils. Within the range of the scale, the relay trip current is adjusted smoothly by turning the arrow. When the coils are connected in parallel, the relay current is doubled. The relay range is from RT-40/0.2 to RT-40/200 with the limits of settings for the relay trip current from 0.05 A to 200 A. The relay power consumption is from 0.2 VA for RT-40/0.2 relay to 8 VA - RT-40/200. The return coefficient is not less than 0.85 at the first setting on the scale and not less than 0.8 at other settings. The relay response time is slightly more than 0.1 s. Accuracy class 5. The relay has one closing and one opening contact.

The RT-40/1D overcurrent relay is used in AC protection circuits in cases where a high multiplicity of the continuous permissible current to the relay trip current is required. The limits of the relay trip settings are from 0.15 to 1 A. The relay return coefficient at any setting is at least 0.7. The relay has one closing and one opening contact.

Relays series RSC-10 SERIES (RSC-11, RSC-12, RSC -13, RSC -14) by its relays are electronic analogs of RT-40 series electromechanical relays and have increased resistance to mechanical stress. The relay reliably operates at such multiplicities of short-circuit currents at which the relay of the RT-40 series fails due to vibration of their contact system. Setting ranges from 0.05 A for relay RSC-11-0.4 to 120 A for RSC-11-32.

The relay return coefficient is not less than 0.9, which provides greater sensitivity of the maximum current protection than the relay of the PT-40 series. The relay trip current is regulated by switches on the front panel according to the formula

$$I_{op} = I_{min} \cdot (1 + \sum N) \quad (2.2)$$

where I_{min} is the minimum setpoint for the corresponding relay type;

$\sum N$ - is the sum of numbers determined by the state of the switch on the relay's front panel (setting scale).

The relay trip current is set discretely, the level of change of settings is $0.1 I_{min}$ which ensures sufficient accuracy of the relay setting. The relay power is 2 times less than that of the RT-40 series. The response time of the PT-11 is also less and is 0.035 s when applied to the input three times the tripping current. The relay has one closing and one opening contact.

In relay protection and automation circuits, time relays of the EV-100, EV-200, RV-100, RV-200, RV-01, VL, etc. series are used to obtain an adjustable time delay. DC time relays of the EV-100 series contain an electromagnetic system with a retractable armature and a clock mechanism with an anchor stroke. In the series of DC time relays EV-100 (EV-112÷EV-144), the clock mechanism is in the wound state when the relay electromagnet is de-energized. When the relay winding is energized sufficiently to trip the relay, the clockwork spring is released and the clock starts to operate, providing long and short-term

contact closure with a specified time delay from the moment the relay is energized. The maximum time delay is 20 seconds. The power consumption is 30 W, and with the introduction of an additional resistor as an instantaneous opening contact, the power consumption in continuous mode does not exceed 15 W.

In the EV-200 series of AC time relays, unlike the EV-100 series, the clockwork is started when the relay electromagnet is energized and released when it is de-energized. Therefore, the set time delay is ensured from the moment the voltage on the relay winding disappears (for example, the starting of the automatic backup transfer switching device with a steady decrease in the voltage at the operating power input). The power of the electromagnetic relay is 20 VA.

Relays of the RV-100(200) series are modernized analogs of the EV-100(200) series. The main disadvantage of the electromechanical time relays of the EV and RV-100(200) series is a significant error in time withholding, which is 3-4% of the largest setpoint.

Time relays RV-01(03) are electronic analogs of electromechanical time relays of RV-100(200) series. The time delay is determined by the adjustable constant time of the integrating RC circuit. With the same dimensions, the relays are vibration resistant, not have complex mechanics and are more accurate with lower power consumption. DC and AC time relays RV-01 provide time-delayed protection, triggering after the supply of operating current voltage. Setpoint adjustment is discrete and amounts to 1% of the maximum setpoint of the rated range. The disadvantage compared to the RV-100 series relay is the lack of instantaneous and temporary (pulse) closing contacts.

AC time relays RV-03 provide time delay after AC voltage is removed. The contact system consists of one instantaneous changeover contact and two opening contacts with independent adjustable time delay. Power consumption, relay, is slightly more than 3 VA.

Investigate the overcurrent relay.

At the teacher's choice, the relay PT-40, PT-40/1D, PCT-10 (Figure 2.1, relay KA) is studied in the work. Make sure that the power supply and equipment for the laboratory work are in good condition by external inspection. Familiarize yourself with the technical data, design, and methods of adjusting the relay trip settings. Study the electrical circuit of the relay, Fig. 2.1.

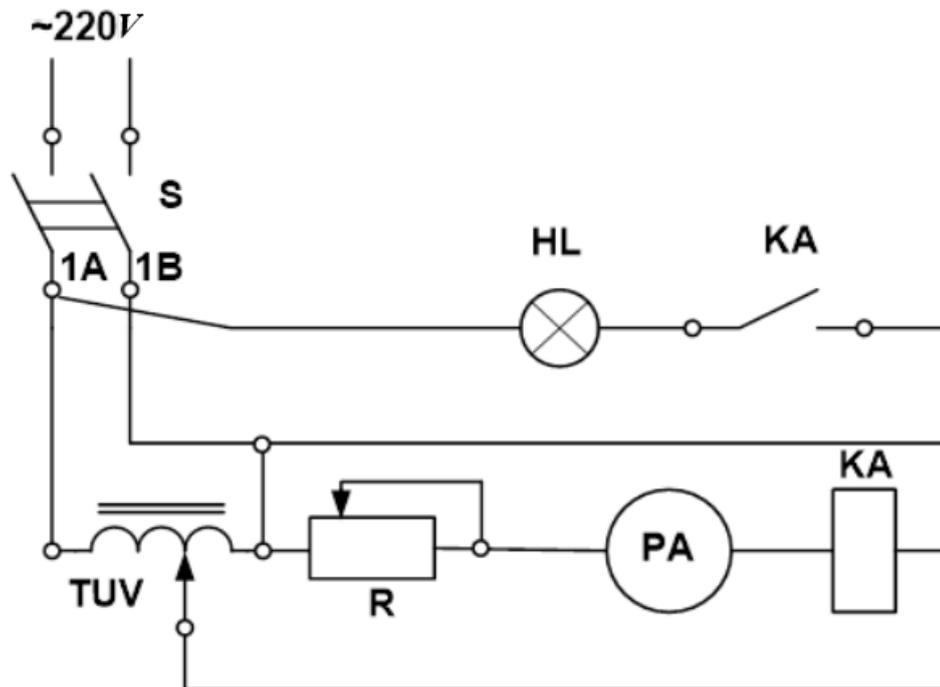


Figure 2.1 - Schematic diagram of the current relay study

Procedure for testing the overcurrent relay:

- 1) Assemble the circuit (Figure 2.1) to study the current relay. Set the minimum value of the setpoint (relay trip current).
- 2) After the teacher checks the assembled circuit, turn on the power:
 - gradually increase the current in the circuit (using a TUV control transformer - roughly, accurately - with a rheostat R), determine its minimum value at which the relay is triggered (lamp NL lights up). The obtained value of I_{op} is recorded in Table 1.1;
 - reduce the amount of current in the circuit, fix its maximum is the value at which the NL lamp goes out (the relay contact opens).
- 3) Enter the resulting value of I_{ret} in Table 2.1. Using expression (1.2), determine the return coefficient k_{ret} and enter its value in Table 2.1.
- 4) Repeat the measurements for the other settings specified by the teacher and listed in Table 2.1.
- 5) Give assessment discrepancies between the measured and data sheet data of the current relay under test.

Table 2.1 - Measurement results

Setpoint current on the scale, A	
Triggering current, A	
Return current, A	
Return rate	

Investigate the time relay.

At the choice of the teacher, the relay of the EV-100, RV-100, RV-01, PL series is

studied in the work (Fig. 2.2, *CT* relay). By external inspection, make sure that the power supply and equipment for laboratory work are in good condition. Familiarize yourself with the technical data, design, and methods of adjusting the relay trip settings. Study the electrical circuit of the relay, Fig. 2.2.

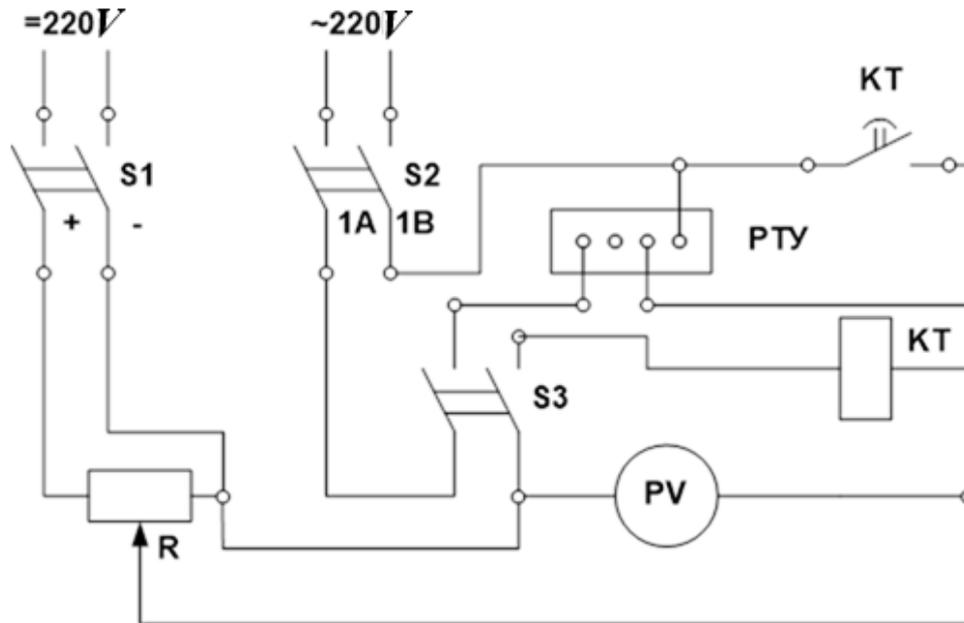


Figure 2.2 - Schematic diagram of the time relay study

The procedure for examining a time relay:

- 1) Assemble the circuit (Fig. 2.2) to study the time relay. Set the maximum value of the time delay.
- 2) After the teacher checks the assembled circuit, turn on the power:
 - gradually increasing the voltage with the help of rheostat R, determine the minimum voltage value at which the relay armature instantly retracts;
 - slowly reducing the voltage, determine the largest voltage value at which the armature instantly drops off. Determine the relay return factor using formula 1.7.
- 3) Check the relay time scale. Enter the data in Table 2.2
- 4) To evaluate the discrepancies between the measured and the passport data of the time relay under study.

