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ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS NAMED AFTER GUMARBEK DAUKEEV

Department of Electric Power Engineering

ELECTRICAL SCHEMES AND EQUIPMENT OF HIGH-VOLTAGE TRANSFORMER SUBSTATIONS

Methodological guidelines for performing calculation- graphic work
For students enrolled in the educational program
6B07101 – Electric power engineering
Field: Engineering and engineering technology

Almaty 2025

AUTHORS: E.G. Mikhalkova, Y.N. Zhagyparov. Methodological Guidelines for Calculation and Graphic Work for students enrolled in the educational program 6B07101 – Electric Power Engineering.– Almaty: “NAO AUES named after G. Daukeyev,” 2025. – 19 pages.

The presented work contains methodological guidelines and assignment options for performing calculation and graphic work in the discipline «Electrical Schemes and Equipment of High-Voltage Transformer Substations».

Ill.4, table 1, bibliography. – 10 titles.

Reviewer: PhD in Education, Associate Professor A.M. Salamatina

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1 Calculation-graphic work №1. Conventional graphic and letter designations in electrical schematics

1.1 Purpose and objectives of calculation-graphic work №1

The purpose of the calculation and graphic work is to study and develop skills in executing conventional graphic and letter designations in electrical schematics.

1.2 Scope and content of the calculation-raphic work

Using drawing tools (pencil, ruler, compass, set square, protractor, etc.), the student must draw the conventional graphic designations listed in Table 1.1 on an A4 sheet (vertical orientation). Each sheet containing graphic and letter designations must have a title block.

The explanatory note must be prepared in a clear and concise manner on A3 format sheets (297×420 mm, horizontal orientation) manually (including the title block, conventional graphic, and letter designations) and using a computer on A4 format sheets (210×297 mm) for the title page, table of contents, conclusion, and bibliography.

1.3 Assignment for the calculation and graphic work

In this work, the student must:

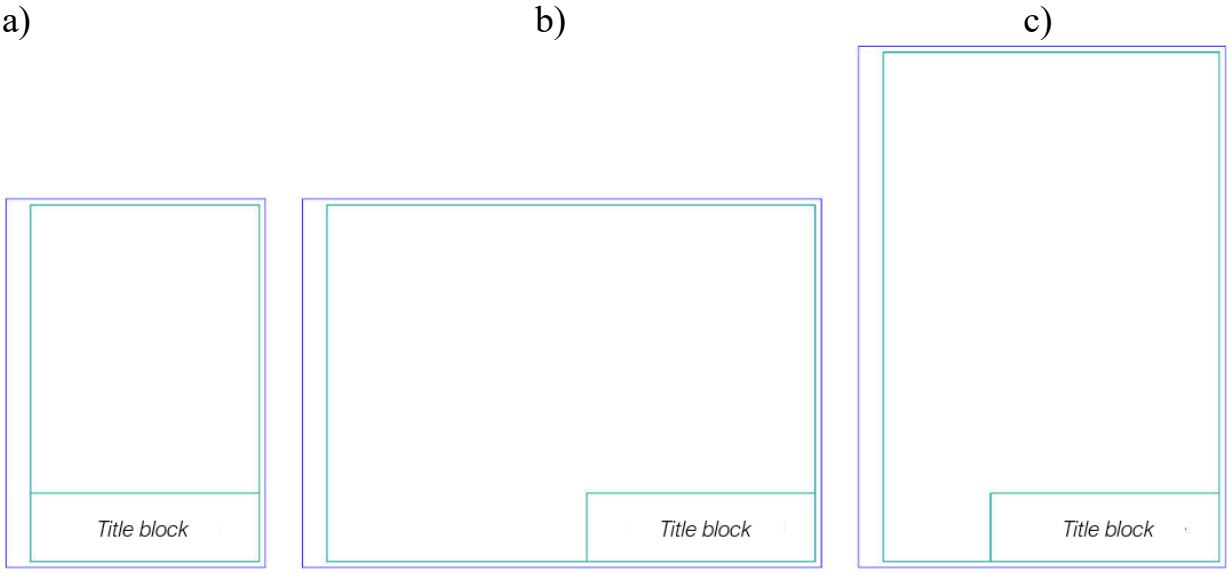
1. Prepare the title block on each sheet according to the methodological guidelines (except for the title page, table of contents, conclusion, and bibliography).
2. Using drawing tools (pencil, ruler, compass, set square, protractor, etc.), draw the conventional graphic and letter designations on A4 sheets (vertical orientation) according to the dimensions given in Table 1.1.

