The Ministry of Education and Sciences of Ukraine

ZAPORIZHZHIA POLYTECHNIC NATIONAL UNIVERSITY

METHODICAL INSTRUCTIONS

for the laboratory works on the subject:
"Investigations and Testing of Electric and Electronic Apparatus"

for the students of the specialty:
141 – Electrical Power, Electrical and Electromechanical Engineering
(Educational program – **"Electric and Electronic Apparatus"**)

2020

Methodical instructions for the laboratory works on the subject: “Investigations and Testing of Electric and Electronic Apparatus” for the students of the specialty 141 – Electrical power, Electrical and Electromechanical engineering (educational program “Electric and Electronic Apparatus”)/ Compiled by O.V. Blyzniakov. – Zaporihzhzia: Zaporihzhzia Polytechnic National University, 2020. – 34 p.

Compiled by docent O. V. Blyznyakov.

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Approved at the meeting of the department
"Electric and Electronic Apparatuses".
Minutes No.2 dated September 7, 2020

Recommended for publication by
scientific-and-methodical commission
of Electrical Engineering Department.
Minutes No.1 of September 17, 2020

CONTENT

INTRODUCTION

Present-time engineering experience shows that a considerable part of engineers involved in the development, production or operation of electrical equipment deal with experimental investigations and testing of power electric and electronic apparatus. Therefore, present-time young engineers must not only be able to calculate and design power electric and electronic apparatus, but to have knowledge about technologies of their investigations and testing. By these causes, the curriculum for the second (master's) level of higher education of the educational program "Electric and Electronic Apparatuses" of the specialty 141 – Electrical Power, Electrical and Electromechanical Engineering includes the appropriate discipline "Investigations and Testing of Electric and Electronic Apparatus".

In particular, the proposed cycle of laboratory works is purposed not only to gain first experience of test equipment engineering, but also to improve the experience to use computer software for electric circuit simulation such as MathLab, Electronics Workbench and others.

Prior to perform the cycle of the laboratory works, students must be instructed as for the safety measures and the computer class regulations, and strictly adhere to the relevant rules when performing the laboratory work. Students who have not passed such instruction are not permitted to perform the laboratory works.

To perform each laboratory work successfully and timely, the student must qualitatively prepare for it beyond the scheduled study. During the preparation, the student should study theoretical basis, to have read the methodical instructions as for the laboratory work subject, as well as to construct a simulating circuit according to the task.

Just after the beginning of the scheduled study, the simulating circuit should be agreed with the teacher, which supervises laboratory works. Once the laboratory work has been performed, the student must agree his findings with the teacher. The findings of the laboratory work must be presented as report performed in compliance with requirements of ДСТУ 3008: 2015.

1. LABORATORY WORK №1. STUDY OF SIMULATED MEASURING CIRCUIT

Duration of scheduled study is 4 hours

1.1 Purpose of the work

The purpose of the laboratory work is to derive practical experience of simulating measuring circuits, as well as research basic characteristics of measuring circuit model with capacitive-resistive voltage divider.

1.2 Subject of study

When performing experimental research, testing, technical diagnosing, repair of electric and electronic apparatus, it is often required to measure voltages of different magnitudes. An experience shows that high voltage measurements are the most difficult problem, when special measuring converters (transducers) are necessarily used. One of the most extensively used measuring transducers in high voltage testing laboratories is voltage divider [4–7, 12, 17–20].

The *voltage* or *potential divider* (*VD*) is a scale-type measuring transducer that proportionally reduces the voltage being measured. The main requirement imposed upon voltage divider is the constancy of the conversion factor (*division ratio*) expressed as follows:

$$n = \frac{U_1}{U_2},$$

where U_1 is the voltage to be measured ;

U_2 is the output voltage of the VD.

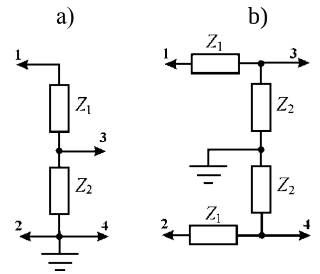

Figure 1.1 – Variations of voltage dividers: a) one-arm; b) two-arm

Basic shortcoming of measuring circuits were VD is applied is the galvanic couple between the recording instrument and the object being investigated, so one of the points of the measuring circuit must be grounded. If the object being investigated has grounded terminal, then one-arm VD, shown in Figure 1.1a, is used in the measuring circuit. If the object has no grounded terminals, then a double-arm VD, illustrated by Figure 1.1b, is used. The voltage divider consists of low voltage arm Z_2 that is connected to recording instrument (terminals 3–4) and high voltage arm Z_1 that is connected to the object to be investigated (terminals 1–2).

There are the following types of voltage dividers for high voltage measurements according to the arm structure:

- *resistive* or *ohmic dividers* that are used mainly for dc and ac voltage measurements at relatively low frequencies;
- *capacitive dividers* that are used for high frequency voltage measurements;
- *resistive-capacitive dividers* that are extensively used for HV measurements in wide frequency range; they are most frequently applied to perform switching and other testing of electric and electronic apparatus.

The measuring circuit with resistive-capacitive VD is illustrated in Figure 1.2, where R_1, R_2, C_1, C_2 are the parameters of the VD; r_1, r_2 are damping resistors serving to limit currents under voltage chopping; $Z_л$ is the surge impedance of the measuring signal transmission line expressed as:

$$Z_л = \sqrt{L_0 / C_0}\ ,$$

where L_0 and C_0 are the running inductance and capacitance of the line.

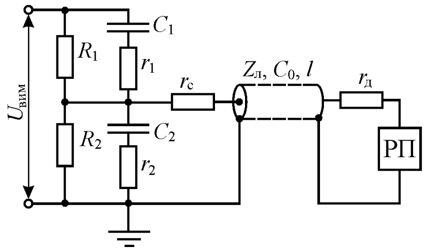

Figure 1.2 – Measuring circuit with capacitive-resistive voltage divider

The circuit also includes so-called *matching resistor* r_c serving to preclude distortion of the measuring signal.

The qualities of the measuring circuit to transmit measuring signal are featured with frequency characteristics: *amplitude response* and *phase response*, as well as *transient function* defined by its *unit step response* after a step-voltage input. Most typical response behaviors are aperiodic (frontal smoothing) and oscillating (voltage overshoots).