Table 2.2 - Measurement results

Set point time on the scale, c	1	2	3	4	5	6	7
Response time, c							
Return rate							

2.3 Preparation of report

The report should contain: the purpose of the work, the principle of operation and characteristics of the relay, electrical diagrams for the study of current relays (Figure 2.1) and time relays (Figure 2.2), tables of measurement results (Tables 2.1, 2.2) and estimates

of differences between the measured and passport data of the relays under study.

2.4 Control questions

1. Explain the principle of operation of current relays of the maximum type.
2. How are the trip current and return current of the relay determined?
3. How are the current relay settings adjusted?
4. Explain the principle of operation of the time relay.
5. Why is the return ratio of current relays higher than that of time relays?
6. The main bodies of maximum current protection.
7. Does the time relay delay depend on the voltage supplied to it?

2.5 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.
2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.
3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.
4. Shelepeten T.M. Protective automation of electrical networks: Study guide for students of specialties 7.090602 and 8.090602 "Electrical Systems and Networks" of all forms of education. - Lviv, 2002, 157 p.
5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovych, V.F. Sokolov et al. Study guide - K.: IZMN, 1996. 288 c.

LABORATORY WORK RS-3 STUDY OF ELEMENTS OF PROTECTION WITH LIMITED TIME DELAY

3.1 Purpose of work

Objectives: consolidation and deepening of theoretical knowledge of the structure, design and characteristics of current relays of the RT-80 series; acquisition of practical skills in the maintenance of relay protection devices.

3.2 Procedure for performing work

Describe the principle of operation and characteristics of the maximum current relay of the RT-80 series.

The PT-80 series induction current relay is a combined relay consisting of two elements: an induction element with a disk that creates a limited time-dependent characteristic of the time delay, and an electromagnetic element that creates a "tripping" at high current multiplicities in the relay winding. Thus, the RT-80 relay has a limited time-dependent characteristic. One common magnetic system is used in the manufacture of these elements.

The PT-80 magnetic system is designed in such a way that it is saturated at approximately ten times the operating current. Further increase of the current does not lead to an increase in the magnetic flux, so the torque and rotation speed of the disk remain constant, and the time exposure also remains constant.

The advantage of maximum current protection with a dependent time delay over maximum current protection with an independent time delay when protecting radial lines with one-way power supply is the possibility of obtaining short time delays when a short circuit occurs at the beginning of each protected section.

The tripping current of the maximum overcurrent protection with time-dependent time characteristic is determined from the following expression

$$I_{op} = \frac{k_{rel} \cdot k_{sch} \cdot k_{str}}{k_{ret}} \cdot \frac{I_{op\ max}}{n_{tr}} \quad (3.1)$$

where $I_{op\ max}$ is the maximum operating current of the load;

k_{rel} - reliability factor, which takes into account the error in the value of the current protection relay, is taken equal to 1.1÷1.2;

k_{sch} is a coefficient that depends on the connection scheme of current transformers and relays;

k_{str} is the startup coefficient, which takes into account the increase in current caused by the self-starting of motors;

k_{ret} - the return coefficient of the current relay is calculated according to formula 3.2;

n_{tr} is the transformation ratio of the current transformer.

$$k_{ret} = \frac{I_{ret}}{I_{op}} \quad (3.2)$$

The trip current is determined from the expression

$$I_{op.t} = k_{rel} \cdot I_{sc} \quad (3.3)$$

where k_{rel} is the reliability factor equal to 1.4÷1.5 for relays of the RT-80 type;

I_{sc} - short-circuit current at the end of the protected section.

RT-81, RT-82, RT-83, RT-84 relays are used to protect electrical machines, transformers and transmission lines against short circuits and to provide overload signaling. Relays of RT-85 and RT-86 types are designed for operation at alternating operating current, have reinforced closing and opening contacts with a common point, and relay RT-86, in addition to the main contacts, has a closing signal contact, similar to relay RT-84.

Reinforced closing and opening contacts in the RT-85 relay can operate either instantaneously or with a time delay. In the RT-86 relay, these contacts operate only instantaneously. The largest setpoint time of operation in independent part of the characteristic is 16 s. The relay return coefficient is 0.8. power consumption - 10 VA at a current equal to the tripping current of the induction element.

RT-91 and RT-95 relays are based on RT-80 series relays and differ from them by the characteristic of time delay versus current.

Investigate the maximum current relay of induction type.

At the choice of the teacher, the relay RT-81, RT-82, RT-83, RT-84, RT-85, RT-86, RT-91, RT-95 is examined (Figure 3.1, relay KA). Make sure that the power supply circuits and equipment for the laboratory work are in good working order by visual inspection. Familiarize yourself with the technical data, design, and methods of adjusting the relay trip settings. Study the electrical circuit of the relay (Figure 3.1).

3.3 Research procedure relay

- 1) Assemble the electrical circuit (Fig. 3.1) for testing the relay. Set the minimum value of the relay tripping current.
- 2) After the teacher checks the assembled circuit:
 - turn on the power;
 - gradually increase the current in the circuit (using a TUV control transformer - roughly, accurately - with a rheostat R) to a value at which the frame worm will engage with a segment of the moving system. The resulting value of the current I_{op} recorded in Table 3.1;
 - reduce the current in the circuit to a value at which the moving the system of the dependent element of the relay type RT-80 will return to its original position. Enter the obtained value of the return current I_{ret} in Table 3.1.

Using the expression (3.2), determine the relay return coefficient k_{ret} and its value are listed in Table 3.1.

- 4) Repeat the measurement for all trip current settings.
- 5) By changing the trip settings with the help of the adjusting screw (at the

minimum value of the trip current setting), determine the trip currents at different settings (the relay movable frame must be held by hand to prevent the dependent element from tripping). Record the values of the trip current in Table 3.1.

6) At the settings of the dependent element by current and time specified by the supervisor, take the characteristic $t_{op} = f(I_r)$. Record the results in Table 3.2. Plot the characteristic $t_{op} = f(I_r)$.

7) Evaluate the discrepancies between the measurements and the passport data of the relay under test.

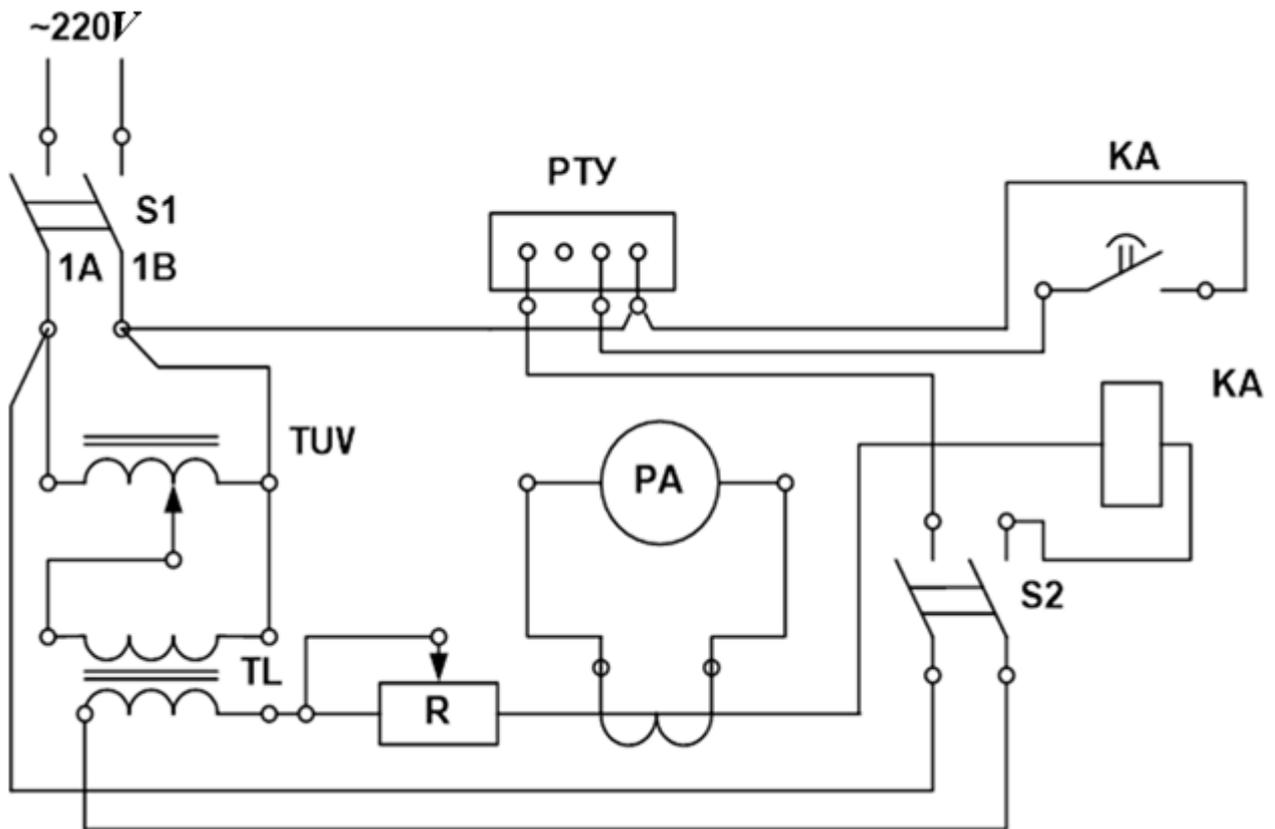


Figure 3.1 - Schematic diagram of the spacecraft relay study

Table 3.1 - Research results

Relay RT-80 serial number	Dependent element	Setpoint current on the scale, A					
		Triggering current, A					
		Return current, A					
		Return rate					
	Independent element	Setpoint current, A					
		Trip value					
		Triggering current, A					

Table 3.2 - Time characteristics

Current in the relay circuit, A					
Response time, S					

3.4 Preparation of report

The report should contain: the purpose of the work; a description of the principle of operation of the relay type RT-80; electrical circuit for the study of the relay type RT-80 (Fig. 3.1); table of results of testing the dependent and independent parts of the relay (Table 3.1); time characteristic (Table 3.2); graph $t_{op} = f(I_r)$.

3.5 Control questions

1. Explain the principle of operation of the RT-80 relay.
2. What protection circuits use relay type RT-80?
3. What is the inertial runaway of a relay?
4. How is the current and response time of induction relays controlled?
5. How are the indicators of related defenses reconciled?