1.4 Methodological guidelines for completing the work

The sheet formats for schematics must comply with the requirements of GOST 2.301 – Formats. The selected format should ensure a compact schematic layout without compromising clarity and usability. For educational purposes, schematics are recommended to be drawn on A3 format sheets (297×420 mm, horizontal orientation).

The title blocks for electrical schematics must comply with the requirements of GOST 2.104 – Title Blocks.

The placement of the title block on drawings and schematics is shown in Figure 1.1.



a) for A4 format; b) for other formats in horizontal orientation; c) for other formats in vertical orientation

Figure 1.1 – Placement of the title block

Drawings and schematics are accompanied by a title block of form 1 (figure 1.2).

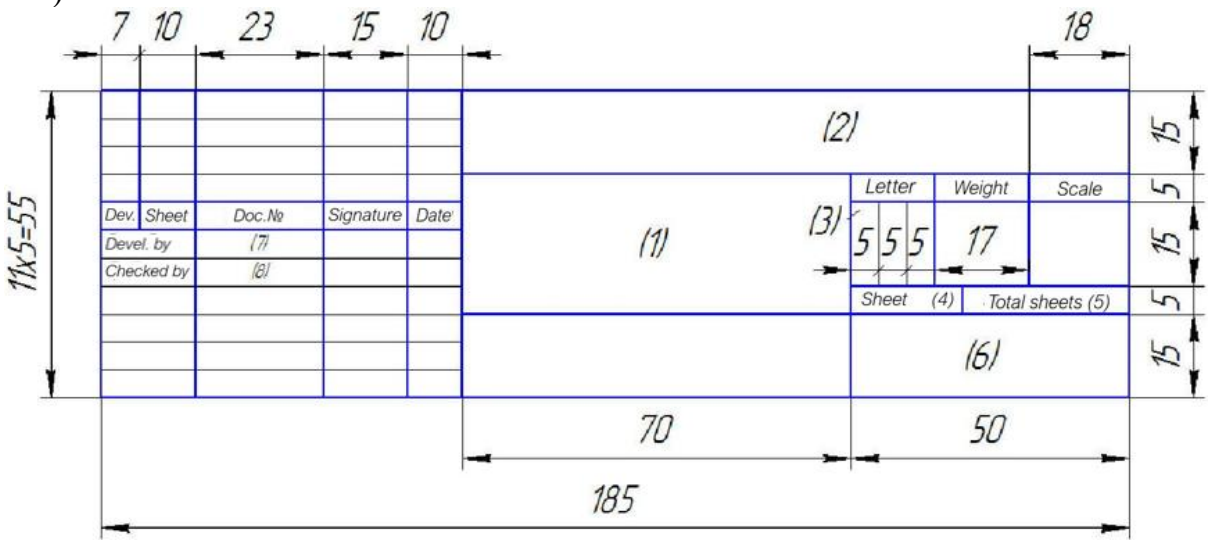
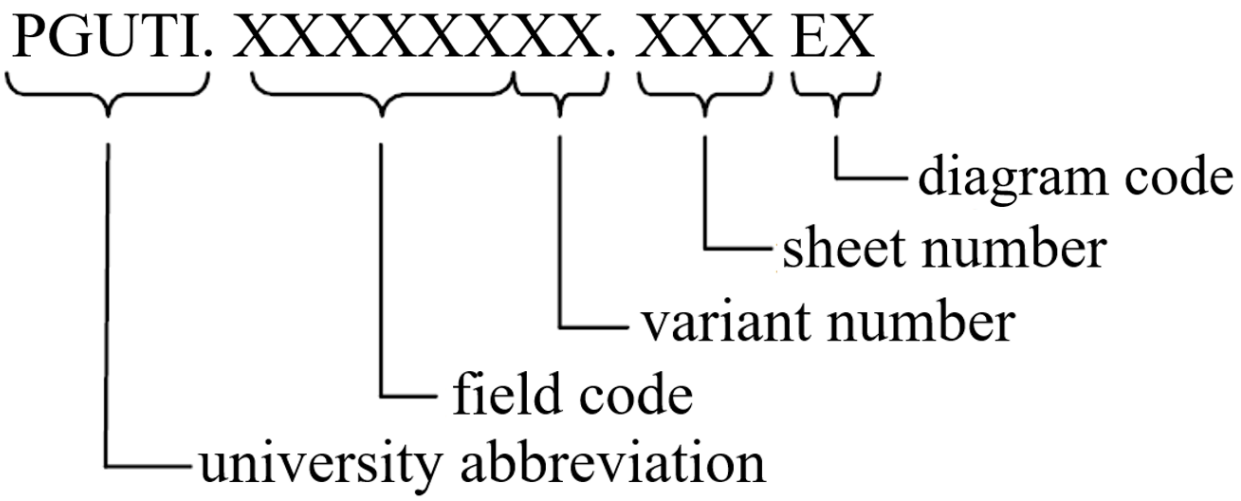