The VD parameters are quantified basing upon predetermined division ratio from the following relationship:

$$n = \frac{C_2}{C_1} = \frac{R_1}{R_2} = \frac{r_1}{r_2}\ .$$

Resistance of the low-voltage arm R_2 should be at least two orders of magnitude greater than the surge impedance of transmission line $Z_л$. Its capacitance should be 50–100 times larger than the total capacitance of the line $C_л = C_0 l$. The resistance of the damping resistor r_2 is selected so that at least two orders less than the surge impedance of the transmission line $Z_л$.

1.3 Task

1.3.1 According to the initial data, calculate the parameters of the measuring circuit with capacitive-resistive VD.

1.3.2 To construct the computer-aided measuring circuit including capacitive-resistive VD.

1.3.3 To measure the amplitude and phase responses of the simulated measuring circuit.

1.3.4 Determine the unit step response of the simulated measuring circuit.

1.3.5 To draw conclusions about the work.

1.4 Procedure for the work execution

1.4.1 Calculations of the simulated measuring circuit parameters should be performed as per the relationships represented in subsection 1.2 or in the references [4–7, 12, 17–20]. The initial data for the measuring circuit are represented in Table 1.1.

1.4.2 Item 1.3.2 of the task should be performed with the help of the computer circuit simulation software „Electronics Workbench" [9].

The measuring signal transmission line is simulated by the element "Transmission line" with corresponding parameters: delay time *TD* and surge impedance $Z_л$. The relationship between these parameters is expressed as follows:

$$TD = Z_л C_0 l ,$$

where *l* is the line length, m.

1.4.3 The task item 1.3.3 is performed in the following order:

a) connect the element „ac voltage source" with any parameters to the input of the simulated measuring circuit;

b) connect the element "Bode Plotter" to input and output of the measuring circuit and set required mode of its operation (amplitude or phase response) and range of measurement keeping in mind that amplification factor in this case is reciprocal of division ratio: $\kappa_П = 1/n$;

c) print resulting characteristics and paste their into the report.

Table 1.1 – Initial data to determine the simulating circuit parameters

Numbers of variants	**Division ratio of VD**	**Length of line, m**	**Surge impedance of line, Ohm**	**Running capacitance of line, pF/m**
1	100	45	300	100
2		10	50	100
3		75	225	34
4	200	25	100	50
5		15	250	50
6		75	225	34
7	500	10	50	100
8		20	150	34
9		75	225	34
10	1000	25	100	50
11		50	175	25
12		75	225	34
13	2000	25	100	50
14		55	200	25
15		75	225	34
16	5000	35	275	68
17		100	75	68
18		250	125	34
19	10000	35	275	68
20		100	75	68
21		250	125	34

1.4.4 Item 1.3.4 is performed in the following order:

a) connect the virtual element “dc voltage source” to the circuit input and set the power voltage equal to 100 V;

b) connect the virtual element “Oscilloscope” to the input and output of the measuring circuit;

c) to investigate the simulated measuring circuit in transient conditions; determine its unit step response after a step-voltage input;

d) print the found transient curve of output voltage and paste it into the report.

1.4.5 The laboratory work report must contain:

a) name, purpose of the work and task;

b) the simulated measuring circuit;

c) frequency response characteristics of the simulated measuring circuit;

d) the time diagram with response of the simulated measuring circuit on step-voltage unit;

e) conclusions on the work.

1.5 Self-check questions

1.5.1 What measuring transducers to measure high voltages are used?

1.5.2 What principle of high voltage measurements with sphere gap voltmeters is used?

1.5.3 Why voltage transformers are unsuitable to measure impulse high voltages?

1.5.4 What is a voltage divider and what parameters it is characterized?

1.5.5 What does components a measuring circuit with VD includes?

1.5.6 What types of VDs exist and what is their scope?

1.5.7 What characteristics determine the transmission properties of a measuring circuit?

1.5.8 How is the response of the measuring circuit to the rectangular voltage pulse determined?

2. LABORATORY WORK № 2. **STUDY OF SIMULATED HIGH VOLTAGE IMPULSE GENERATOR**

Duration of scheduled laboratory study is 4 hours

2.1 Purpose of the work

The laboratory work is aimed to study operation and circuit designs of HV impulse generators, as well as to gain practical experience to simulate and adjust the generator of lightning and switching impulses.

2.2 Subject of study

It is known that when a high voltage apparatus is operated, its insulating structures are permanently stressed by the nominal (maximal operating) voltage, as well as the momentary lightning and switching overvoltages. Lightning overvoltages occur usually in power transmission lines as a result of lightning strokes. Switching overvoltages are usually occurred with switching operations in power systems. That is why the insulation of high-voltage apparatus undergo both power frequency and impulse (lightning and switching) withstand voltage testing [1, 4, 7, 8, 12–14, 17–23].

Lightning impulse withstand voltage or *basic impulse level* (*BIL*) (full wave) is the test voltage with waveform illustrated by Figure 2.1.

BIL (full wave) is specified by the following parameters:

- the *test voltage magnitude* corresponding to the wave crest (point F);
- *front time* T_{front} is the time interval between the conventional start of the impulse (point O_1) and the time moment corresponding to the intersection point of the prolonged line segment (section AB) with the axis corresponding to the test voltage (point O_2);
- *time to half* or *tail time* T_{half} defined as the time interval between the conventional start of the impulse (point O_1) and time moment corresponding to its half value on the impulse falling section (point D).

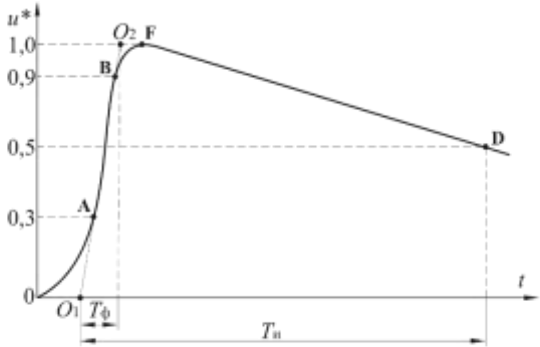

Figure 2.1 – Waveform and parameters of BIL (full wave)

The standard BIL (full wave) is designated in the following manner: **1.2/50**, where the first value means that $T_{front} = 1.2\ \mu s$**,** the second one is $T_{half} = 50\ \mu s$.

