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DEVELOPING THE POWER SUPPLY SYSTEM DESIGN COMPETENCY OF FUTURE ENGINEERS BASED ON DIGITAL TWIN TECHNOLOGY

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Abstract
The article examines the scientific and methodological possibilities of using digital twin technology in teaching the subject "Power Supply of Industrial Enterprises". It substantiates the creation of a virtual model of an industrial enterprise power supply system within the digital twin framework, and the possibilities for analyzing load, transformers, electrical networks, emergency conditions, and energy efficiency. The article also highlights the pedagogical significance of digital twin technology in developing future engineers' competencies in design, diagnostics, technical decision-making, and optimization of production processes.

Keywords: Digital twin, power supply, industrial enterprise, engineering education, design competency, digital model, virtual laboratory, technical analysis, energy efficiency.

Introduction

Today, the stable operation of industrial enterprises, the continuity of production processes, and the affordability of product costs are largely dependent on the reliability and energy efficiency of the power supply system. In an environment where energy systems are becoming increasingly complex, it is one of the most pressing tasks not only to equip future engineers with theoretical knowledge, but also to prepare them to analyze, design, model, and optimize real production processes.

The subject "Power Supply of Industrial Enterprises" occupies an important place in shaping the professional training of future engineers at technical higher education institutions. Through this subject, students acquire professional and practical knowledge such as calculating electrical loads of industrial facilities, selecting transformer substations, drafting electrical network diagrams, determining short-circuit currents, selecting protective devices, and evaluating power quality.

However, in the traditional teaching process, students often study power supply systems based only on drawings, formulas, and static calculations. This limits their ability to deeply understand the dynamic changes, load fluctuations, emergency situations, and factors affecting system efficiency that occur in real production environments. For this reason, teaching this subject based on digital twin technology is considered an effective methodological solution for developing the professional competencies of future engineers.

Digital twin technology is an innovative technology that enables the creation of a virtual copy of a real object, process, or system in a digital environment, and allows monitoring, analyzing, and managing it in real time. In a power supply system, a digital twin serves to create a virtual model of transformers, power transmission lines, distribution devices, loads, protective means, and control systems.

The purpose of this article is to analyze the methodological possibilities of teaching the subject "Power Supply of Industrial Enterprises" based on digital twin technology, and to substantiate ways of developing future engineers' competency in designing power supply systems.

Literature Review

The use of digital technologies in engineering education has been widely researched in recent years in the fields of pedagogy, technical education, and energy. In foreign scientific literature, digital twin technology is interpreted as a tool for modeling, monitoring, and optimizing real objects in the areas of industrial production, energy, automotive, mechanical engineering, construction, and logistics.

The main advantage of digital twin technology is that it allows testing various technical conditions, modeling emergency situations, comparing efficiency indicators, and making optimal decisions without directly interfering with the real object. This aspect is especially important in engineering education, as students learn complex technical processes in a safe virtual environment.

From a pedagogical perspective, digital twin technology is directly linked to constructivist, competency-based, and activity-oriented educational approaches. The student does not passively receive ready-made knowledge, but independently constructs knowledge through working with a virtual model, analyzing a problem situation, developing a technical solution, and evaluating results.

Local research also emphasizes the need for digital modeling, virtual laboratories, automated design systems, and simulation-based teaching technologies in engineering education. Particularly in the energy field, practically oriented teaching methods are of great importance for developing students' competencies in calculation, design, technical analysis, and solving production problems. At the same time, existing scientific works have not sufficiently addressed the application of digital twin technology specifically to the subject "Power Supply of Industrial Enterprises". This creates a need to develop and scientifically substantiate methodological approaches in this direction.

Research Methodology

The study employed methods of theoretical analysis, comparative analysis, modeling, pedagogical observation, and a systematic approach. Through theoretical analysis, scientific sources on digital twin technology, engineering education, teaching power supply systems, and competency-based approaches were studied.

Using comparative analysis, the traditional teaching methodology and the teaching process based on digital twin technology were compared. Through the modeling method, the digital model of an industrial enterprise power supply system was considered as a didactic tool.

Methodologically, the research was based on the following approaches:

First, the competency-based approach. According to this approach, the student's acquisition of knowledge is not the final goal; rather, the main outcome is forming the ability to effectively use this knowledge in professional activity.

Second, the systems approach. The power supply system was analyzed not as a collection of separate elements, but as an integrated system of interconnected transformers, cable lines, loads, protective devices, control apparatus, and energy consumers.

Third, the activity-oriented approach. Students were directed toward designing the power supply system in a digital twin environment, identifying faults, assessing load changes, and making optimal technical decisions.

Fourth, the problem-based learning approach. In the teaching process, students are given problem situations close to real production processes — for example, tasks such as transformer overloading, voltage drop, short-circuit conditions, power quality disturbances, or selecting a backup supply scheme.