Figure 1.2 – Title block of form 1

For educational purposes, the following completion of the title block fields is recommended for electrical schematics:

Field 1 – Name of the product with a mandatory indication of the document type, e.g., "Electrical Schematic – Block Diagram" or "Electrical Schematic – Principal Diagram," depending on the type of schematic.

Field 2 – Document designation (code) in the following format:



Field 3 – Letter designation assigned to this document ("U" for an educational drawing).

Field 4 – Sequential sheet number (for single-sheet documents, this field is left blank).

Field 5 – Total number of sheets in the document.

Field 6 – Student group number who completed the drawing.

Field 7 – Last name of the student who completed the drawing.

Field 8 – Last name of the instructor who reviewed the drawing.

Text-based design documents (first or title sheet) (for an electrical schematic – the List of Elements) are accompanied by a title block of form 2 (Figure 1.3).

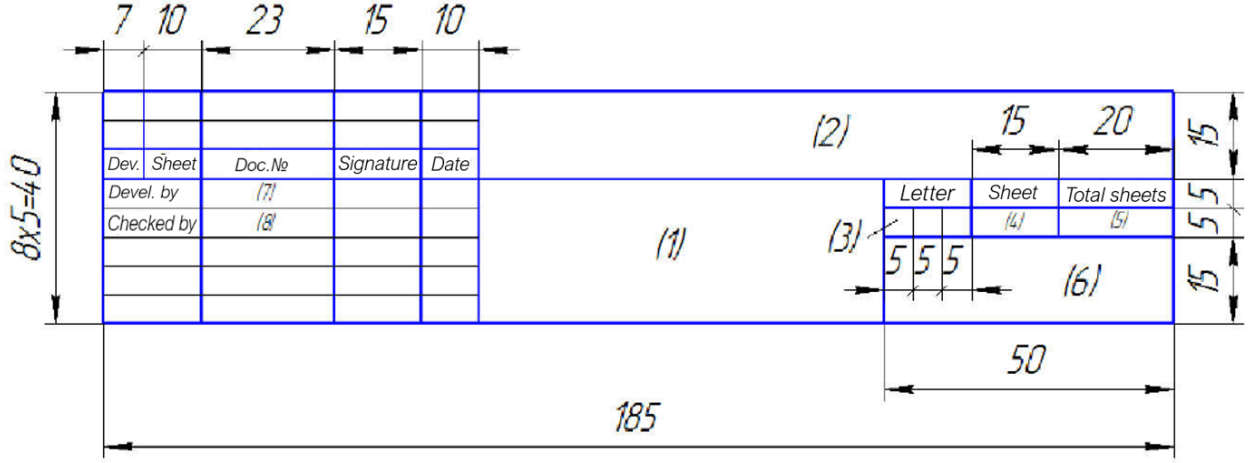


Figure 1.3 – Title block of form 2

The completion of the fields in the title block of form 2 is similar to that of form 1. Field 1 specifies the product name and the document title – List of elements.

Text-based design documents (second and subsequent pages) are accompanied by a title block of Form 2a (Figure 4).