Along with full wave, BIL (chopped waves) are applied for testing apparatus windings. There exist front and tail chopped waves shown in Figure 2.2a and 2.2b, respectively. They are also specified by the parameter called *time-to-chop* T_c.

a) b)

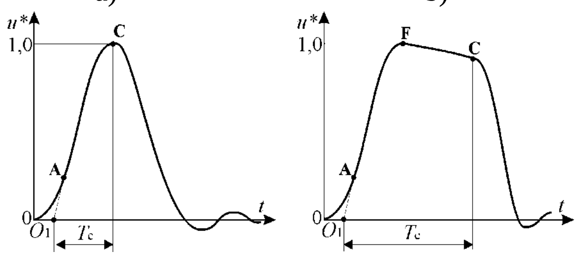

Figure 2.2 – Wave-forms and parameters of BIL (chopped waves):
a) front chopped; b) tail chopped

The *switching impulse* is a test voltage whose waveform can be aperiodic, Figure 2.3a or oscillating, Figure 2.3b.

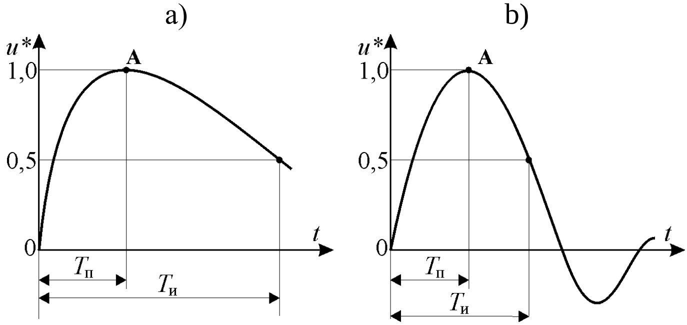

Figure 2.3 – Wave-forms and parameters of switching impulses:
a) aperiodic; b) oscillating

Switching impulses are specified by the *time-to-peak* T_{peak} and *time-to-half* T_{half}. The magnitude of the test voltage of switching impulses corresponds to its maximal instantaneous value (point A). The standard aperiodic switching impulse 250/2500 ($T_{\text{peak}} = 250\,\mu\text{s}$; $T_{\text{half}} = 2500\,\mu\text{s}$) is used for testing internal and external insulation of almost all HV equipment of 330 kV and above. For testing internal insulation of gas-filled apparatus, the oscillating switching impulse 4000/7500 is used.

Impulse voltages are generated by so-called *high voltage impulse generators* (*HVIG*). It is capacitor system that is pre-charged during relatively long term, and then, very rapidly discharged to the load (test object) [4, 7, 8, 12, 17-20]. HVIGs adjusted for generation of switching impulses are commonly called *system overvoltage generators*. Their basic shortcomings are low utilization rate, as well as great extent of readjustment when changing the impulse parameters or its type. Therefore, frequently enough for this purpose test transformer fed from a capacitor bank via inductance is used.

2.3 Description of the simulated circuit under study

The real HVIG circuits can be represented as typical equivalent circuit illustrated by Figure 2.4, where C_1 is the capacitance "in strike", C_2 is the capacitance at the output of the generator, R_2 is the resistance defining tail time of the impulse, R_1 is the resistance defining its front time, $L_п$ is the inductance of the "discharging loop".

The voltage across C_2 is generally determined as follows [8]:

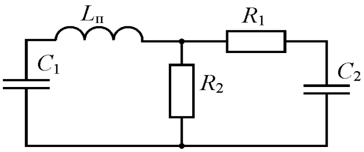

Figure 2.4 – Equivalent discharge circuit of a HV impulse generator.

$$U_2 = \eta U_1(0)\left(e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}}\right), \qquad (2.1)$$

where $U_1(0)$ is the voltage across capacitance C_1 prior to discharging or its charging voltage;

η is the coefficient taking into account the decrease in impulse voltage crest in relation to the voltage $U_1(0)$; for this circuit it can be practically always determined as follows:

$$\eta = \frac{C_1}{C_1 + C_2}; \qquad (2.2)$$

τ_1 and τ_2 are the time constants defined by the circuit parameters:

$$\tau_1 = R_2(C_1 + C_2); \quad \tau_2 = \frac{C_1 C_2}{C_1 + C_2} R_1. \qquad (2.3)$$

Their values for lightning impulses may be previously found from the following expressions:

$$T_{\text{front}} = \left(3{,}15 - 6{,}7\frac{T_{\text{front}}}{T_{\text{half}}}\right) \cdot \tau_2; \quad T_{\text{front}} = \left(0{,}7 + 1{,}7\frac{T_{\text{front}}}{T_{\text{half}}}\right) \cdot \tau_1. \qquad (2.4)$$

For switching impulses:

$$T_{\text{peak}} = \frac{\tau_1 \tau_2}{\tau_1 - \tau_2} \cdot \ln\frac{\tau_1}{\tau_2}; \quad T_{\text{half}} = \tau_1 \cdot \ln\left(\frac{2}{\eta}\right), \text{ when } T_{\text{half}} \le 10T_{\text{peak}}. \qquad (2.5)$$

When $T_{\text{half}} > 10T_{\text{peak}}$, this parameter is determined according to (2.4).

2.4 Task

2.4.1 Study the operation of HVIG.

2.4.2 Draw up a simulating circuit for HVIG.

2.4.3 Calculate the parameters of the lightning impulse generator components and construct the simulating circuit with the help of computer technologies.

2.4.4 Adjust the simulating circuit according to the predetermined parameters of lightning impulse.

2.4.5 Calculate the parameters of the switching impulse generator components and readjust the simulating circuit according to the predetermined switching impulse parameters.

2.4.6 Draw the conclusions on the laboratory work.

2.5 Procedure for the work execution

2.5.1 To study the operation of HVIG, use lection texts, subsection 2.2 of the methodical instructions or corresponding references [4, 8, 12, 17–20].

2.5.2 Simulation of HVIG is virtually performed with the help of computer circuit simulation software “Electronics Workbench” [8].

2.5.3 Aside from discharge subcircuit (see Figure 2.4), the simulating circuit of the HVIG must contain:

a) a charge subcircuit with dc voltage source $U_1(0)$ and limiting resistor with resistance 1 kOhm; charging voltage $U_1(0)$ is determined as

$$U_1(0) = \frac{U_{2\max}}{\eta};$$

b) switch to provide change over the capacitor C_1 from charge to discharge operation; its capacitance is accepted in the range $(5\ldots15)\cdot C_2$;.

c) recording instrument (oscilloscope) to record the charge process of the capacitor C_1 and measure impulse voltage parameters.

2.5.4 Another parameters of the simulating circuit components are calculated using the expressions represented in subsection 2.3 or in corresponding references [4, 8, 12, 17–20]. Predetermined ratings of the circuit are represented in table 2.1.