3.6 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.
2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.
3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.
4. Shelepeten T.M. Protective automation of electrical networks: Study guide for students of specialties 7.090602 and 8.090602 "Electrical Systems and Networks" of all forms of education. - Lviv, 2002, 157 p.
5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovich, V.F. Sokolov et al. Textbook - K.: IZMN, 1996. 288 c.

LABORATORY WORK RS-4 STUDY OF THE OPERATION OF ADJACENT CURRENT PROTECTORS WITH DEPENDENT TIME DELAY

4.1 Purpose of work

Purpose: to consolidate and deepen the lecture material on the study of the operation of adjacent maximum current protections with a limited time-dependent time delay, to acquire practical skills in matching the characteristics of adjacent protections and meeting the requirements of selectivity, sensitivity and speed of the analyzed electrical installation protections.

4.2 Procedure for performing work

Describe the principle of matching adjacent maximum overcurrent protections with a dependent time delay.

Protection matching of two sequentially connected sections, for example, lines L1 and L2, is carried out by restoring them in time by the selectivity degree t at the fault at the beginning of the previous section, i.e., at the protection matching point. The point of protection matching is the point at which, at s.c. through the largest current passes through both coordinated protections. In this case, the time difference between the matched protections is the smallest. At lower fault currents, the time difference increases, which ensures selectivity. In Fig. 4.1 shows a diagram of the protected network. On the line L2 on the supply side, there is a circuit breaker Q2, and on the line L1 on the supply side, there is a circuit breaker Q1.

Fig. 4.2 shows the characteristics of the response time (induction - solid line and electromagnetic - dashed line) of the relay elements depending on the distance of the fault location from the power supply, for the line protection relay L2 (curve 2) and for the line protection relay L1 (curve 1).

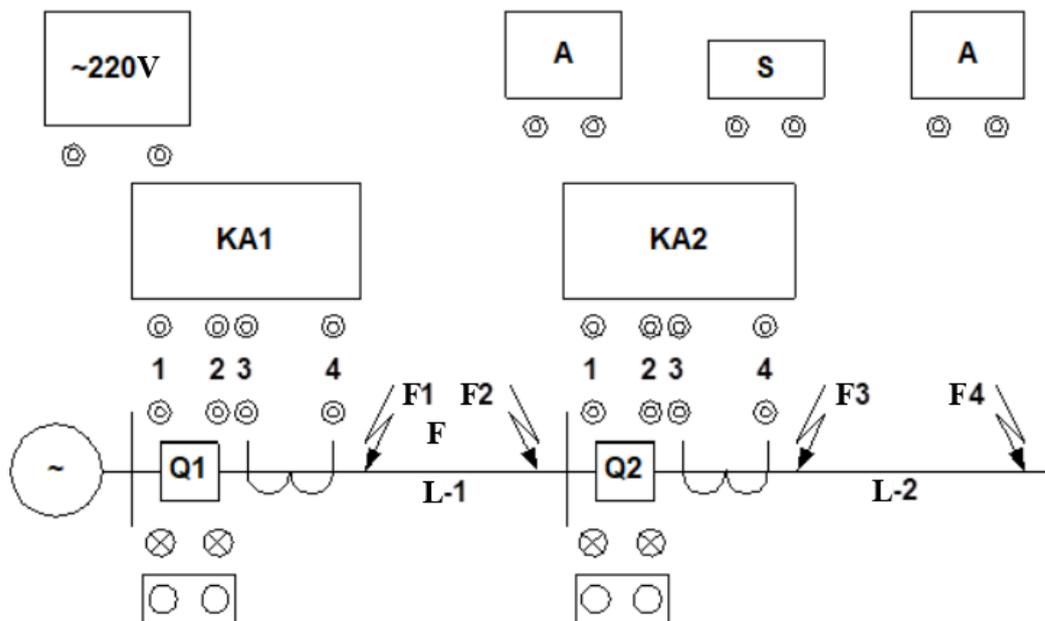


Figure 4.1 - Protection scheme for two power lines connected in series

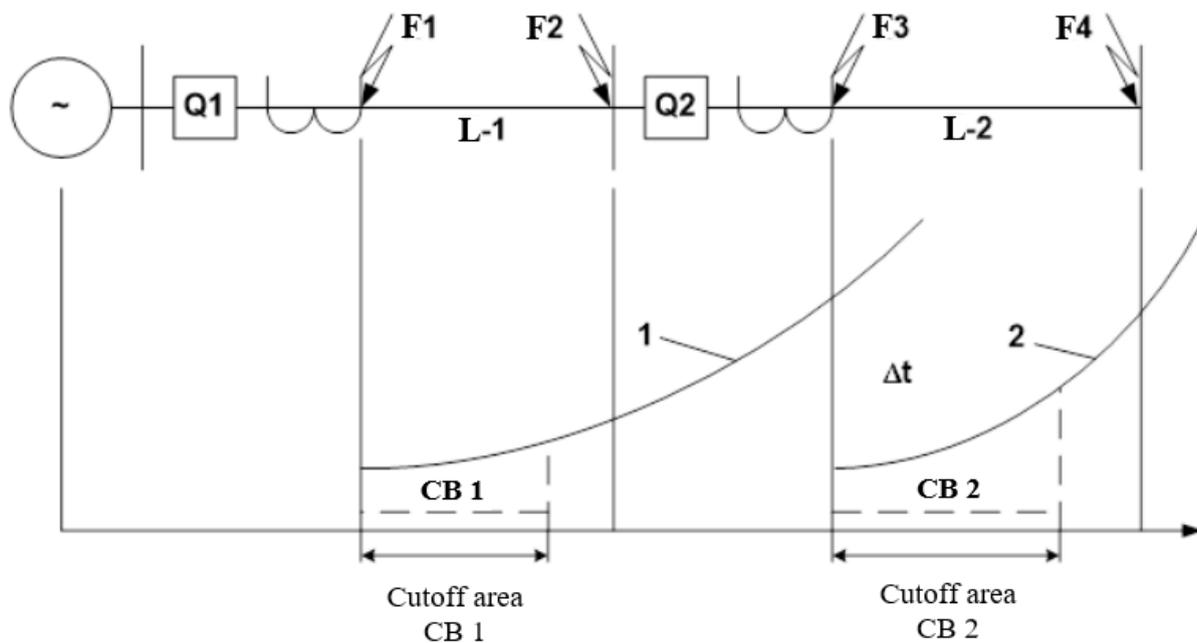


Figure 4.2 - Characteristics of maximum overcurrent protections with limited-dependent time delay

In practice, the protection is restored as follows: by passing a current through the relay KA2 of line L2 protection equal to the short-circuit current at the beginning of the line (with a rough trip), they influence the mechanism of changing the time delay of the induction part of the relay and achieve that the relay operates with a given time delay, in this work - 2 s. At the same current, repeat this operation for the relay KA1 of line L1 protection, achieving its operation with a time delay exceeding the time of operation of the line L2 protection relay by a degree of selectivity (0.7 s).

The full characteristics of the time-delay versus current for both relays are taken after matching the line and feeder protection, without changing the position of the time-delay mechanism. For each characteristic, 4-5 points are required in the range of real currents that can flow through the protection relay.

Describe the laboratory installation of a model of protected electrical installations.

The model of the protected electrical installations is a section of a radial network (see Fig. 4.1), namely: busbars of substation 2, power line L2, busbars of substation 1 and outgoing line L1. The line L2 from substation 2 and the line L1 from substation 1 are equipped with maximum current protection with a dependent time delay. The protection is provided by relays of the RT-81/1 type. Line and feeder circuit breakers are simulated by magnetic AC starters controlled by on/off buttons. On both lines, at points F1, F2, F3, F4, it is possible to perform three-phase short circuits using the buttons. The load is simulated by active resistances. Line and feeder resistances are also simulated with active resistances. Two ammeters, an electric stopwatch, and a transformer with adjustable transformation ratio of the "Variak. The power supply is switched on automatically from the top of the stand.

The voltage from one of the phases of the power supply is applied (behind the bench)

to one terminal of the starter coil. The second terminal of this coil must be supplied with the voltage of the other phase of the test bench power supply through the opening contacts of the RT-81 relay. The relay windings are connected to the line current transformers (see Fig. 4.1).

When the starter is switched on (by pressing the "On" button), the red light comes on. When line protection is in operation, the opening contacts of the corresponding relay open, the starter coil current circuit is interrupted, and the damaged section of the network is disconnected. The green light is on. The line can be and pressing the "Off" button.

The circuit shown in Fig. 4.3 is assembled with the removal of the characteristics of the relay time delay depending on the current through its winding.

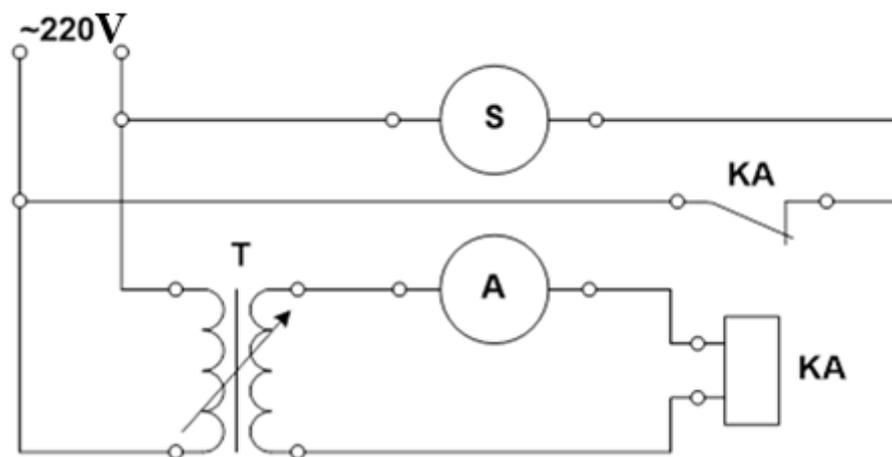


Figure 4.3 - Scheme for characterization of RT-81/1 relay

Ammeters installed on the stand are used. When power is applied to the circuit, the current relay and stopwatch start working simultaneously. When the relay is triggered, its contacts open and stop the stopwatch. Thus, the stopwatch measures the time of the relay operation.

Investigate the operation of adjacent protections with limited time-dependent characteristics:

Connect pins 1 and 2 of the circuit breaker control circuit (above the starters). Experimentally determine the values for setting the protection:

a) the load current of the protected network is measured using an ammeter with a lower measuring limit, which is connected to the current transformer of line L1; at the same time, the current transformer of line 2 is shorted. Turn on the starters. The ammeter will show the load current $I_{load\ max}$;

b) short-circuit currents at points F1, F2, F3, F4. Connect an ammeter with a large measuring limit to the current transformer of line L2. Turn on the starters. Using the buttons, perform short circuits in turn and measure $I_{F1}, I_{F2}, I_{F3}, I_{F4}$.