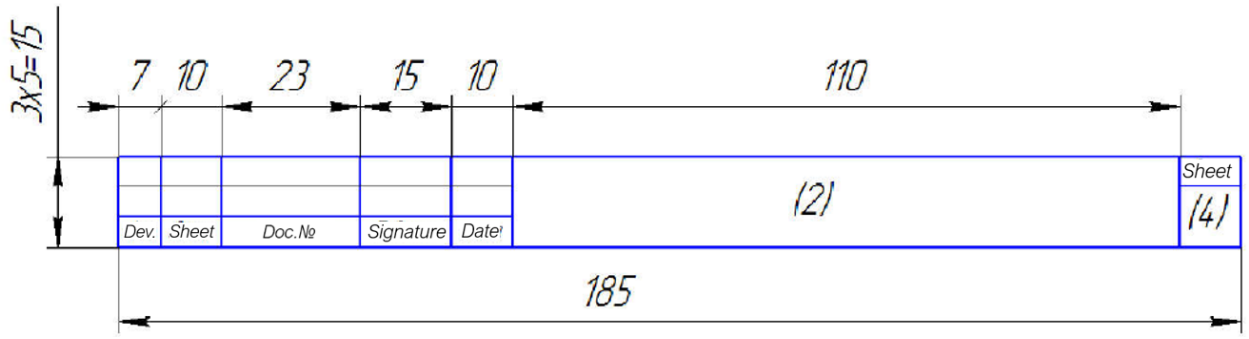


Figure 1.4 – Title block of form 2a

Only fields 2 and 4 are filled out, following the same rules as the title block of form 2.

Schematic construction:

1) Schematics are drawn without scale adherence (the *Scale* field in the title block is left blank).

2) Standardized graphical symbols (SGS) for components, devices, functional groups, and interconnecting lines should be arranged to provide the best representation of the product structure and the interaction of its components.

3) SGS of elements are depicted in sizes established by relevant standards of the Unified System for Design Documentation. The dimensions of SGS are provided in table 1.

4) All SGS dimensions can be proportionally adjusted.

5) SGS in schematics should be drawn using the same line thickness as interconnecting lines.

Interconnecting Lines:

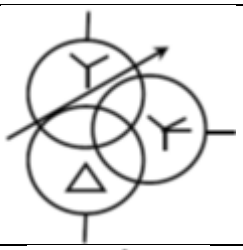
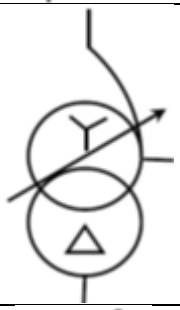
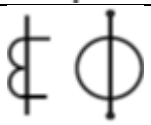
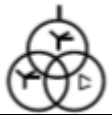
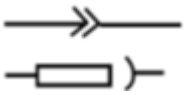
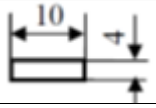
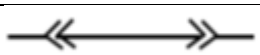
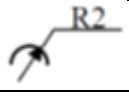
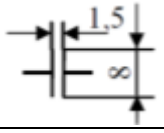
1) The thickness of interconnecting lines should range from 0.2 mm to 1.0 mm, depending on the schematic format and SGS sizes. The preferred thickness is 0.5 mm.

2) Interconnecting lines should consist of horizontal and vertical segments, with the fewest possible bends and crossings.

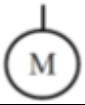
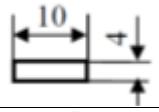
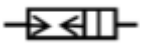
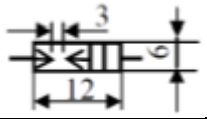
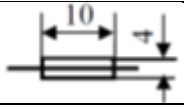
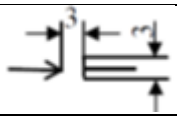
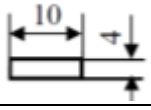
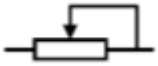
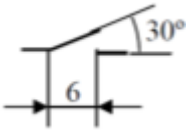
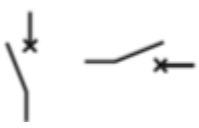
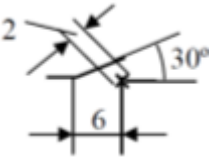
Table 1.1 – Standard graphical and letter designations of some elements in electrical schematics

Name	Designation		Dimensions in mm
	Graphic	Letter	
1	2	3	4
Three-phase power transformer, two-winding, with on-load voltage regulation; winding connection: star-delta		T	Diameter – 10, arrow length – 20, inclination angle – 45°, distance between circle centers – 6. For main circuit elements, dimensions should be doubled.