2.5.5 Simulating circuit of the HVIG is adjusted by variation of the circuit components R_1 and R_2 so that the parameters of the impulse to be measured comply with predetermined ones, such as:

a) test voltage $U_{test} = U_{2\max}$, front time T_{front} and tail time T_{half} for the lightning impulse generator;

b) test voltage $U_{test} = U_{2\max}$, time-to-peak T_{peak} and time-to-half T_{half} for the switching impulse generator

2.5.6 Derived impulse voltage time diagrams should be printed and pasted into the report.

2.5.7 Report on the laboratory should contain:

a) name and purpose of the work;

b) equivalent simulating circuit and calculations of their parameters;

c) derived impulse voltage time diagrams;

d) conclusions on the work.

2.6 Self-check questions

2.6.1 What types of test voltages are used to test the insulation of electrical apparatus?

Table 2.1 – Ratings of the HV impulse generator

№ var.	**Test voltage U_{2max}, кВ**	**Capacitance at the output of HVIG C_2, пФ**	**Designation of lightning impulse**	**Designation of switching impulse**	**Inductance of “discharge loop”, $L_п$, мГн**
1	1100	650	1,8/55	4000/7500	65
2		1200	1,5/40	100/2500	100
3		1500	1,2/50	250/2500	150
4	1150	400	2,0/60	500/2500	100
5		650	1,8/55	4000/7500	65
6		1000	2,2/45	2000/5000	70
7	1500	650	1,8/55	4000/7500	65
8		1200	1,5/40	100/2500	100
9		1500	1,2/50	250/2500	150
10	1600	800	1,5/40	100/2500	70
11		1200	1,5/40	100/2500	100
12		1500	1,2/50	250/2500	150
13	2100	800	1,5/40	100/2500	70
14		1500	1,2/50	250/2500	150
15		2000	1,2/50	250/2500	75
16	2400	800	1,5/40	100/2500	70
17		2000	1,2/50	250/2500	75
18		3000	2,0/60	500/2500	80
19	2900	2000	1,2/50	250/2500	75
20		2800	1,8/55	4000/7500	90
21		3500	2,5/75	1000/50000	85

2.6.2Why impulse voltage is used to test the insulation of electrical apparatus?

2.6.3 What types of impulse voltages are used to test the insulation of electrical apparatus?

2.6.4 Name and characterize the basic parameters of lightning (switching) impulse.

2.6.5 How does HVIG operate?

2.6.6 How does the multi-stage HVIG operate?

2.6.7 How do the parameters of HVIG particular components influence the impulse voltage parameters?

3. LABORATORY WORK №3. STUDY OF SIMULATED SHORT-CIRCUIT GENERATOR

Duration of scheduled laboratory study is 4 hours

3.1 Purpose of the work

The purpose of the laboratory work is to study operation and take practical experience of simulation and adjustment of short-circuit generators.

3.2 Subject of study

Switching tests of switching devices (manly circuit-breakers) frequently necessitate generation of short-circuit currents. Such testing are usually carried out in specially equipped *high power laboratories* [2–4, 12]. With increase of voltage ratings and short-circuit currents required to interrupt the tests become more and more problematic due to lack of sufficient power at the test facilities. To build the test setups for high powers is not economically feasible, because first great investments numbered in millions and even tens millions dollars are required, and secondly, switching devices (circuit-breakers) with high switching capability are manufactured in very small series.

This problem is solved by application of two test methods for high-voltage circuit-breakers direct and indirect.

Direct test method is used in the case when the supply source power is sufficient to provide required power to be switched for the breaker. In this case three phase circuit-breaker is tested on a three phase circuit at full current and full voltage. If the power of supply is not sufficient to perform direct test, so-called indirect test is performed.

There are some indirect test methods. It is, first, *single phase tests*, when only one pole of the breaker undergoes the test under full power to be switched by the breaker pole. Another indirect test method is so-called *unit tests* that are the variation of single phase tests. Such tests are suitable for ultra-high-voltage breakers having a several identical interrupters in series on each pole. The third variation of indirect test methods is so-called *two part test* that consists of two essentially independent tests. The first test is one where the interrupter is tested at full rated voltage and at a reduced current. In the second test the maximum current is applied at a reduced voltage. And finally, the most extensively used indirect test method is so-called *synthetic test*. It is essentially a two part test that is done all at once. The test is performed with application of so-called *synthetic circuit* combining a moderate voltage source which supplies the full primary short circuit current (short-circuit generator) with a second, high voltage, low current, power source which injects a high frequency, high voltage pulse at a precise time near the natural current zero of the primary high current [3, 12, 21].

Short-circuit generator is the most important component of testing circuit for switching tests. It is for the most part one of variation of energy storages, such as, capacitive, inductive, mechanical and chemical as well as theirs various compositions. In a *capacitive storage* the energy is accumulated in capacitor bank as electrostatic field energy. Storage process occurs here in charging capacitors from low-power rectifier, and then discharge is initiated by connection to load via switches (mainly arresters). In performing switching tests of HV circuit-breakers *mechanical storages* (*impact-excited generators*) made as special purpose three-phase turbo-generators are extensively used. At last time *inductive energy storages* are coming into use in short-circuit generators. Here energy storage occurs in charging inductive coil from dc power source.

As recovery voltage source either step up transformer supplied from current source of synthetic circuit or oscillating circuit adjusted to recovery voltage frequency are used in synthetic circuits.

3.3 Description of the simulated circuit under study

It is generally recognized that the testing conditions most closely corresponding to the actual ones are simulated in the case the current subcircuit of the synthetic circuit is supplied from impact-excited generator. However, due to their high cost and investments, an oscillating circuit is extensively enough used as the current source as illustrated by Figure 3.1.

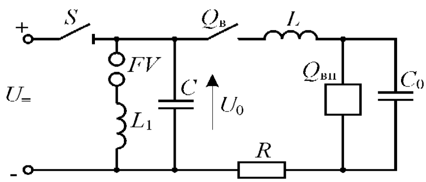

Figure 3.1 – Circuit diagram of oscillating circuit

In the circuit, the capacitor bank *C* is pre-charged up to the value corresponding to the power frequency recovery voltage amplitude from rectifying installation of moderate power during relatively long time (usually a few minutes). Once the charging process is completed, it is disabled from the charging subcircuit with disconnector *S*. In testing process, auxiliary breaker $Q_в$ is closed and the capacitor bank *C* is started to discharge into the breaker being tested $Q_{вп}$ via the reactor *L*. At this moment gradually decaying sine current starts to flow in the circuit:

$$i = I_{\text{m}} e^{-\frac{R}{L}t} \sin \omega t \ ,$$

where R is the pure resistance of the oscillating circuit.