Using formula (4.1), calculate the tripping current of the induction element of the line protection relay. Based on the calculated current, set the required desoldering on the scale of trip settings.

Assemble the diagram in Fig. 4.3. To do this, connect the relay winding CA2

(terminals 3, 4) through an ammeter with a range of 0-5 A to the output of the Variac transformer. Connect the relay contacts 1, 2 to the power supply via a stopwatch.

When performing the test, set the cutoff setting to the maximum value so that the cutoff does not trip during characterization. Increase the current supplied to the relay KA2 from 0 to $I_{op.max}$ and observe the moment of relay operation.

To adjust the relay KA2 in the diagram of Fig. 3.3, connect an ammeter with a range of 0-30 A instead of an ammeter of 0-5 A. Using a transformer, set the current entering the relay equal to the current I_{kA} . Turn off the machine. Return the stopwatch to the zero position. Turn on automatic. The stopwatch counts down the relay operation time. In order to make this time equal to 2 s, change the setting on the time scale and check the protection action again in the same way. After that, the entire characteristic of the dependence of the time delay on the current multiplicity should be removed (change the current within the range from I_{s-h} to I_{s-c}).

To set up the relay KA1, in the diagram of Fig. 3.3, instead of terminals 1, 2, 3, 4 of relay KA2, connect terminals 1, 2, 3, 4 of relay KA1, respectively.

Using a transformer, set the current entering the relay equal to the current I_{sc} . By changing the setpoint on the time scale, make sure that the time counted by the stopwatch is equal to 2.7 seconds. After setting the relay, remove time versus current characteristic (the current can be changed in the range from 14, 16, 18, 20 to 22 A).

Set the calculated multiplicity of the line and feeder protection trip current on relays KA1 and KA2 (with the electromagnetic relay screw)

$$K = \frac{I_{op.trip}}{I_{set.relay}} \quad (4.1)$$

where $I_{op.trip}$ is the tripping current (calculated by the formula);

$I_{set.relay}$ - current setpoint for the relay.

Assemble the protection circuit according to Fig. 4.1.

By creating short circuits, check the correct operation of the protection (inductive and electromagnetic elements). In case of failure of the line protection L2, check the redundancy of the protection L1.

4.3 Contents of report

1. Experimental results: values of I_{load} , I_{F1} , I_{F2} , I_{F3} , I_{F4} .
2. Calculation of the trip current of the inductive element of the protection relay and the trip current $I_{op.sec}$, $I_{op.trip}$, (for both lines).
3. Experimental data on the construction of time dwell characteristics (for of both relays) depending on the current multiplicity.
4. The diagrams are presented in the paper.
5. The characteristics of the dependence of the protection time durations of lines

L1 and L2 (taking into account the cutoffs) on the current multiplicity for real currents are constructed and the point of protection matching is indicated.

4.4 Control questions

1. What should be understood by line protection coordination?
2. Why is the fault current protection matched at the beginning of L2 and not, for example, at the end of L2? What would be the result of matching the fault current protection at the end of L2?
3. How can I experimentally check the protection characteristic indicated on the relay nameplate?
4. What will the removed protection characteristics of lines L1 and L2 look like, taking into account the area of operation of the cutoffs? Limit the characteristics of the protections to the left and right, taking into account the actual values of the overcurrents that are possible in operation.
5. How to compare the characteristics of line protection if, in addition to the line shown on the stand, there is a second line from another station feeding L2, and therefore, at fault on L2, the currents flowing through L1 and L2 are different?
6. Explain the diagram in Fig. 3.1 and the diagram in Fig. 4.3. What part did you build yourself?
7. What percentage of the line length is protected by the cutoff and why 't it protect 100%?

4.5 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.
2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.
3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.
4. Shelepeten T.M. Protective automation of electrical networks: Study guide for students of specialties 7.090602 and 8.090602 "Electrical Systems and Networks" of all forms of education. - Lviv, 2002, 157 p.
5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovich, V.F. Sokolov et al. Textbook - K.: IZMN, 1996. 288 c.

LABORATORY WORK RS-5 STUDY OF RELAYS POWER

5.1 Purpose of work

Objectives: consolidation and deepening of theoretical knowledge of the device, design and characteristics of power relays; acquisition of practical skills in the maintenance of power relays; removal of angular and volt-current characteristics of power relays.

5.2 Procedure for performing work

Describe the principle of operation and characteristics of power relays.

The use of power relays for the protection of electrical installations is conditioned by the requirement of protection selectivity, which ensures shutdown in case of short circuits of the damaged element of the power system. The following power relays are widely used: RBM-171, RBM-177, RBM-178, RBM-271, RBM-277, RBM-278, RBM-275, RBM-276, RM-11, RM-12, and RSM-13.

The power relay of the RBM series is a measuring instrument influenced by two electrical quantities that are compared in phase. The main element of the relay is a four-pole magnetic system with a moving hollow cylindrical rotor between the poles of the magnetic circuit. The relay has two windings: current and voltage. The operation of the relay is determined by its characteristics: angular - the dependence of the power or voltage (current) of the relay on the angle between the current supplied to the relay and the voltage; voltammetric - the dependence of the operating voltage on the current at the angle of maximum sensitivity, at which the positive torque is maximized.

RBM-171, 177, 178, 271, 277, 278 relays have one or two closing contacts, depending on the purpose. If there is one closing contact, these are single-acting relays used in directional protection circuits to determine the power sign in case of short circuits or other modes (RBM-171, RBM-177, RBM-178). If there are two closing contacts - double-acting relay, which is used in the schemes of directed transverse differential protection of parallel lines to detect a damaged line (RBM-271, RBM-277, RBM-278). The power directional relays differ in the rated current of 1 or 5 A and additional devices in the voltage winding circuit to obtain a different angle between the current and voltage vectors supplied to the relay.

The RBM-171 and RBM-271 relays are mainly used in protection against interphase short circuits.

Relays RBM-177, RBM-178, RBM-277, RBM-278 are used in zero-sequence protection in networks with a high earth fault current.

Relays of RBM-276 and RBM-275 types are used as a control device for active (RBM-275) and reactive (RBM-276) power. The relay has an adjustable setting for the tripping power from 2 to 100 VA at a rated current of 1 A and from 10 to 500 V A at a rated current of 5 A.

The main disadvantages of electromechanical power relays of the RBM series are significant power consumption (up to 90 VA in the voltage circuit and up to 10 VA in the current circuit), the possibility of vibration when current transformers are saturated, distortion of the relay's maximum sensitivity angle when the magnetic circuit is saturated,

and the possibility of relay self-travel.

Power relays of RM series with two influencing quantities are semiconductor measuring relays. RM-11 and RM-12 relays are used in relay protection circuits as a power directional device. The relays are made in a unified SURA design. The size of the characteristic angle for RM-11 is 30° and -45° , and RM-12 is $+70^{\circ}$. The response time of the relay with increased speed is not more than 0.03 s, the relay with increased switching capacity is not more than 0.05 s. Power consumption in the input current circuits is not more than 0.5 VA, in the input voltage circuits not more than 3 VA, in the operational DC circuits not more than 10 W.

The RSM-13 static power relay reacts to the amount and direction of active power and has increased resistance to mechanical. Angle maximum sensitivity $0 \pm 5^{\circ}$. The power consumption of the current circuit is not more than 0.9 VA, with a voltage circuit not exceeding 1.2 VA. Relay response time is 0.07-0.1 s.

To study the power directional relay of the RBM-171 type

Visually inspect the power supply circuit and laboratory equipment to ensure that they are in good working order. Familiarize yourself with the design and technical parameters of the power relay. Study the electrical circuit of the relay, Fig. 5.1.

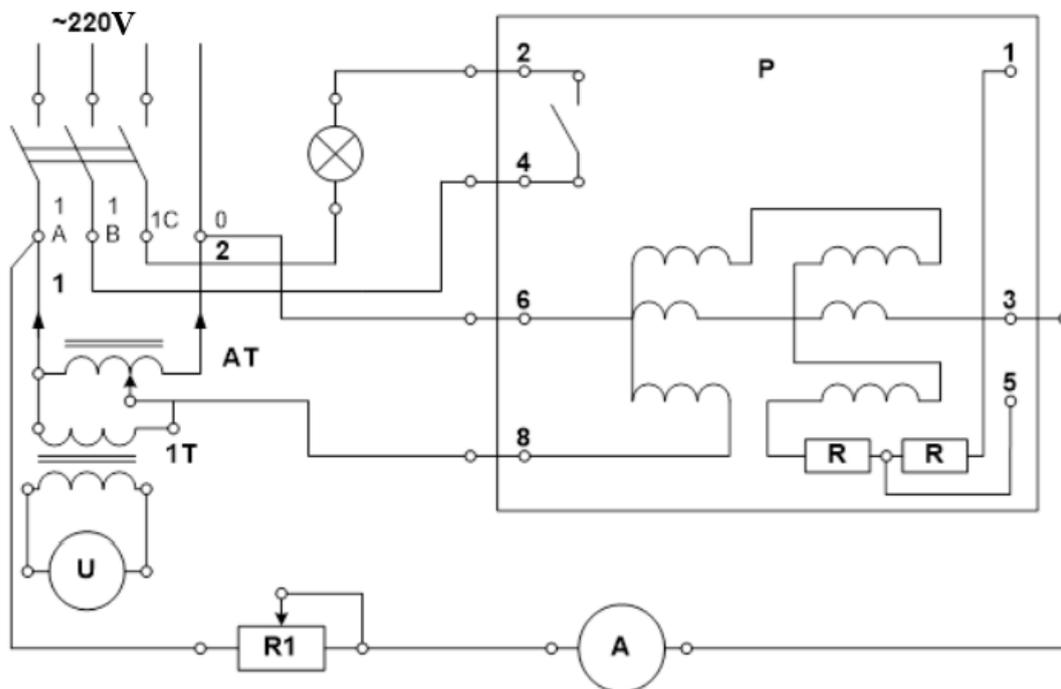


Figure 5.1 - Schematic diagram of the power relay test

The procedure for examining the relay:

- 1) Assemble the electrical circuit (Fig. 5.1) for the study of relay P.
- 2) After the teacher checks the assembled circuit:
 - connect the AT inputs (1 and 2) "mains" to the power panel according to Table 5.1 at $\varphi=0$;

- apply power to the circuit and, using rheostat R1, set the current in the relay winding to 1 A. Keep the current and monitor it with an ammeter;
- by increasing the voltage with the help of the AT, determine $U_{r.r.}$;
- repeat for all values of the angle φ indicated in Table 5.1.