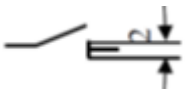
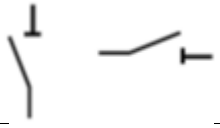
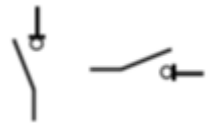
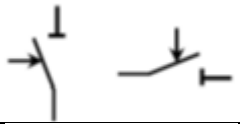
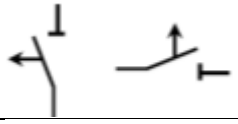
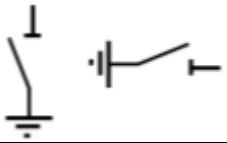
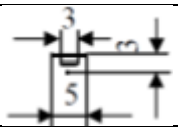
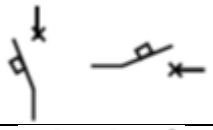
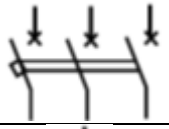
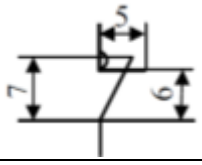
Continuation of table 1.1

1	2	3	4
Three-phase power transformer, three-winding; medium voltage winding has a neutral lead		T	- « -
Three-winding autotransformer		T	- « -
Current transformer		TA	Circle diameter – 10, arc radius – 2.5
Zero-sequence current transformer		TA	Arc radius – 2.5
Single-phase two-winding voltage transformer		TV	Circle diameter – 10, distance between circle centers – 6
Three-phase voltage transformer		TV	- « -
Cable			
Detachable Contact Connection		X	
Switching Jumper			
Inductance Coil		L	
Current-Limiting Reactor		LR	Diameter – 12 mm
Double Reactor		LR	- « -
Power Capacitor Bank		CB	

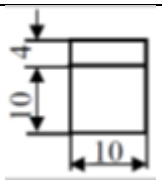
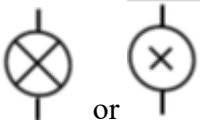
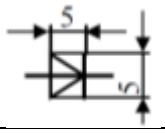
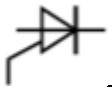
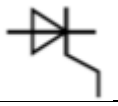
Continuation of table 1.1

1	2	3	4
Generator		G	Circle diameter – 10 mm. For main schematic elements, dimensions should be doubled.
Synchronous Compensator		GS	- « -
Electric Motor		M	- « -
Surge Arrester		FV	
Valve-Type Surge Diverter		FV	
Tube-Type Surge Diverter		FV	- « -
Fuse (Standard)		FU	
Fast-Acting Fuse		FU	- « -
Expulsion Fuse		FU	
Switch-Fuse		QF	
Fixed Resistor		R X Z	
Variable Resistor		R X Z	- « -
Knife Switch, Low-Voltage Single-Pole		QS or SA (for control and signaling circuits)	
Knife Switch, Low-Voltage Three-Pole			
High-Voltage Switch		Q	

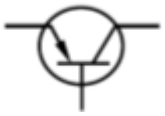
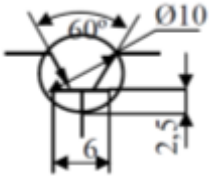
Continuation of table 1.1

1	2	3	4
Withdrawable Switch		Q	
Disconnector		QS	
Load Break Switch		QW	
Short-Circuiting Switch		QN	
One-Way Isolator		QR	
Earthing Knife Switch		QSG	
Grounding			
Circuit Breaker		QF SF	
Three-Pole Circuit Breaker		QF SF	
Contactor Closing Contact		KM	
Contactor Opening Contact		KM	
Ammeter: a – indicating; b – recording	 a) b)	PA	Diameter – 10; Square 10×10
Voltmeter: a – indicating; b – recording		PV	- « -

