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METHODOLOGY FOR ORGANIZING INDEPENDENT WORK OF STUDENTS IN ELECTRICAL ENGINEERING

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Abstract
This article provides for the implementation of laboratory and practical exercises and independent work assignments for teaching students in electrical engineering. When studying electrical engineering, it is shown that various transformations are often encountered in electrical circuits of direct and alternating current. When studying electrical engineering, it is often possible to encounter various transformations in electrical circuits of direct and alternating current. Initially, on the topic “Direct Current Circuits”, students are given the transformation (winding) method and calculations are shown using the Equivalent Transformation Method. In addition, the equivalent transformation method is also used when calculating single-phase alternating current circuits. It is shown that it is especially convenient to use this method in a complex form to solve a simple circuit with a mixed connection of elements.

Keywords: Electrical engineering, mathematical skills, information, schemes, graphs, diagrams, drawing, instruments, transformers, induction machines, asynchronous machines and DC machines.

Introduction

Research and practical experience made it possible to determine that high-quality mastery of electrical engineering disciplines can be achieved only with sufficiently active independent work of students, which necessitated the development of a methodology for its organization in the process of professional training in electrical engineering. Considering independent work as one of the main types of students' educational and cognitive activity, when developing this methodology, it was taken into account that the effectiveness of independent work is ensured by: setting specific goals for students, organizing the educational process, developing a software and methodological complex that ensures the implementation of a system-integrated approach, developing didactic materials that allow activating students' educational and cognitive activity, forming an active creative position in its implementation [7].

Literature Review

Students work independently in all types of classes on the subject "Electrical Engineering." The preparatory stage for laboratory work involves the student's independent work with lectures or recommended educational literature. In addition, based on the materials of methodological instructions for laboratory work, the student becomes acquainted with research, control, regulating, and measuring devices. Permission to perform laboratory work is granted only after effective independent preparation for laboratory classes.

Completing an experiment during a laboratory session does not mean that the laboratory work is finished, since the student must independently complete the report and prepare for its defense. Completing the laboratory report requires the student to additionally study certain topics from the recommended literature or lecture course; to develop data processing skills (mathematical skills and the ability to work with information); and to construct electrical circuits, graphs, and diagrams (skills acquired in the engineering graphics course).

Furthermore, constructing electrical circuits, like any graphical document, requires the student to know the standards for preparing drawings and helps them become accustomed to working according to these standards. After completing calculations, circuits, graphs, and diagrams, it is necessary to analyze the obtained results and draw conclusions about the work.

In such cases, additional knowledge on the topic of the laboratory work is often required, which is usually acquired independently. Laboratory work and practical sessions require more time for independent study than classroom lessons [1].

During practical sessions, students begin to master the general methods of analyzing and synthesizing electrotechnical elements and systems, and they start performing individual tasks, gaining skills in solving specific practical problems.

To analyze independent work, the important elements and connections characteristic of the system are highlighted. Each element of the educational activity, in turn, is considered an object of organization or control. During the “Electrical Engineering and Electronics” course, lectures, laboratory sessions, and practical classes are conducted, and calculation-graphic assignments are performed. Accordingly, in the process of completing independent work, the teacher’s actions and tools, which determine the student’s corresponding actions and resources, are identified. While explaining theoretical material on the topic, the teacher uses textbooks, lecture notes, educational and practical manuals, diagrams, models, data for electrical devices, electronic boards, and flipcharts. The teacher’s actions require the student to record the presented material, make notes in the workbook, and include symbols, diagrams, graphs, and other necessary entries.

In the “Electric Machines” section, excerpts from the instructions for completing calculation-graphic assignments intended for independent work are provided. The purpose of this calculation-graphic assignment is to develop students’ skills in solving problems for the “Electric Machines” course, strengthen their theoretical knowledge, teach them to use reference literature, construct electrical circuits, and apply conventional graphical symbols for circuit elements during the process of solving professional engineering problems, for both full-time and part-time students.

Research Methodology

Full-time students complete calculation-graphic assignments, while part-time students perform control tasks. Before starting their calculation-graphic assignments, students familiarize themselves with the relevant sections of the lecture course and recommended literature.

The methodological guidelines provide 200 variants of initial data for calculating real electrical machines, such as three-phase transformers, three-phase asynchronous motors, and direct current motors. The assignment variants are selected to maximize individualization of students' work, not only within a single group but also across the teaching stream and even among engineering students studying simultaneously in different streams. In the assignment, passport data of electrical machines is used for general industrial purposes applicable in most technologies and production processes. General guidelines for completing calculation-graphic assignments (or control tasks) are provided to indicate the requirements for these works. When preparing calculation-graphic assignments, students write down the initial data for calculations, indicating the variant number, and record the calculation formulas by explaining the symbols included. Students independently understand the conventional symbols of different types of electrical machines and demonstrate this knowledge when defending their work. It is recommended to use current State Standards (GOSTs) for drawing schematic elements and specifying electrical quantities [2].