Keeping in mind that value of R is actually very low, the angle frequency of the current flowing through the oscillating circuit will be

$$\omega = 2\pi f = \frac{1}{\sqrt{LC}} \ .$$

Parameters of the oscillating circuit are reasonably picked so that the frequency f is equal to the power network frequency (50 or 60 Hz). The peak value of the current through the circuit will be

$$I_{\text{m}} = \frac{U_0}{\omega L} \ .$$

Once the arc between the contacts of the test breaker extinguishes, the voltage starts to recovery across the breaker contacts that is quantified by the following expression:

$$u_{\text{в}} = U_{\text{m}} \frac{C}{C + C_0} \left(1 - \cos \omega_0 t\right),$$

where C_0 is the capacitance of the capacitor bank providing the required frequency of TRV; it is selected according to the following expression:

$$f_0 = \frac{1}{2\pi\sqrt{LC_0}} \ ,$$

which, in turn, must comply with specified value of the rate of rise of TRV.

At the current-zero instant the arrester *FV* is triggered and the reactor $L_1 = L$ is connected across the capacitor bank C. It results in the TRV curve will have two components: a power frequency component and high frequency component (fundamental frequency of the oscillating TRV).

3.4 Task

3.4.1 To study the operation of actual circuits of short-circuit generators with capacitive (oscillatory circuit) and inductive storages.

3.4.2 Draw up the simulating circuit of short-circuit generators with capacitive (oscillating circuit) and inductive storages.

3.4.3 Calculate the parameters of the circuit components and construct the simulating circuits of short-circuit generators with the help of PC.

3.4.4 Adjust the simulating circuits according to predetermined parameters.

3.4.5 Draw conclusions on the laboratory work.

3.5 Procedure for the work execution

3.5.1 To study the operation of actual circuits of short-circuit generators using the lection texts, information represented in subsection 3.3 of the methodical instructions, as well as related literature [3, 12, 21].

3.5.2 The simulating circuit of short-circuit generator with capacitive storage must contain:

a) charging subcircuit with dc voltage source U_0 and charging limiting resistor by resistance 10 Ohms;

b) a switch providing changeover of pre-charged capacitor C onto the discharging subcircuit of the short-circuit generator;

c) recording instrument (oscilloscope) to control the charging process of the short-circuit generator condenser and to measure the parameters of the current impulse obtained.

3.5.3 The parameters of the simulating circuits are calculated according to the expressions represented in subsection 3.3 or in [3, 12]. The initial data are predetermined by table 3.1 according to the variant specified by the teacher.

3.5.4 Adjustment of the simulating circuit is performed by variation of the simulating circuit parameters: L, C and C_0. It is necessary that the parameters of the current impulse derived comply with predetermined ones (see table 3.1).

3.5.5 Derived time diagrams of short-circuit current impulse should be represented into the laboratory work report.

3.5.6 Report on the laboratory work should contain:

a) name and purpose of the work, as well as task on the work;

b) equivalent simulating circuit and calculations of its parameters;

c) obtained time diagrams of the short-circuit current impulse;

d) conclusions on the work.

3.6 Self-check questions

3.6.1 What is the main problem of HV circuit-breakers switching tests?

3.6.2 What methods of switching tests are used for testing high-voltage circuit breakers?

3.6.3 How synthetic circuits function?

3.6.4 What equipment are used in switching tests of high-voltage circuit breakers?

3.6.4 What is purpose of short-circuit generators?

Table 3.1 – Initial data for finding the parameters for the simulating circuits of the short-circuit generator

№№ of var.	**Power frequency recovery voltage, U_0, кВ**	**Current being interrupted (peak value) I_m, кА**	**Power frequency, f, Гц**	**TRV frequency, f_0, кГц**
1	4,9	14,1	50	5
2		22,6	50	10
3	8,165	18,2	50	8
4		28,5	50	12
5	16,33	22,6	50	10
6		58,2	60	40
7	28,6	28,5	50	12
8		60,5	60	55
9	89,8	32,6	50	15
10		75,0	60	75
11	179,63	35,9	50	18
12		52,6	60	32
13	269,44	42,4	60	22
14		52,6	60	32
15	408,25	48,6	60	25
16		60,5	60	55
17	612,37	52,6	60	32
18		75,0	60	75
19	918,56	52,6	60	32
20		60,5	60	55
21		75,0	60	75

3.6.5 Name and feature the basic types of energy storages.

3.6.6 How oscillating circuit operates in switching test process?

3.6.7 How do the parameters of the particular components of short-circuit generator affect the parameters of current impulse.

4. LABORATORY WORK №4. **STUDY OF SIMULATED TESTING CIRCUIT**

Duration of scheduled laboratory study is 4 hours

4.1 Purpose of the work

The purpose of the laboratory work is to take practical experience as for simulation and adjustment of the testing circuit for switching capability tests of low voltage apparatus.

4.2 Subject of study

The switching capability of the apparatus (switching device) is its ability to perform a predetermined number of switching (make-break) operations at the predetermined parameters of the circuit to be switched, saving its operability. In order to perform the switching capability test the so-called *test circuit* is usually used. It must ensure the switching conditions as close as possible to conditions taking place in an actual power system [2, 12, 16].

The main parameters of the test circuit that ensure equivalent conditions for the switching tests are the magnitude of the current to be switched, its electromagnetic time constant and the recovery voltage parameters, which must comply with the normalized ones. For low voltage control apparatus, such as contactors, magnetic starters etc., as per [2, 12, 16] the parameters of the circuit to be switched is specified by *switching duty* and *utilization category* of the apparatus.

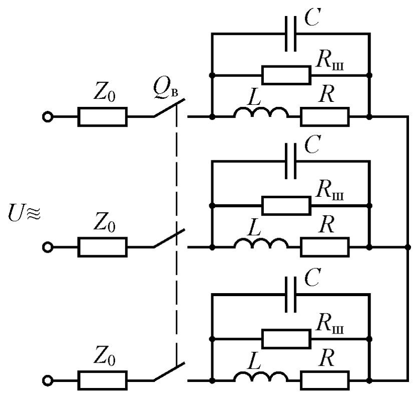

Figure 4.1 – Test circuit for the switching conditions of load and overload currents

Full test circuit for switching conditions of load and overload currents is represented in Figure 4.1. In the circuit, the parameters *L*, *R*, *C*, $R_ш$ provide the specified parameters of the test circuit; $Z_о$ is a limiting resistor inserted upstream of the switching device being tested $Q_в$.