Continuation of table 1.1

1	2	3	4
Wattmeter: a – indicating; b – recording		PW	- « -
Varmeter a – indicating; b – recording		PVA	- « -
Wattmeter with zero in the center of the scale		PW	Diameter – 10
Varmeter with zero in the center of the scale		PVA	- « -
Active energy meter		PI	
Reactive energy meter		PK	
Incandescent lamp: a) Lighting; b) Signal		a) EL b) HL	Diameter – 6-8
Diode		VD	
Zener diode		VD	- « -
Bidirectional zener diode		VD	- « -
Thyristor with anode control		VS	- « -
Thyristor with cathode control		VS	- « -
Photodiode		VD	- « -
LED (Light Emitting Diode)		VD	- « -
Tunnel diode		VD	- « -

Continuation of table 1.1

1	2	3	4
PNP Transistor		VT	
NPN Transistor		VT	- « -

1.5 Preparation for work

1. Familiarize yourself with the description of this assignment, the necessary literature, and sources.
2. Prepare all the required materials for writing and formatting the work.
3. Provide oral answers to the control questions.

1.6 Procedure for completing the work

1. Study materials and sources.
2. Process and systematize the material.
3. Format the material according to the assignment and explanations provided above, in accordance with [1].
4. Be able to answer the control questions orally.

1.7 Report content

1. Title page of the work.
2. Table of contents.
3. Symbols and notations (A3 format sheets).
4. Conclusion.
5. List of references.

1.8 Control Questions and Tasks

1. What sheet formats are used for drafting electrical diagrams according to GOST standards?
2. How are the title block fields filled in electrical diagrams?
3. What is the procedure for constructing a diagram?
4. How are interconnection lines drawn on schematics?
5. How is a transformer with a winding split into three parts designated on electrical diagrams?
6. Provide the conventional graphic symbol for an arc-extinguishing normally closed contact of a magnetic starter on electrical diagrams.

7. Provide the conventional graphic symbol for a «Three-phase, three-winding power transformer where the high-voltage winding includes a neutral lead. the HV winding has a neutral lead».

8. Provide the conventional graphic symbol for an «Autotransformer with a winding split into three parts».

9. Provide the conventional graphic symbol for a «Three-phase, two-winding power transformer with on-load tap changing; star-delta winding connection ».

10. Provide the conventional graphic symbol for a capacitor bank.

2 Calculation-graphical work №2: Electrical Connection Diagrams of Substations

2.1 Purpose and objectives of calculation-graphical work №2

The purpose of this calculation and graphical work is to develop independent analysis skills on the main sections of the course, the ability to answer assigned questions, and the ability to work with technical literature.

2.2 Scope and content of the calculation-graphical Work

The explanatory note must include a title page, an introduction, necessary textual and numerical informational material, a bibliography, and a table of contents. The explanatory note for the calculation and graphical work should be 20–25 pages long, in accordance with reference [1].

The input data for completing the calculation and graphical work are strictly individual. The input data for RGR No. 2 are provided in Tables 2.1 and 2.2. Each student determines their theoretical assignment variant based on the academic year of studying the discipline, according to two criteria—the last and second-to-last digits of their personal identification number (IIN).

According to Table 2.1, the last digit of the IIN, considering the year of studying the discipline, determines the number of the first theoretical question. According to Table 2.2, the second-to-last digit of the IIN, considering the academic year in which the discipline is studied, determines the number of the second theoretical question. The variants of the first and second theoretical questions are presented below.

Table 2.1 – Data for Selecting the first theoretical question

Academic Year	Last Digit of IIN									
	0	1	2	3	4	5	6	7	8	9
2024/2025	X	IX	VIII	VII	VI	V	IV	III	II	I
2025/2026	II	I	IV	III	VI	VII	VIII	V	X	IX
2026/2027	V	IV	III	II	I	X	IX	VIII	VII	VI
2027/2028	I	II	V	IV	III	VI	X	VII	IX	VII
2028/2029	IX	VIII	IX	VI	VII	I	II	IV	III	V

Table 2.2 – Data for selecting the second theoretical question

Academic Year	Last Digit of IIN									
	0	1	2	3	4	5	6	7	8	9
2024/2025	X	VIII	IX	VI	VII	I	II	IV	III	V
2025/2026	II	I	IV	III	VI	VII	VIII	V	X	IX
2026/2027	I	II	V	IV	III	VI	X	VII	IX	VII
2027/2028	X	IX	VIII	VII	VI	V	IV	III	II	I
2028/2029	V	IV	III	II	I	X	IX	VIII	VII	VI

2.3 Variants of theoretical questions for calculation-graphic work №2

2.3.1 Variants of theoretical question №1

I - Principles of constructing electrical connection schemes for energy facilities.