Table 5.1 - Angular characteristic of the relay

φ	0	30	60	90	120	150	180	210	240	270	300	330
U (V)	AO	AB	-BO	CB	CO	CA	-AC	BA	BO	BC	-CO	AC
Ur.r. (V)												

1) Plot the angular response of $U_{r.r.} = f(\varphi)$ at $I_r = 1 \text{ A} = \text{idem}$. Determine the angle of maximum sensitivity, i.e., the angle at which the value of the relay response voltage is minimal.

2) At the angle of maximum sensitivity, take the voltammetric characteristic (sensitivity characteristic) $U_\varphi = f(I_r)$. Record the results in Table 5.2.

Table 5.2 - Volt-current characteristic

I_r (A)	1	2	3	4	5
$U_{r.r.}$ (B)					

5.3 Preparation of report

The report should contain: the purpose of the work, an electrical circuit for the study of power relays (Fig. 5.1), a table of dependence $U_{r.r.} = f(\varphi)$ (Table 5.1), a graph $U_{r.r.} = f(I_r)$ according to Table 5.2, conclusions about the scope of the relay.

5.4 Control questions

1. Determine the scope of the power directional relay.
2. Explain the principle of operation of an inductive power directional relay.
3. What is the phenomenon of power relay self-propulsion?
4. How to convert a sine relay to a cosine relay?
5. What determines the angular response of a relay?
6. Why is the voltammetric characteristic called the sensitivity characteristic?

5.5 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.
2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.
3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.

4. Shelepeten T.M. Protective automation of electrical networks: Study guide for students of specialties 7.090602 and 8.090602 "Electrical Systems and Networks" of all forms of education. - Lviv, 2002, 157 p.

5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovich, V.F. Sokolov et al. Textbook - K.: IZMN, 1996. 288 c.

LABORATORY WORK RS-6 STUDY OF CURRENT-DIRECTED LINE PROTECTION

6.1 Purpose of work

Objective: consolidation and deepening of the lecture material on the study of the operation of maximum current-directed line protection in bilateral power supply networks; acquisition of practical skills in the operation of power directional relays and its switching scheme, taking vector diagrams of currents in protection circuits and assessing the correctness of the measurement devices.

6.2 Procedure for performing work

Describe the principle of operation of maximum current directional protection and the diagram of the laboratory setup (Fig. 6.1).

In ring networks and radial networks with two-sided power supply, it is usually impossible to implement selective operation of maximum current line protection with stepwise setting of time durations, so in such networks it is necessary to use maximum current directional protection, which is triggered only when the short-circuit power is directed from the busbars to the line. So, for example, the maximum current-directed protection, protecting line L1 (Figure), will operate the event of a short circuit at point F1 and will not operate in the event of a short circuit at point F2, even if the current in the current relay (the starting device of the maximum directional protection) exceeds its tripping current. This is achieved by the fact that the positive operating current, when the current relay contacts are closed, is transferred to the intermediate relay and, therefore, the circuit breaker will trip only when the power direction relay contact is closed.

Power directional relay of induction type RBM-171 contains

A magnetic circuit with current and voltage windings and a moving part. Under the influence of the magnetic fluxes of the windings, a torque is generated in the moving part of the relay is a torque that changes its sign when the direction of current in the relay current winding changes (i.e., when the direction of short-circuit power changes).

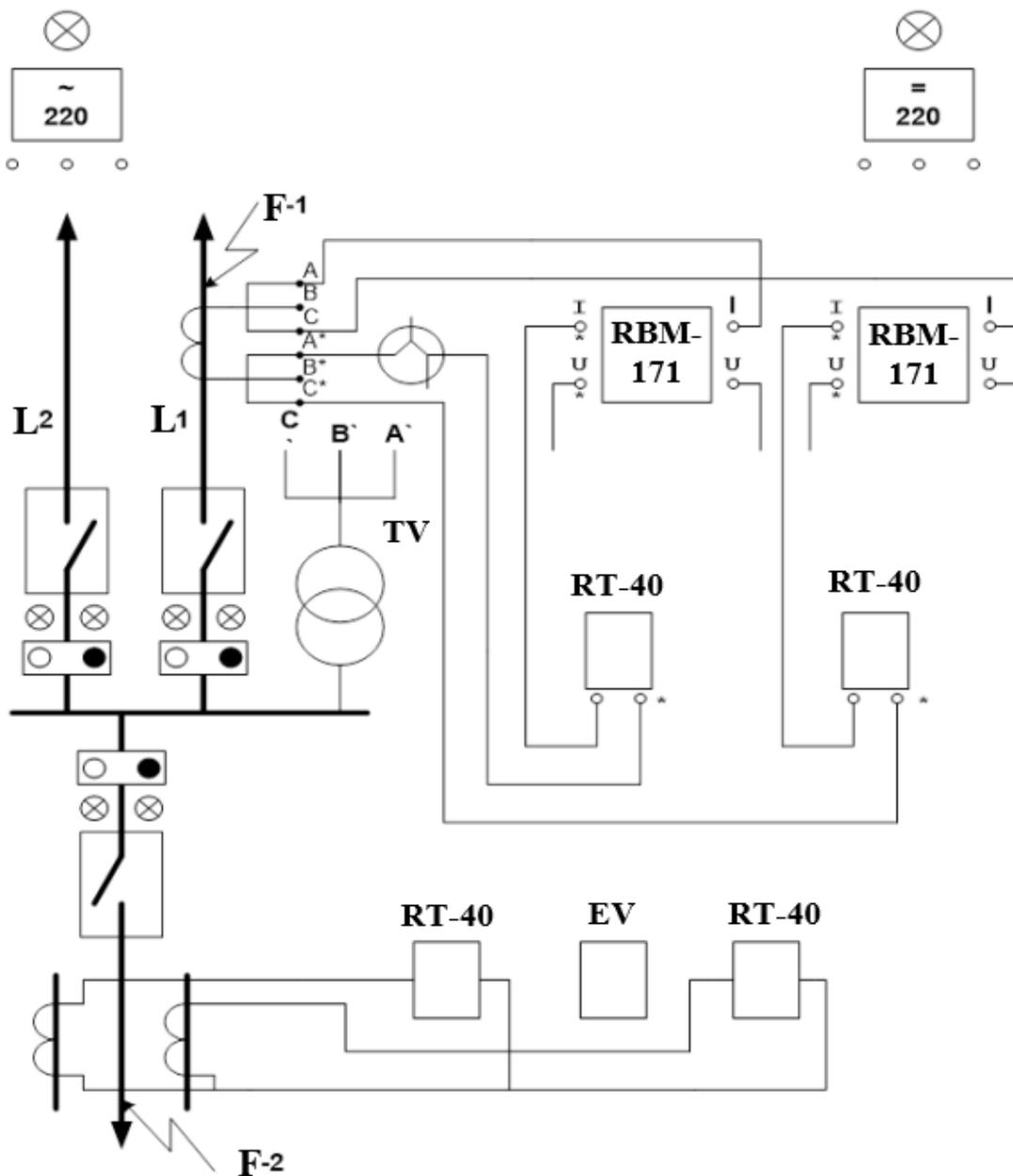


Figure 6.1 - Diagram of the laboratory setup

For protecting overhead lines from short interphase short circuits are used relays of mixed type relay RBM-171(with one closing contact) or RBM-271 (with two closing contacts). The torque that causes the relay to operate for these relays is determined by the expression

$$M = k \cdot U_r \cdot I_r \cdot \sin(\gamma - \varphi_r) \quad (4.1)$$

where U_r, I_r are the voltage and current supplied to the relay windings;

γ - is the angle between the voltage U_r and the current I_r in the relay voltage winding;

φ_r is the angle between U_r and I_r .

For the clear operation of the power direction relay (clear detection of the power direction in the event of a short circuit), the torque must be as large as possible. Because the product $U_r \cdot I_r$ changes little in a short circuit, the current value and the sign of the torque are determined by the angle $(\gamma - \varphi_r)$. The angle γ is chosen when designing the relay, the angle φ_r depends on the type of short circuit and the way the relay windings are switched on. The best results are obtained when $\gamma=45-60^\circ$ and the relay is switched on according to the so-called "90° scheme", in which, in normal operation of the protected line, with a purely active load current, the angle between the current in the power direction winding and the voltage supplied to this relay is 90°. In this case, the relay, the current winding of which is connected the current of phase A, must be supplied with the voltage U_{BC} , and the relay, the current winding of which is connected to the current C, - voltage U_{AB} .

To verify the correctness of the assembly of current circuits of protections, including maximum directional protections, vector diagrams are taken after the assembly of the circuits of these protections. For this purpose, the current winding of the wattmeter is included in the current circuit, the vector of which is to be plotted against the linear voltage.

In this case, it is necessary that the beginning of the secondary winding of the current transformer is connected to the beginning of the current winding of the wattmeter (as an example, the figure shows the wattmeter being turned on to take a vector current diagram phase A). Then the voltage winding of the wattmeter is alternately connected to the linear the power supply voltage of the stand. In this case, make sure that the beginning of the wattmeter voltage winding is connected to the phase that is first in the voltage index. For example, when applying voltage AB, the beginning of the voltage winding is connected to phase A. If the wattmeter arrow deviates to the left, the beginning of the voltage winding is connected to the phase and the power reading in divisions is recorded with a minus sign. As a result of measuring the power for the same current with three line voltages, the data that must be entered in Table 6.1 of the following form (conditional data) are obtained

Table 6.1 - Measurement data

U/I	U_{AB}	U_{BC}	U_{CA}
I_A	+2	+3	-5

The sum of the three wattmeter readings should be zero.

Based on the table data, a vector diagram is constructed by plotting segments proportional to the wattmeter readings in divisions, taking into account the sign of the reference. From the ends of the segments (0-1; 0-2; 0-3), perpendiculars to the linear voltages are plotted. The point of intersection of the perpendiculars gives the end of the desired vector U_A .

For the current of phase C, the vector diagram is constructed similarly.

The stand represents a section of the ring network: 2 ring lines, substation buses, and

a dead-end line. The line that closes the ring is not shown in the mnemonic diagram, but it is behind the bench. Line 1 on the substation side is equipped with a two-phase overcurrent protective device without time delay. This protection is made by means of two RT-40 relays, two RBM-171 relays and an intermediate relay. On the opposite side of the line, it is assumed that there is a current protection with a time delay (not installed on the stand).