The magnitude of the inductance *L* and the resistance *R* (keeping in mind the impedance $Z_о$) are defined by the current being switched and the power factor at the predetermined rated voltage of the apparatus. Hence, the total inductance and pure resistance of the test circuit are determined as follows:

$$R_к = \frac{U_н}{\sqrt{3} \cdot I_0} \cdot \cos\varphi_0; \quad L_к = \frac{U_н}{\sqrt{3}\omega I_0}\sqrt{1-\cos^2\varphi_0},$$

where I_0 is rms value of the current being switched ;

$U_н$ is the rated supply line-to-line voltage;

$cos\varphi_0$ is the power factor of the circuit being switched.

The recovery voltage across the contacts of the switching device under study is specified by two quantities: fundamental frequency f_0 and peak factor κ_a. They are picked according to the value of the current being switched and power frequency recovery voltage from empirical formulas [2, 12, 16]:

$$f_0 = A_0 \cdot I_0^{0,2} \cdot U_0^{-0,8} \pm 10 \text{ кГц}$$

$$\kappa_a = B_0 + C_0 \cdot \exp\left(-0{,}016 A_0 \cdot I_0^{0,2} \cdot U_0^{-0,8}\right) \pm 0{,}05.$$

For “heavy” duties: $A_0 = 2600; B_0 = 1.15; C_0 = 0.5$.

For “easy” duties: $A_0 = 2000; B_0 = 1.1; C_0 = 0.4$.

The values of $R_ш$ and C for the test circuit can be approximately evaluated by the following formulas:

$$R_ш = \frac{0{,}4(4\pi^2 + m^2) f_0 L}{m}, \text{ Ом}. \quad C = \frac{1{,}4}{4(\pi^2 + m^2) f_0 L}, \text{ Ф},$$

where $m = 2\ln\left(\frac{1}{\kappa_а - 1}\right)$; $U_0 = \sqrt{\frac{3}{2}} \cdot U_н$.

4.3 Task

4.3.1 Calculate the parameters of the test circuit R, L, f_0, $\kappa_а$, $R_ш$ and C basing upon the initial data.

4.3.2 Construct a virtual test circuit with the use of PC.

4.3.3 Check out the constructed virtual test circuit in respect to the interrupted current and the power factor.

4.3.4 Check out the constructed virtual test circuit in respect to transient recovery voltage.

4.3.5 Draw conclusions on the work findings.

4.4 Procedure for the work execution

4.4.1 Calculate the parameters of the simulating test circuit according to the expressions given in subsection 4.2 or references [2, 12, 16]. The initial data are taken from Table 4.1 according to the variant specified by the teacher. Impedance $Z_о$ is accepted equal to zero.

4.4.2 Item 4.3.2 is performed with the help of computer simulation software „Electronics Workbench” [9].

4.4.3 Item 4.3.3 is performed in the following order:

a) research the virtual test circuit in steady state conditions and determine the currents in the lines, as well as the phase shift between the current and phase voltage;

Table 4.1 – Initial data for finding the simulating circuit parameters

№№ of variants	**Rated voltage, V**	**Utilization category**	**Power factor of the circuit being switched, cosφ**	**Rated operating current, A**	**Current being switched**
1	660	AC-4	0.35	25	$8I_{нр}$
2	660	AC-2	0.65	100	$4I_{нр}$
3	660	AC-1	0.95	400	$1.5I_{нр}$
4	380	AC-3	0.35	160	$6I_{нр}$
5	380	AC-3	0.65	630	$1.5I_{нр}$
6	380	AC-1	0.95	630	$8I_{нр}$
7	660	AC-4	0.35	10	$8I_{нр}$
8	660	AC-2	0.65	16	$4I_{нр}$
9	660	AC-1	0.95	320	$1.5I_{нр}$
10	380	AC-3	0.35	250	$6I_{нр}$
11	380	AC-3	0.65	160	$1.5I_{нр}$
12	380	AC-1	0.95	100	$8I_{нр}$

a) compare these values with predetermined ones and correct the parameters of the virtual test circuit to coincide with the initial data.

4.4.4 Item 4.3.4 is performed in the following order:

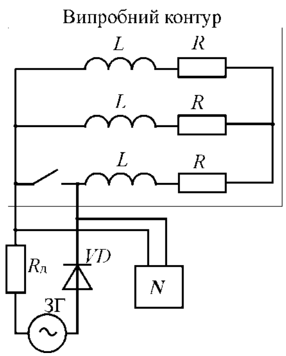

Figure 4.2 – Circuit for adjustment of surge parameters

a) disconnect the virtual test circuit from three-phase voltage source and connect it to high-frequency voltage source according to Figure 4.2;

b) adjust the working frequency of the source according to the magnitude of the current being interrupted: 2 kHz at $I_0 \le 1000\,\text{A}$ or 4 kHz at $I_0 \ge 1000\,\text{A}$;

c) the resistance $R_д$ is determined from the following relationship:

$$R_д \ge 10\sqrt{R^2 + (\omega L)^2}\ ,$$

where ω=2π*f* is the angular frequency of the power source;

d) the amplitude of the working current is selected from the equality of derivatives at current zeros that is equivalent to the following relationship:

$$I_0 f_0 = If\ ,$$

where I_0, f_0 are the current to be interrupted and its frequency, respectively;

I, *f* are the current and frequency of HF source, respectively;

e) research the virtual test circuit in steady state conditions and determine the frequency and peak factor of the transient recovery voltage; if it is required, correct obtained findings by the variation of the test circuit parameters: $R_{ш}$ and *C*;

f) print the derived findings and paste their into the report.

4.4.5 The laboratory work report should contain:

a) the name and purpose of the work, as well as the task;

b) the virtual test circuit under study;

c) time diagrams of checking the test circuit in respect to the circuit current and recovery voltage parameters;

d) conclusions on the work.

4.5 Self-check questions

4.5.1 What is the switching capability of a switching device?

4.5.2 What is the purpose to perform switching ability tests of a switching device?

4.5.3 What is the point of the test circuit adjustment?

4.5.4 Explain the purpose of particular components of the test circuit for switching tests (see Fig. 4.1)?

4.5.5 How are the test circuit parameters determined?

4.5.6 What is synthetic circuit?

4.5.7 What are the methods of adjustment of circuit wave parameters?

5. LABORATORY WORK №5. **ELECTROMECHANICAL TESTING OF ON-LOAD TAP-CHANGER**

Duration of scheduled laboratory study is 4 hours

5.1 Purpose of the work

The purpose of the laboratory work is to study the program and procedure of electromechanical testing of on-load tap-changer, as well as to gain practical experience to measure the circular and time diagrams of its contacts and mechanisms.