II - Standardization and unification of main electrical connection schemes of substations.

III - Typical electrical connection schemes of substations: general guidelines for application.

IV - Typical electrical connection schemes of substations: guidelines for the application of block schemes.

V - Typical electrical connection schemes of substations: guidelines for the application of bridge schemes, "in-out" schemes, and "triangle" schemes.

VI - Typical electrical connection schemes of substations: guidelines for the application of quadrangle and hexagonal schemes.

VII - Typical electrical connection schemes of substations: guidelines for the application of busbar schemes with a single circuit breaker per connection.

VIII - Typical electrical connection schemes of substations: guidelines for the application of busbar schemes with two and "one-and-a-half" circuit breakers per connection.

IX - Typical electrical connection schemes of substations: guidelines for the application of GIS (Gas-Insulated Substations) schemes.

X - Typical electrical connection schemes of substations: guidelines for the application of switchgear schemes for 10(6) kV.

2.3.2 Variants of theoretical question №2

I - Recommendations for selecting the main electrical connection schemes of substations: factors influencing the choice of HV switchgear schemes.

II - Guidelines for the application of compensating device connection schemes.

III - Recommendations for selecting the main electrical connection schemes of substations: list of 110-220 kV schemes.

IV - Recommendations for selecting the main electrical connection schemes of substations: list of 500-750 kV schemes.

V - Recommendations for selecting the main electrical connection schemes of substations: list of switchgear schemes for 10 (6) kV, line voltage regulation transformers for 35 kV, synchronous compensators, and controlled shunt capacitor banks for 10(3)-35 kV.

VI - Recommendations for selecting the main electrical connection schemes of substations: algorithm for selecting 35 kV switchgear schemes.

VII - Recommendations for selecting the main electrical connection schemes of substations: algorithm for selecting 110 and 220 kV switchgear schemes.

VIII - Recommendations for selecting the main electrical connection schemes of substations: overvoltage protection.

IX - Recommendations for selecting substation auxiliary power supply schemes.

X - Structural implementation of switchgear.

2.4 Preparation for work

1. Familiarize yourself with the description of this work, necessary literature, and sources.
2. Prepare all necessary materials for writing and formatting the work.
3. Answer the control questions orally.

2.5 Work execution procedure

1. Study materials and sources.
2. Process and systematize the material for answering theoretical questions.
3. Format the material according to [1].
4. Be able to answer the control questions orally..

2.6 Report content

1. Title page.
2. Table of contents.
3. Introduction and purpose of the work.
4. Answer to the first theoretical question.
5. Answer to the second theoretical question.
6. Conclusion.
7. List of references.

2.7 Control Questions and Tasks

1. What sheet formats, according to GOST standards, are used for drawing electrical diagrams?
2. How are the title block fields filled in for electrical diagrams?
3. What is the procedure for constructing an electrical diagram?
4. How are interconnection lines drawn on electrical drawings?
5. How is a transformer with a split winding into three parts represented on electrical diagrams?

6. Provide the conventional graphical symbol for a normally open arc-suppressing contact of a magnetic starter on electrical diagrams.

7. Provide the conventional graphical symbol for a three-phase, three-winding power transformer with a neutral terminal on the high-voltage winding.8. List of 500-750 kV schemes.

8. Provide the conventional graphical symbol for an autotransformer with its winding split into three parts.

9. Provide the conventional graphical symbol for a three-phase, two-winding power transformer with on-load voltage regulation and star-delta winding connection.

10. Provide the conventional graphical symbol for a capacitor bank.

3 Calculation-graphic work №3. Electrical safety in high-voltage installations

3.1 Purpose and objectives of calculation-graphic work №3

The purpose of this calculation and graphic work is to develop skills in independently reviewing materials on the main sections of the course, the ability to answer assigned questions, and to enhance skills in working with technical literature.

3.2 Scope and content of the calculation-graphic work

The explanatory note must include a title page, an introduction, the necessary textual and numerical informative material, a list of references, and a table of contents.

The explanatory note of the calculation and graphic work should be 20-25 pages long, formatted according to [1].