The dead-end line extending from the substation busbars has a maximum time-delayed current protection consisting of two RT-40 relays, a relay time and intermediate relay. Line circuit breakers are simulated by magnetic AC starters. Line 1 and the dead-end line can be faulted with three-phase and two-phase short circuits. The load is simulated by ohmic resistors. The ohmic resistances limit the current during artificial short circuits on the lines. To take vector diagrams, the following are installed near the test bench: an ammeter, a wattmeter, and a phase indicator. Voltage is supplied to the stand by automatic machines installed in the upper part of the stand. The left one is used to supply alternating current, the right one - direct operating current. The primary switching circuits of the stand are shown in the figure with bold lines, the protection circuits with thin lines. All circuits are permanently mounted on the bench, except for the voltage and current circuits of the maximum current directional protection, which are assembled by the students themselves. The mnemonic diagram of the bench (top left) shows three clamps for phases A, B, C. They are designed to apply voltage to the voltage winding of the wattmeter when taking vector diagrams.

Investigate the current-directed protection of lines.

1) Assemble the electrical circuit (Fig. 6.1) for the protection study. Connect the current circuits of RT-40, RBM-171 relays and voltage circuits of RBM-171 in accordance with the diagram, using the terminal panels provided on the stand.

2) Take a vector diagram of currents in the current windings of the RBM relay during normal operation of the line and make sure that the protection circuit is correct.

Note: before switching the line on, remove the operating current from the directional protection to avoid disconnecting the line in case of incorrect protection activation.

3) Check the operation of the protection in case of three-phase and two-phase (phases AB and BC) short circuits on the dead-end line and on line 1 to be protected, and make sure that the protection of both lines is correct and selective. Record which relays are tripped and at what type of fault.

Pre-set the dead-end line protection to a protection time of 2 seconds.

4) Take vector diagrams of currents in the directional protection circuits and in phase at a two-phase short circuit on line 1 and on the dead line. When taking the diagram, the short circuit shall be carried out periodically for a time sufficient to perform one measurement, with a break of 2-3 minutes between measurements. At the same time, measure the line voltages supplied to the RBM relay and plot them on the diagram. In order not to burn the wattmeter when taking diagrams during a short circuit, it should be connected through an additional current transformer (not necessary in this scheme).

6.3 Preparation of report

The work report must contain: the diagram given in the instructions, a vector diagram of currents in the protection circuits in normal mode, vector diagrams of currents and

voltages in the protection circuits in case of a two-phase short circuit on line L1 and on the dead line.

6.4 Control questions

1. What is the principle for selecting the maximum overcurrent protection time?

How are the tripping currents selected?

2. What is the directionality of a power directional relay?

3. When does targeted protection have a cascading effect?

4. What is a "90° circuit"? What is the main requirement for the power directional relay circuit?

5. What should the vector diagram of a three- and two-phase short circuit on a dead-end line look like and how does it differ from the diagrams for the corresponding short circuits on the protected line?

6. Design and operation of power direction relays.

7. What is the angle of maximum sensitivity of a relay? Why is it equal to the RBM-171 relay?

8. How is the phased startup implemented in the diagram on the stand?

6.5 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.

2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.

3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.

4. Shelepeten T.M. Protective automation of electrical networks: Study guide for students of specialties 7.090602 and 8.090602 "Electrical Systems and Networks" of all forms of education. - Lviv, 2002, 157 p.

5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovich, V.F. Sokolov et al. Textbook - K.: IZMN, 1996. 288 c.

LABORATORY WORK RS-7 STUDY OF CURRENT DIFFERENTIAL RELAYS

7.1 Purpose of work

Objective: consolidation and deepening of theoretical knowledge of the device, design and characteristics of current differential relays of the RNT type; acquisition of practical skills in the maintenance of differential current relays RNT.

7.2 Procedure for performing work

Describe the principle of operation and characteristics of differential relays of the type

Special differential relays are used in differential protection circuits: RNT-562, RNT-563, RNT-563/2, RNT-564, RNT-565, RNT-566, RNT-566/2, RNT-567, RNT-56/2. Relays of types RNT-562 and RNT-565 are used for differential protection of two- and three-winding power transformers, generators, powerful shunt reactors, substation busbars, and electric motors with voltage above 1 kV.

The difference between the RNT-565 relay (produced since 1965) and the old RNT-562 relay is that the RT-40 current relay with a higher return coefficient than that of the ET-521 in the RNT-562 relay is used as the actuator, and that the number of turns of the short-circuited winding is regulated by soldering in the RNT-562 relay to recover from transient currents, while in the RNT-565 relay the active resistance in the short-circuited winding circuit is regulated by the value of the active resistance.

The main element of the RNT relay is a special saturating current transformer (NCT) containing a core ferromagnetic core with primary, secondary and short-circuited windings. The NCT is designed to recover the relay from unbalance currents during transients and to equalize the magnetomotive forces (MMF) arising under the influence of secondary currents of different differential protection arms. The sensitivity of the RNT relay depends on the shape of the current curve in the primary windings of the NCT. With sinusoidal current, the saturating current transformer has virtually no effect on the relay operation. In the event of external short circuits and when power transformers are switched on, a transient process occurs, characterized by the presence of an aperiodic current component that strongly saturates the magnetic circuit of the LTC: the magnetization resistance drops sharply, the magnetization current increases, the secondary current of the relay decreases, which increases the transformation ratio of the LTC and reduces the sensitivity.

In the event of a short circuit in the protected area, when an aperiodic current component occurs, the protection operates with a delay of no more than two periods for the time of saturation of the NCT magnetic circuit. The RNT-565 relay has a larger

The current rating of the relay is higher (100 A-min) than that of the RNT-562 (60 A-min) and more desoldering in the primary windings, which allows for a wider and more accurate adjustment of the protection tripping current and the degree of current equalization in the protection arms. The primary windings (operating and equalizing) of the RNT-562 and RNT-565 relays can withstand a continuous current of 10 A and in normal mode the total magnetic flux in the NCT core generated by these windings is close to zero. The

working winding of RNT-562 and RNT-565 is included in the differential protection circuit and the relay has one closing contact.

Relays of the RNT-563, RNT-563/2, RNT-566, RNT-566/2 types are designed for differential protection of power transformers using current transformers with different rated secondary currents. The RNT-563 and RNT-566 relays have three primary windings for protection of three-winding transformers, and the RNT-563/2 and RNT-566/2 relays have two primary windings for protection of two-winding transformers. The difference between the RNT-566 and RNT-566/2 relays and the old version of the RNT-563 and RNT-563/2 relays is the same as the difference between the RNT-565 and the RNT-562 relays.

Relays of the types RNT-564 (old version), RNT-567, RNT-567/2 are used for differential protection of busbars, have two primary operating windings with rated secondary currents of 5 A for relays RNT-564, RNT-567 and 1 A for the RNT-567/2 relay. These relays have one closing and one opening contact.

Investigate the differential relay of the RNT-565 type

The relay consists of an intermediate saturating transformer NTS and a PT-40 actuator (Fig. 6.1). The intermediate NTS has a three-core core. On the left core is the secondary winding W_{sec} to which the actuating relay is connected. On the middle core magnetic circuit there are two primary windings W_r , which are included in the current circuit's differential protection. In addition, the middle and right rods have two sections W'_{sc}, W''_{sc} of a short-circuited winding, that is used to improve the recovery from magnetizing currents of power transformers and unbalance currents in the transient mode in case of external faults. The middle core also contains two equalizing windings, which are used to recover from unbalance currents of current transformers.

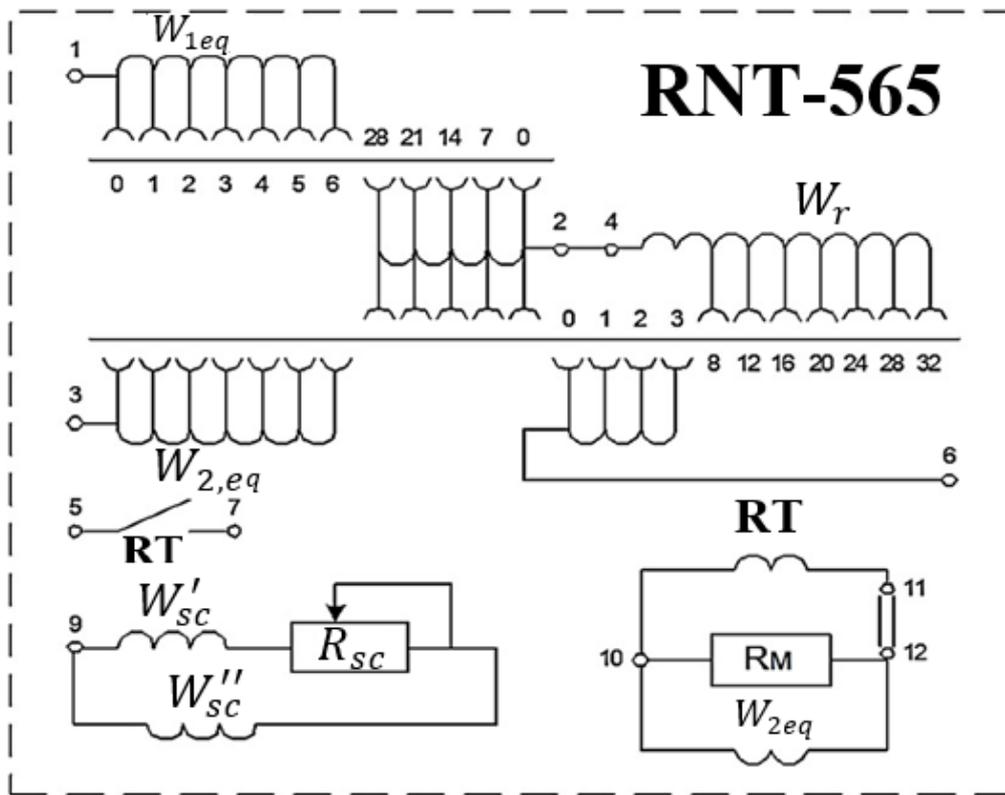


Figure 7.1 - Schematic diagram of the relay RNT-565

The degree of recovery from transient currents with the help of a short-circuited winding is regulated by changing the value of the resistance R_{sc} , which is connected in series to the short-circuit winding. With a fully introduced R_{sc} , is obtained with the least coarsening of the relay, with reduction R_{sc} , the recovery from the aperiodic component of the primary current is improved.

Visually inspect the power supply circuits and laboratory equipment to ensure that they are in good working order. Read the technical data, design and methods of adjusting the settings relay operation. Study the electrical circuit of the relay, Fig. 7.2.