5.2 Subject of study

The power transformer on-load tap-changer (OLTC) is a complex electromechanical device that contains a number of mechanisms and contacts having different functional purpose and operate in strictly specified sequence [10]. The main purpose of electromechanical testing of OLTC is to verify the functioning of its mechanisms and contact systems, as well as the correct sequence of their operation [1, 23].

There are following verifications executed in the process of electromechanical testing:

1. Contact pressures (loads) of the selector and diverter contacts.
2. Resistances and voltage drops across current-carrying systems of the selector and diverter (transition impedance test).
3. Torques on the driving mechanism shaft, as well as the individual components of the tap-changer (mechanical test).
4. Correctness of the driving mechanism functioning.
5. Operating sequence of the contacts and mechanisms (sequence test).

One of the most important verifications carried out during electromechanical testing is to verify the operating sequence of contacts and mechanisms, since its correctness is one of the main factors of the correct and reliable operation of the OLTC and the power transformer as whole.

The operating sequence of the OLTC contacts are verified by the measurement of the contacts operating diagrams named also *all-round* and *time diagrams* of the OLTC contacts operation. During the type tests, a all-round diagram of a selector and time diagram of a diverter are measured on a test bay.

5.3 Description of the test installation

The object for testing (OLTC of the type PHTA-35/125) represents two modules: tap switching device, containing a tap selector and diverter switch, and a motor-drive mechanism, containing electric motor with reduction gear and control and protection switchgear that mounted within a metal case. The motor-drive mechanism provides the possibility to change of the device from one position to another manually by the handle and by the motor.

In the measurement process of all-round diagram of the tap selector contacts, the changeover operation is carried out manually using the method of signaling lamps. For this purpose the electric circuit shown in Figure 5.1a is used. It is supplied from 24 V ac power source and includes OLTC being tested and signaling lamps HL1 and HL2. The close and open moments of the tap selector contacts S1 and S2 are indicated by the ignition and quenching the lamps. At the actuation moment of the diverter mechanism, a short-term change in the lamps glow occurs.

The time diagram of the diverter contacts operation is measured with an oscilloscope according to the circuit represented in Figure 5.1b. This circuit is supplied by 24 V dc power source. Basing upon the time diagrams derived, the diagrams of the contacts operation are constructed, and are compared with the normalized ones.

a) b)

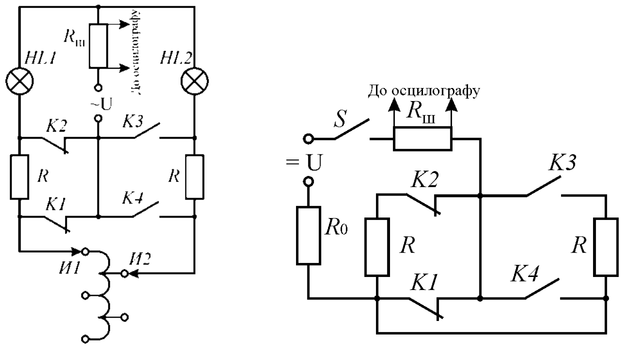

Figure 5.1 – Circuit for measurement of: a) circular diagram; b) time diagram

5.4 Task

5.4.1 Study the constructions and electric circuits of the tap selector and diverter switch included by the OLTC to be tested.

5.4.2 Study the program and procedure of electromechanical testing of on-load tap-changers.

5.4.3 Study the electric circuits for measurements of all-round and time diagrams for the contacts of the OLTC to be tested.

5.4.4 Measure the all-round diagram for the selector contacts of the OLTC to be tested.

5.4.5 Measure the time diagram for the diverter contacts of the OLTC to be tested.

5.4.6 Make conclusions related to correct operation of the selector and diverter of OLTC to be tested.

5.5 Procedure for the work execution

5.5.1 To study the design, electric circuit of the OLTC, procedure and circuits for electromechanical testing using recommended literature [10, 23].

5.5.2 To execute item 5.4.4 of the task, there are following operations should be made:

a) to construct the circuit according to Figure 5.1a and agree it with the teacher;

b) to energize the circuit and verify its operability: at the initial position, both signal lamps must glow; when the selector contacts S1 or S2 opens (closes), the lamps HL1 or HL2 should go out (come on), respectively;

c) set the OLTC being tested to its initial position; in the process, it is necessary that rotational direction of the motor-drive mechanism, from which the all-round diagram is started to measure, must strictly coincide with the direction of further measurement of the diagram; this is necessary to ensure that all the device plays are completely eliminated in the rotational direction to preclude errors in the angles measurements; at the initial position the indicating lams should not glow;

d) set the indicating pointer to zero of the scale and hereafter not change the position of the scale and pointer;

e) slowly rotating the motor-drive mechanism handle towards the next position, record the rotational angle of the motor-drive mechanism output shaft, at which occurs:

- opening the selector contacts S1 (S2), when the indicating lamp HL1 (HL2) goes out;

- closing the selector contacts S1 (S2), when the indicating lamp HL1 (HL2) comes on;

- actuation of the diverter mechanism, when the sound is emitted or the lamps glow is shortly increased;

f) repeat item e) while the tap-changing from 1-st to n-th position;

g) after coming the n-th position, it is necessary to rotate the handle just further and then repeat item e) while the device is changed from n-th to 1-st position;

h) the measuring findings are to be registered into table 5.1; basing upon the findings, construct all-round diagram for operation of the tap selector contacts.

5.5.3 To execute item 5.4.5, it is necessary to make the following operations:

a) construct the circuit according to Figure 5.1b and agree it with the teacher;

b) prepare an oscilloscope to operation;

c) make several checking changes according to the instructions of the teacher;

d) paste derived time diagrams into the report on the laboratory work;

e) compare the derived findings with s the normalized parameters and make a conclusion about operability of the diverter switch.

Table 5.1 – Test findings as for the time diagram measurement

Operation	Lamps		Rotational angle of the shaft, degrees					
	HL1	HL2	Travel from... to...			Travel from... to...		
			a	b	c	a	b	c
S1 opens S2 closes S1 closes S2 opens								

Remark. The ignition of indicating lamp is to be designated by the sign "+". The extinction of indicating lamp is to be designated by the sign "-".

5.5.3 To execute item 5.4.5, it is necessary to make the following operations:

a) construct the circuit according to Figure 5.1b and agree it with the teacher;

b) prepare an oscilloscope to operation;

c) make several checking changes according to the instructions of the teacher;

d) paste derived time diagrams into the report on the laboratory work;

e) compare the derived findings with s the normalized parameters and make a conclusion about operability of the diverter switch.