The initial data for the completion of the calculation and graphic work is strictly individual. The initial data for Work No. 3 is presented in Tables 3.1 and 3.2. Each student determines their variant of the theoretical assignment based on the academic year of studying this discipline, considering two criteria—the last and the second-to-last digits of the identification number (IIN).

According to Table 3.1, the last digit of the identification number (IIN), considering the academic year of study, determines the number of the first theoretical question.

According to Table 3.2, the second-to-last digit of the identification number (IIN), considering the academic year of study, determines the number of the second theoretical question.

The variants of the first and second theoretical questions are presented below.

Table 3.1 – Data for selecting the first theoretical question

Academic Year	Last Digit of IIN									
	0	1	2	3	4	5	6	7	8	9
2024/2025	X	IX	VIII	VII	VI	V	IV	III	II	I
2025/2026	II	I	IV	III	VI	VII	VIII	V	X	IX
2026/2027	V	IV	III	II	I	X	IX	VIII	VII	VI
2027/2028	I	II	V	IV	III	VI	X	VII	IX	VII
2028/2029	IX	VIII	IX	VI	VII	I	II	IV	III	V

Table 3.2 – Data for selecting the second theoretical question

Academic Year	Last Digit of IIN									
	0	1	2	3	4	5	6	7	8	9
2024/2025	X	VIII	IX	VI	VII	I	II	IV	III	V
2025/2026	II	I	IV	III	VI	VII	VIII	V	X	IX
2026/2027	I	II	V	IV	III	VI	X	VII	IX	VII
2027/2028	X	IX	VIII	VII	VI	V	IV	III	II	I
2028/2029	V	IV	III	II	I	X	IX	VIII	VII	VI

3.3 Question variants

3.3.1 Variants of theoretical question №1

I - The effect of electric current on the human body. Types of electrical injuries.

II – First aid for electric shock victims.

III – Phenomena occurring when current flows into the ground. Touch voltage.

IV – Phenomena occurring when current flows into the ground. Step voltage.

V – Phenomena occurring when current flows into the ground. Electrical resistance of the ground.

VI – Analysis of electric shock hazards in various electrical networks. Single-phase networks.

VII – Analysis of electric shock hazards in various electrical networks. Three-phase networks.

VIII – Protective grounding.

IX – Neutral grounding.

X – Protective disconnection.

3.3.2 Variants of theoretical question №2

I – Protective equipment used in electrical installations. Purpose, design, and application rules.

II – Protective equipment used in electrical installations. Testing of insulating protective equipment.

III – Protection against the influence of the industrial frequency electric field in high and ultra-high voltage electrical installations.

IV – Safety during phase-by-phase maintenance of overhead power lines. Electrostatic influence.

V – Safety during phase-by-phase maintenance of overhead power lines. Electromagnetic influence.

VI – Safety during live-line work on high-voltage overhead power lines.

VII – Analysis of potential hazards when working under voltage.

VIII – Organization of safe operation of electrical installations. General provisions.

IX – Organization of safe operation of electrical installations. Operational maintenance of active electrical installations.

X – Organization of safe operation of electrical installations. Work execution in active electrical installations.

3.4 Preparation for work

1. Familiarize yourself with the description of this work, necessary literature, and sources.
2. Prepare all necessary materials for writing and formatting the work.
3. Answer the control questions orally.

3.5 Order of work execution

1. Study the materials and sources.
2. Review and systematize the material for answering the theoretical questions.
3. Format the material according to [1].
4. Be able to answer the control questions orally.

3.6 Report Structure

1. Title page.
2. Table of contents.
3. Introduction and purpose of the work.
4. Answer to the first theoretical question.
5. Answer to the second theoretical question.
6. Conclusion.
7. List of references.

3.7 Control questions

1. What are the criteria for electrical safety?
2. What types of electric shock injuries exist?
3. What is an electrical injury?
4. What is an electric shock?
5. What is the mechanism of death from electric current?
6. What are the first aid measures for electric shock victims?
7. What is the procedure for freeing a person from electric current exposure?
8. What is the procedure for artificial respiration?
9. What is the procedure for indirect heart massage?
10. What protective equipment is used in electrical installations?

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Methodological guidelines for performing calculation- graphic work
For students enrolled in the educational program
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