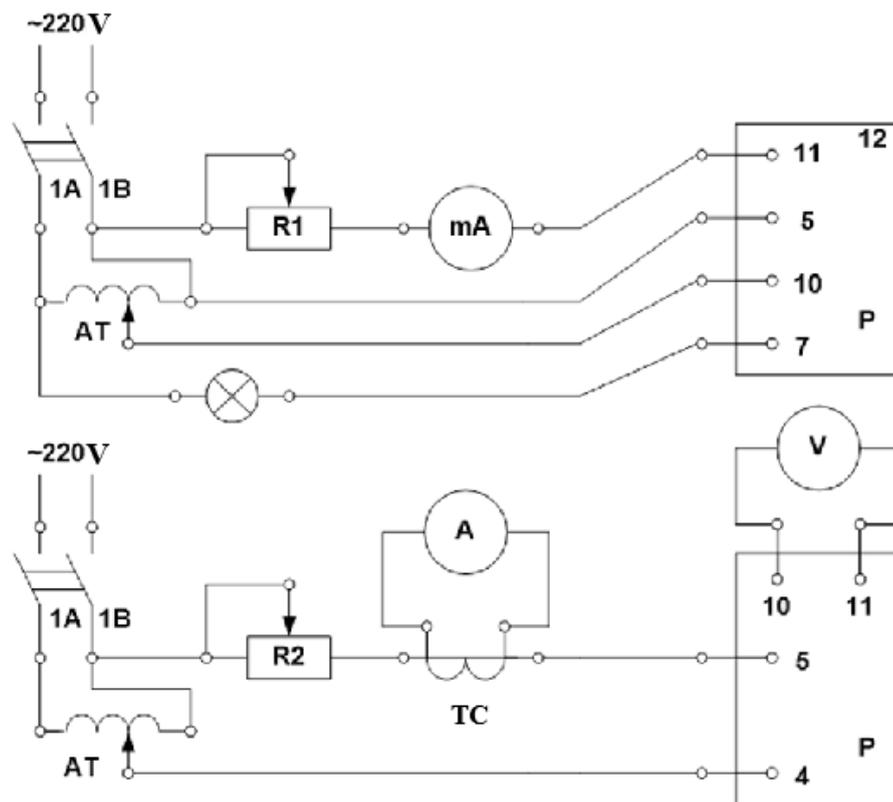


Figure 7.2 - Diagram of the study of the RNT relay

7.3 Research procedure relay

1) Assemble the electrical circuit (Fig. 6.2) to study the actuator of the RNT-565 relay. Remove the jumper 11-12 in the relay.

2) After the teacher checks the assembled circuit:

- turn on the power supply. Using the AT and the rheostat R_1 , increase the current in the actuator winding until it is triggered. Control the actuation by lighting the lamp L. In this case, the actuation current should be 0.17 ± 0.01 A;

- determine the return ratio of the relay actuator.

3) Assemble the electrical circuit for checking the NTS, install a jumper between terminals 11-12 in the RNT-565 relay.

4) After checking the circuit by the teacher, remove the dependence between the primary winding current and the voltage on the terminals of the actuating relay. To do this:

- remove the relay cover and set the slider of the resistor R (short-circuit) to the lowest position;

- set the number of turns of the working winding using the plug screws as indicated in Table 7.1.

- turn on the power supply and, using the AT and rheostat R_2 , increase the current in the working winding until the NTS is saturated. Saturation is characterized by the fact that the voltage measured by the voltmeter becomes constant despite the further increase in current;

- by changing the number of turns of the working winding according to Table 7.1, remove the dependence $U = f(I)$;
- set the slider of the resistor R (short-circuit) to the uppermost position and repeat the test.

5) To plot the characteristic of $U = f(F_{pr})$; at different positions of R_{sc} ; F_{pr} is calculated by multiplying the current by the number of switched turns of the primary winding.

Table 7.1 - Experimental results

	$R_{sc,max}$						$R_{sc,min}$					
W_r windings	3	8	12	20	24	32	3	8	12	20	24	32
I , A												
F_{pr} A windings												
U , V												

7.4 Preparation of report

The report should contain: the purpose of the work, the principle of operation of differential relays, electrical schemes for checking the actuator of the relay type RNT-565 (Fig. 6.2) and checking the serviceability of the NTS, a table for removing the dependence $U=f(I)$; (Table 6.1), a graph $U = f(F_{pr})$ conclusions on the work (advantages and disadvantages of the relay).

7.5 Control questions

1. In what protection circuits is the relay of the RNT-565 type used?
2. What is the purpose of the main components of the RNT-565 relay?
3. What is the principle of magnetization?
4. How are relay setpoints of the RNT-565 type selected?
5. What is the principle of operation of the relay type RNT-565?

7.6 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.
2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.
3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.
4. Kidiba VP, Shelepeten T. M. Protection of transformers and autotransformers. Lviv: Lviv Polytechnic National University Publishing House, 2004. 180 c.
5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovich, V.F. Sokolov et al. Textbook - K.: IZMN, 1996. 288 c.

LABORATORY WORK RS-8 STUDY OF DIFFERENTIAL PROTECTION OF A TWO-WINDING TRANSFORMER

8.1 Purpose of work

Objective: to consolidate and deepen the lecture material on the study of current differential protection of transformers, to acquire practical skills in taking and constructing vector diagrams using a wattmeter and ammeter, to draw up and check the schemes of longitudinal differential protection of two-winding transformers.

8.2 Procedure for performing work

1. Describe the principle of operation of longitudinal differential protection of a transformer.

Differential protection of the transformer is designed to protect it from internal damage (short circuits).

The current transformers and differential protection relays are connected in such a way that during normal operation of the transformer, as well as in the event of external short circuits (outside the transformer - behind the current transformers), the current in the relays connected to the difference in secondary currents of the current transformers is close to zero. This is achieved by the following measures.

The connection scheme of current transformers is taken identical to the connection scheme of the power transformer windings, but the current transformers from the side of the power transformer "star" are included in the "triangle", and from the side of then of the "triangle" into a "star" (Fig. 8.1). This compensates for the 30° offset between the currents of the $I_A I_B I_C$ and $I_a I_b I_c$ power transformer, and the secondary currents in the wires connecting current transformers (i'_a, i'_b, i'_c and $i_a i_b i_c$) coincide in phase.

The secondary currents of current transformers are equalized by value using a relay of the RNT-565 type. The RNT-565 relay consists of an actuator based on the RT-40/0.2 current relay and an intermediate busbar transformer (BCT). The magnetic core has a three-core magnetic circuit. The middle core contains the primary windings, one of which is differential (working) W_d , and two equalizing windings W_{1eq}, W_{2eq} . The middle and right rods contain two sections W'_{sc} and W''_{sc} short-circuited winding, which is used to improve recovery from magnetizing current surges of power transformers and unbalance currents in the transient mode in case of external faults. On the left of the rod is the secondary winding W_{sec} , in the circuit of which the relay PT-40 is switched on Fig. 8.2.

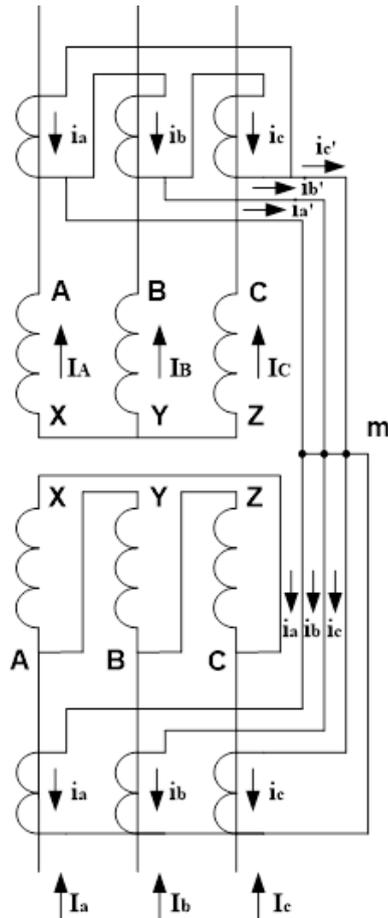


Figure 8.1 - Connection diagram of the secondary windings of a current transformer

The working (differential) winding has a number of turns of 35, with soldering points 0, 1, 2, 3 on one side and 32, 28, 24, 20, 16, 12, 8 on the other.

The first and second equalizing windings are made with soldering points 1, 2, 3, 4, 5, 6 on the one hand and with soldering points 0, 7, 14, 21, 28 on the other.

The secondary winding has no soldering.

The relay setpoint adjustment and ampere alignment in the differential protection arms are performed by changing the number of turns of the primary windings. The number of amperes turns of the RNT-565 relay is 100 A-turn.

In the event of short circuits between phases or single-phase earth faults on the star side of the power transformer, the balance of secondary currents of the current transformer is disturbed (the direction of currents in one of the groups of current transformers may also change), and a rather large current flows into the relay. The relay trips, turning off the transformer.

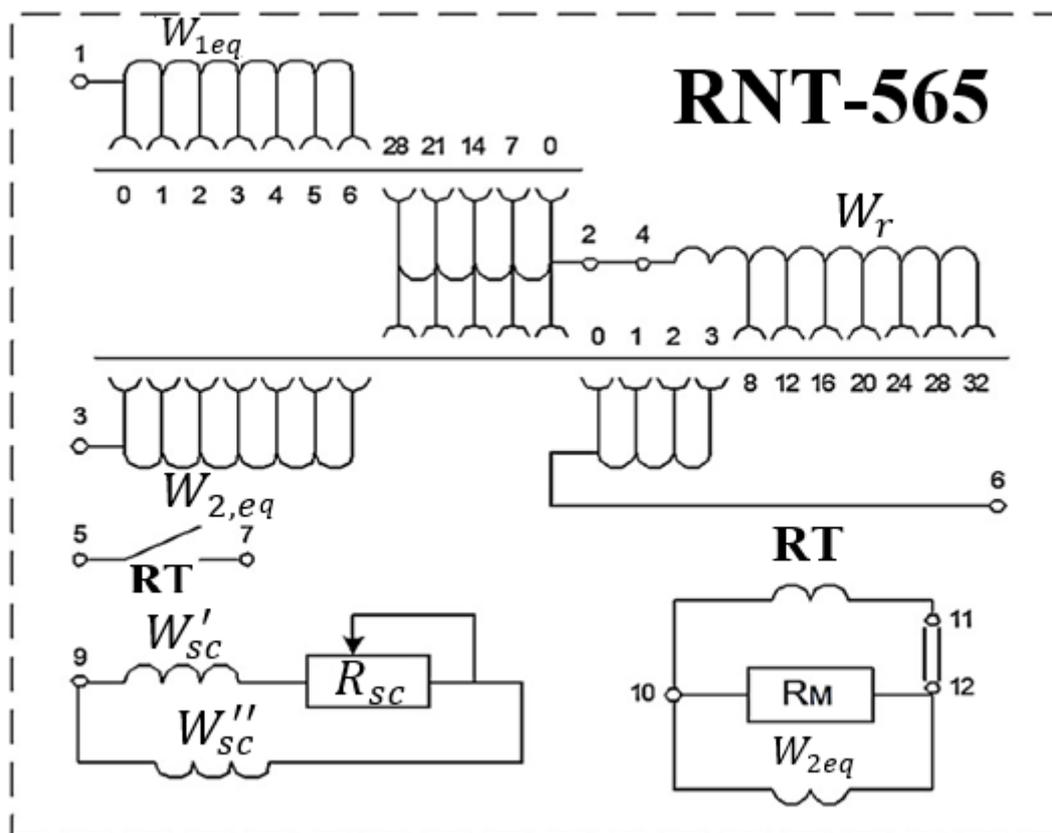


Figure 8.2 - Schematic diagram of the relay RNT-565

Correctness inclusion transformers current is checked in the normal mode by taking vector diagram in secondary current transformer circuits (i.e., currents i'_a, i'_b, i'_c and i_a, i_b, i_c). At correct switching on, the currents i'_a and i_a (and, accordingly, other phases) are opposite in direction, secondary currents circulate through the wires connecting the current transformers.