It is not recommended to present conclusions based solely on formulas found in the recommended literature. During problem solving, brief explanations should be provided, and the units of all quantities obtained in calculations must be indicated. At the beginning of each problem, a concise statement of the task is given, including the conversion of all numerical values into the SI system. Schematics, graphs, and diagrams are constructed using drawing tools; convenient scales are chosen, and coordinate axes with corresponding dimensions are indicated. The appendix of the methodological guidelines provides a sample title page for the calculation-graphic assignment and examples of solved problems on these topics.

Analysis and Results

To defend their calculation-graphic (or control) assignments, students study the sections on "Transformers," "Asynchronous Machines," and "Direct Current Machines" in the recommended literature. A calculation-graphic (or control) assignment is considered valid only if it is completed correctly, accurately, fully, and orally defended [4].

Problem

For a three-phase transformer with a rated power of S_N = 100 kVA and a winding connection of Y/Y_0-0, the following data are given: Primary winding rated voltage at the terminals: U_{1N} = 6000 V, Secondary winding no-load voltage at the terminals: U_{20} = 400 V, Short-circuit voltage: u_k = 5.5 %, Short-circuit power: (P_q = 2400 W, No-load power: P_0 = 600 W, No-load current: ($I_0 = 0.07\ I_{1N}$

Determine the following:

1. The resistances of the transformer windings.
2. The equivalent total, active, and reactive impedances of the transformer in the open-circuit (no-load) condition.
3. The magnetizing loss angle.

Additionally, draw the phasor diagram of the transformer at a load equal to 0.8 of the rated power S_N and with a power factor $cos\varphi_2$ = 0.75).

This problem covers several tasks of the calculation-graphic assignment, but not all of them. In the process of solving this problem, the student is provided with methods for simple calculation,

selection, operation, and rational use of electrical devices. While completing calculation-graphic assignments, students gain skills in preparing graphical documentation, performing calculations, constructing characteristics based on the calculated data, as well as analyzing the obtained results and drawing conclusions on the analysis of the completed electrical devices.
In the process of solving professional electrotechnical problems, one of the principles of analytical-synthetic activity is applied. This includes methods for analyzing and synthesizing functions based on prospective technologies, as well as the principles of equivalence and analogy, and the laws of symmetry and duality.

Method of Equivalent Transformations

While studying electrical engineering, students often encounter various transformations in both direct and alternating current circuits. Initially, in the topic “Direct Current Circuits,” students are introduced to the transformation (winding) method. This method is studied with considerable difficulty, and about 60–70% of students are able to complete the tasks independently. At the same time, mastering this method and acquiring sufficient skills for calculating circuits with mixed connections is essential. Indeed, when studying electrical engineering, one frequently has to work with mixed connections. These include single-phase AC circuits, three-phase AC circuits, connection schemes for DC electrical machines, current measuring devices and various shunt circuits, adjustment schemes, semiconductor device connection schemes, and similar cases [8].
One should not approach the study of mixed connections immediately. As usual, the series and parallel connections of resistors are first considered. It is important to achieve a solid understanding of the characteristics of these connections and to develop the skills to solve problems based on them.
First, let us consider series connections. Their definition is provided at the outset. A series connection is one in which the sections of the circuit are connected consecutively without branching, and therefore have the same current. It is useful to note that in a section of an electrical circuit, not only consumers of electrical energy (resistors) but also sources of electrical energy may be present.
Next, the most important characteristics of series connections are established:

1. The current in any section of a series circuit is the same.

Students often make the following mistake: they assign currents I_1, I_2, and I_3 to the sections R_1, R_2, and R_3 respectively and denote them as:

$$I_1 = \frac{U}{R_1}, \qquad I_2 = \frac{U}{R_2}, \qquad I_3 = \frac{U}{R_3}$$

Although this seems obvious, such a seemingly simple question requires special attention.

2. The voltage across the terminals of the circuit is equal to the sum of the voltages across all its sections. This relationship appears straightforward but also demands careful consideration.
3. In a series connection, the voltage across each section is directly proportional to the resistance of that section.

Before moving on to parallel connections, it is recommended that students solve more series connection problems to develop solid skills in specific solutions.