5.5.4 The laboratory work report should contain:

a) the name and purpose of the work as well as the task;

b) basic types and summary of electromechanical tests;

c) electric circuits for electromechanical tests carried out in this laboratory work;

d) tables with the findings derived, time diagrams, as well as constructed all-round and time diagrams of the device to be tested;

e) conclusions as for operability of the device to be tested.

5.6 Self-check questions

5.6.1 Enumerate the main types of verifications carrying out during electromechanical testing.

5.6.2 Show the working sequence for the OLTC contacts action.

5.6.2 What is the all-round diagram of OLTC?

5.6.4 What is the purpose to measure an all-round diagram of OLTC?

5.6.5 What is the time diagram of OLTC?

5.6.6 What is the manner to determine the diverter switch operability from the time diagram?

6. LABORATORY WORK №6. **ACCEPTED TESTS OF SWITCHGEAR PANEL**

Duration of scheduled laboratory study is 4 hours

6.1 Purpose of the work

The purpose of this laboratory work is to study the program and procedure of acceptance tests of switchgear panels, as well as to gain practical experience in their performance.

6.2 Subject of study

6–10 kV electrical distribution systems currently are assembled not of separate apparatus and devices, but of large modules named *metal-enclosed switchgears* or *switchgear panels* that industrially produced by electrical corporations and factories [11, 22].

The switchgear panel includes power equipment that combines the main circuits, as well as devices of protection, automation, control, monitoring, indication, measurement, etc. that combine auxiliary circuits. From the standpoint of construction, the switchgear panel represents metal box of skeleton-panel type that consists of a case, withdrawable unit, where the main equipment (e.g., a circuit-breaker) is mounted, relay casing (low voltage compartment), where auxiliary circuit switchgear is installed. At the present time the elemental base of auxiliary circuits is microprocessor-based devices.

Each switchgear panel and its individual components undergo acceptance tests carried out in compliance with [1, 22]. The content of acceptance tests is as follows:

1. Visual examination and verification of correspondence to technical specifications.

2. Electromechanical tests that includes the following verifications:

a) the travel and alignment of releasable contact connections;

b) the correctness of functioning the main and auxiliary circuits;

c) functioning of mechanisms and interlocks;

d) contact loads in releasable contact connections;

e) switching devices of the main circuits for closing and opening.

3. Dielectric test.

6.3 Description of the test installation

The experimental setup contains the switchgear panel to be tested, as well as a high voltage power source with measuring and protective devices for testing the electric strength of the insulation in the main and auxiliary circuits. The scheme of the setup is shown in Figure 6.1. It includes test stepping up transformer T_{test}; current-limiting resistors R_1 and R_2; measuring arrester FV_m carrying out also protective functions against sudden application of the voltage that in far excess of the test voltage; measuring devices on high and low voltage sides of the stepping up transformer PV1 and PV2 to control of the test voltage magnitude.

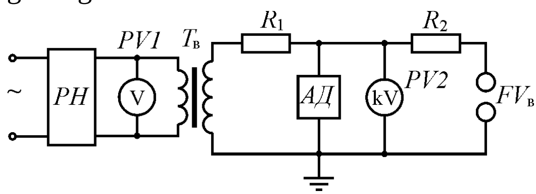

Figure 6.1 – Circuit to perform the power frequency withstand voltage test

6.4 Task

6.4.1 Study the construction and carry out visual examination of the switchgear panel according to its test program and procedure.

6.4.2 Perform check out the functioning of mechanisms and interlocks of the case, withdrawable unit and main electric equipment.

6.4.3 Perform measurements of the travel, alignment and contact loads of releasable contact connections.

6.4.4 Perform testing the electric strength of the main and auxiliary circuit's insulation with power frequency withstand voltage.

6.4.5 Draw conclusions from test findings.

6.5 Procedure for the work execution

6.5.1 Study the construction of the switchgear panel using the recommended literature [11].

6.5.2 By means of visual inspection:

a) check out the availability of protective coat of the panel details made of ferrous metals;

b) make sure that the inner and outer surfaces of the panel case are coated with enamel and its color of face surfaces must be the same;

c) make sure that a recognizing coats of the panel current-carrying parts are available: (yellow color on the phase A; green – on the phase B; red - on the phase C; black – on the grounding buses);

d) make sure that the handles of the grounding knife drives are coated with enamel;

e) check out the presence of lubricant on the surfaces that undergo friction;

f) check out quality of the protective coats of the contact surfaces;

g) check the condition of the insulating parts surfaces for dust, oils, chips, cracks and other mechanical damages;

6.5.3 To carry out item 6.4.2 it is necessary to:

a) carry out one travel operations of the withdrawable unit from the repair to the working position and back, in the process, any disturbances in the operation of the shutter mechanism, locking devices and the grounding sliding contacts between withdrawable unit and panel casing should not occur;

b) check out the functioning the circuit-breaker by performing five make-break operations at nominal (220 V), maximal (242 V) and minimal (187 V) voltages across the windings of electromagnetic components; during the test, all the circuit-breaker components must well operate without false actuations and failures.

6.5.4 Measurement of travel in the releasable contact connection between the movable (knife) and fixed (socket) contacts should be performed with standardized facilities (ruler, measuring reel) or special template in the working position of withdrawable unit of the panel.

6.5.5 Alignment of releasable contact connections in vertical and horizontal planes should be checked with standardized measuring facilities (rule, measuring reel).

6.5.6 The contact force in releasable contact connections should be measured in the working position of the contacts with the help of load gauge or other measuring facility. The contact force is measured by means of pulling away the movable contact-piece at the apply point towards action of the contact force until the contacts open moment that is registered by liberation of gauge or spacer of width no more than 0.1 mm gripped between the contacts. For each contact being measured should perform three measurements between which should perform three make-break operations by travelling the withdrawable unit. The contact force value should be accepted as the midvalue of three measurements.

6.5.7 To carry out item 6.4.4, it is necessary to make the following operations:

a) to construct a circuit according to Figure 6.1;

b) to disable all designed groundings;

c) to connect the test voltage source to the panel being tested;

d) apply the test voltage during 1 minute in compliance with [13];

e) to draw conclusions from the test findings.

6.6 Self-check questions

6.6.1 Enumerate the main components of switchgear panel and their purpose.

6.6.2 What are the components the main (power) circuit of switchgear panel include?

6.6.3 What are the components the auxiliary (secondary) circuit of switchgear panel include?

6.6.4 Enumerate the main types of verifications carried out during approval tests of switchgear panels.

6.6.5 What is the content of electromechanical tests of switchgear panels?

6.6.6 What types of test voltages are used for testing the electric strength of switchgear panel insulation?

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