2. Investigate the differential protection of a power transformer. The laboratory setup includes:
 - two-winding power transformer (connection group) $\lambda/\Delta - \text{II}$;
 - six ITT-I current transformers (three on the power supply side and three on the transformer load side);
 - relay RNT-565 with a signal lamp;
 - three 5 A ammeters for measuring the current in the operating and two equalizing windings of the relay;
 - 5 A and 220 V wattmeter for taking vector diagrams;
 - mnemonic scheme with electrical outputs secondary windings of current transformers;
 - a panel with three lamps (transformer load).

8.3 Procedure for researching differential protection

1) Measure the secondary currents of both sides of the power transformer and draw their vector diagrams. To do this, assemble the protection circuit of the power transformer (Fig. 8.1) (current transformers are assembled in a "star" and "triangle" in advance, their leads are on the panel). The leads from each group of current transformers are connected to a single point (point m in Fig. 8.1) with a special six-ended conductor. The current winding of the wattmeter is connected to the line wires (alternately in each phase), the end of the winding is connected to the point m. The measurements were taken for i'_a, i'_b, i'_c and i_a, i_b, i_c . Summing up to the voltage windings of the wattmeter alternately linear voltages U_{AB}, U_{BC}, U_{CA} , determine current of each phase, with the terminal of the wattmeter voltage winding always connected to the first phase of the listed voltages. The measurement data are recorded in Table 8.1.

Table 8.1 - Measurement data

u/i	U_{AB}	U_{BC}	U_{CA}
i_a	60	-20	-40

2) Draw vector diagrams for both groups of transformers on graph paper and correct any errors in the wiring diagram. If the diagram is correctly drawn, the currents from the "triangle" side of the current transformers will be in opposite phase to the currents from the "star" side of the current transformers. An example of building a vector diagram is shown in Fig. 8.3.

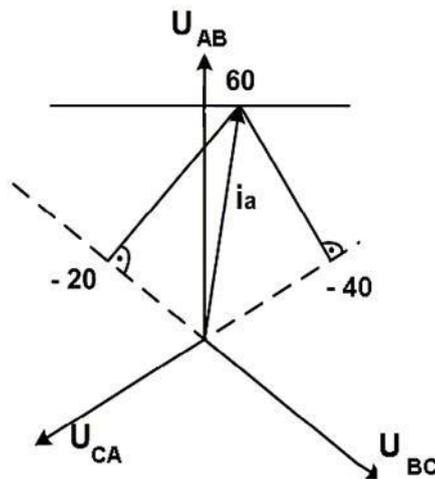


Figure 8.3 - An example of building a vector diagram for the current i_a

3) Assemble the differential protection circuit by connecting the RNT-565 relay to phase C (Fig. 8.3).

Under conditions of external three-phase short-circuit (performed in the presence of the head of classes) measure current unbalance in circuit differential protection, as well as

secondary currents of current transformers i'_c and i_c .

Protection activation condition

$$I_{sc} = k_{rel} \cdot I_{ub.max} \quad (8.1)$$

where k_{rel} is the reliability factor, assumed to be, 1.4-1.6.

The sum of the equalizing and working windings of one arm.

$$W_{1eq} + W_d = \frac{F_{pr}}{I_{sc}} \quad (8.2)$$

Moreover, $F_{pr} = 100A \cdot wind$, and $W_d = 20$ windings. According to I_{sc} , and measured by secondary currents (i'_c and i_c) to determine the number of turns of equalizing windings of the RNT-565 relay W_{1eq} and W_{2eq} . The choice is made in such a way that the magnetizing forces of the arms are equal.

$$(W_{1eq} + W_d) \cdot i'_c = (W_{2eq} + W_d) \cdot i_c, \quad (8.3)$$

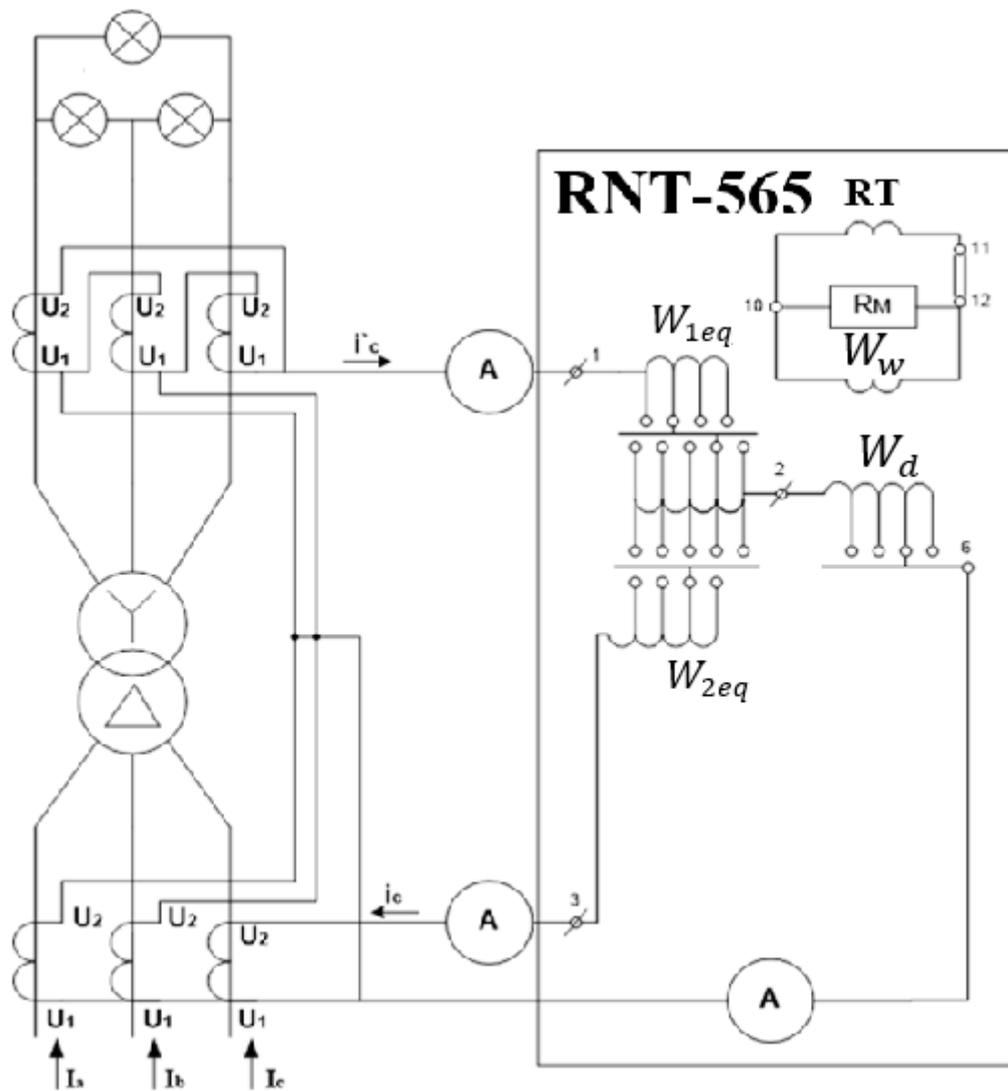


Figure 8.4 - Differential protection circuit of a power transformer

The obtained value W_{1eq} and W_{2eq} are set to the relay.

4) Check the operation of the differential protection in the transformer load mode for external and internal short circuits. Short circuits are performed only in the presence of the laboratory instructor.

8.4 Preparation of report

The work report must contain: a table of measurement results by wattmeter; vector diagrams of secondary currents of current transformers of both sides of the power transformer; a complete protection scheme for a two-winding transformer; results of calculation of the protection tripping current and the number of turns of equalizing windings.

8.5 Control questions

1. Does differential protection work in case of short circuits?
2. How is the transformation ratio of current transformers whose secondary windings are connected in a "triangle" selected?

3. Why are current transformers on the star side of a power transformer connected in a delta, and on delta side in star, and not vice versa?
4. How is the current selected in a transformer differential protection relay?
5. In what mode does the counter-phase of the currents of the secondary side of differential current transformers indicate the correctness of the differential protection circuit? How to properly turn on the current winding of a wattmeter when taking vector diagrams?

8.6 Recommended sources of information

1. Relay protection of electric power systems: Textbook. - Lviv: Lviv Polytechnic National University Press, 2013. - 533 p.
2. Relay protection and automation: Study guide / S. Panchenko, V. Blindyuk, V. Bazhenov and others; edited by V. Bazhenov - Kharkiv: UkrDUZT, 2021. - Part 2. - 276 p.
3. Kidyba VP, Shelepeten TM Protection of electric transmission lines. Lviv: Lviv Polytechnic National University Press, 2004. 185 c.
4. Kidiba VP, Shelepeten T. M. Protection of transformers and autotransformers. Lviv: Lviv Polytechnic National University Publishing House, 2004. 180 c.
5. Relay protection and automation in power supply systems / P.P. Govorov, G.A. Senderovich, V.F. Sokolov et al. Textbook - K.: IZMN, 1996. 288 c.