The study of parallel connections begins with its definition.
A connection in which several branches are connected to the same pair of nodes is called a parallel connection.
After that, the characteristics of this connection are established:
1. For any node in an electrical circuit, the algebraic sum of currents is zero (Kirchhoff's first law). Currents "entering" the node are taken with a plus sign, and currents "leaving" the node with a minus sign. Not all students can apply this property in practice, so it is necessary to highlight a particular node and explain that the rest of the circuit is not considered when writing the corresponding equation.
2. The voltage across all branches of a parallel connection is the same. It is important to emphasize that some students incorrectly assume that these voltages are constant in all cases and extend this assumption to mixed connections. They then mistakenly believe that the voltage remains constant in branched sections and does not change even if the resistances in other sections of the circuit vary.
3. The currents in the branches are proportional to their resistances. Unfortunately, many students mistakenly determine the currents in parallel branches as if they were in series, which is a common error. Therefore, this point also requires careful attention.
4. Equivalent resistance in a parallel connection.
The formula is usually given for three resistances:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Next, the special case of two resistances connected in parallel is considered. Based on the above formula, the following expression is used:

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

A common mistake among students is to incorrectly apply this formula for three or more resistances as follows:

$$R_{eq} = \frac{R_1 R_2 R_3}{R_1 + R_2 + R_3}$$

It is essential to make students aware of this widespread error.
After considering these elementary connections, we need to move on to calculating mixed connections. In most textbooks and manuals, a circuit that immediately includes both series and parallel connections is presented. Calculating such a circuit usually does not cause any difficulties for students. This problem serves as an initial stage for studying the method of equivalent transformations.
However, it is not sufficient to limit ourselves to only such a circuit. The time allocated for this topic in the curriculum is limited, so it is recommended either to dedicate some time in subsequent sessions to analyze more complex problems or to assign this material for independent study. Gradually, during the transformation process, the number of intermediate circuits can be reduced. Eventually, students may reach a stage where they can solve problems without having to simplify the circuits step by step.
In the calculation of direct current circuits, there are schemes with complex connections of elements that cannot be classified as either series or parallel. Students often struggle with

solving such problems. In these circuits, "star" and "delta" connections are not always present. One such circuit consists of a delta configuration with three nodes forming a triangle, and the sides are three passive branches connected between these nodes. To simplify the calculation of such circuits, it is often convenient to replace the "delta" with an equivalent "star" configuration. After this equivalent transformation, the circuit becomes a simple mixed connection, which can be calculated without significant difficulty [3].

Typically, the "star" and "delta" representations do not correspond to the conventional visual representations of these forms, which can complicate the calculation of the circuits. After the transformation, the circuit is analyzed using the widely known method for calculating circuits with mixed connections.

The method of equivalent transformation is also applied to single-phase AC circuits. This method is particularly convenient for solving simple circuits with mixed connections in a comprehensive way. However, before applying this method to AC circuits, it is appropriate to recall the physical meaning of representing periodic quantities using vectors and complex numbers.

Practical experience in teaching electrical engineering shows that students often forget that both vectors and complex numbers are a symbolic method of representing sinusoidal currents, voltages, and electromotive forces of sources. It is useful to emphasize that the vectors representing periodic current, voltage, and electromotive force are symbolic rather than physical. Therefore, the method of solving sinusoidal AC circuits using complex numbers is called a symbolic method of equivalent transformation.

It is important to remember the connection between time and phasor diagrams. This connection should be explained, emphasizing that any parameter of an AC can be determined from both the time diagram and the phasor diagram, provided that the vector rotates with angular frequency (\omega = 2\pi/T). Periodic AC physical quantities are evaluated by their instantaneous, effective (RMS), amplitude, or average values. Most electrical measuring instruments record the instantaneous values of voltage and current, which should be considered when explaining this topic. For this purpose, the instrument scales are calibrated according to these values [5]. It is necessary to distinguish between instantaneous, amplitude, average, and effective values. Instantaneous values can be conveniently obtained from phasor diagrams and their relation to time. Using phasor diagrams in the study and calculation of AC circuits allows visual representation of the processes being studied and simplifies the calculations performed.

Students often do not understand the reasons for choosing the symbolic method for calculating sinusoidal AC circuits. By referring to complex number theory, an analytical expression describing the position of the rotating vector at any moment in time should be provided. From this expression, the instantaneous value at any time can be determined. Sinusoidal current (voltage, electromotive force) can be represented using a vector or in analytical form as a complex number representing the vector. All forms of representing a complex number and methods for converting from one form to another should be shown. Students should practice addition (subtraction) and multiplication (division) of complex numbers. Attention should be paid to the correspondence of the algebraic form of a complex number to the Cartesian coordinate system, and the exponential form to the polar coordinate system. Many instructors consider it appropriate to begin the study of AC circuits with the symbolic method of equivalent transformation. Later, the calculation of complex AC circuits can be performed based on their similarity to complex DC circuits [6].

Conclusion and Recommendations

Equivalent methods are powerful tools for analyzing circuits: contour currents, node potentials, equivalent generators, transformations of "star" and "delta" structures, and series and parallel connections based on the physical laws of Ohm, Kirchhoff, Ampère, and Faraday. Signal graph methods enable the conversion of analog, pulse, and discrete circuits into mathematical representation, while voltage divider methods synthesize equivalent structures in the main forms of functional representation.

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