Analysis and Results

The use of digital twin technology brings the content of the subject "Power Supply of Industrial Enterprises" closer to real production processes. The student sees the power supply diagram of an industrial enterprise not merely as a drawing, but as an operational digital system. He or she observes in the virtual environment the increase or decrease of loads, changes in transformer temperature, voltage drops, emergency situations in the electrical network, and the operation of protective devices.

Teaching based on a digital twin creates the following didactic opportunities:

– creating a visual and interactive model of the power supply system;
– teaching students in conditions close to real production situations;
– modeling emergency situations in a safe virtual environment;
– analyzing changes in electrical loads in real time;
– pre-evaluating the effectiveness of technical decisions;
– organizing independent study and laboratory work in a digital environment.

In traditional teaching, a student sees the power supply diagram in the form of a paper or electronic drawing. In teaching based on a digital twin, the student gains the opportunity to observe how this diagram operates, the effect of each element on the system, and what consequences arise when a fault occurs.

For example, when teaching the topic of transformer substations, the following processes can be organized using digital twin technology:

– The student enters the electrical load of the industrial enterprise.
– The program presents options for selecting transformer capacity.
– The student compares transformers of different capacities.
– When the load increases, the transformer's heating and energy losses are observed.
– The optimal technical-economic solution is selected.

In this process, the student does not merely perform calculations but also sees the consequences of the technical decision. This develops his or her engineering thinking and professional responsibility.

Teaching organized on the basis of digital twin technology can be implemented in the following stages:

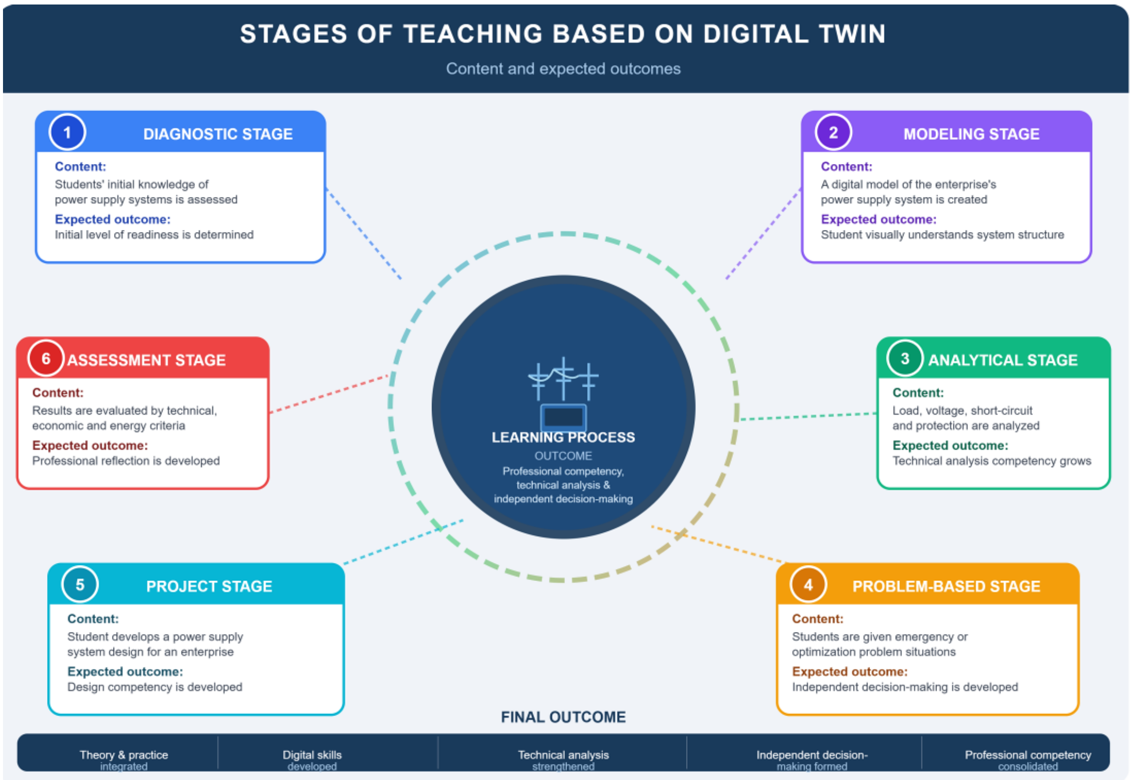

Figure 1. Stages of digital education teaching

In the teaching process based on a digital twin, the following competencies are developed:

Technical competency – deep understanding of the elements, diagrams, and operating principles of the power supply system.

Design competency – designing the power supply system of an industrial enterprise, selecting transformers, cables, protective devices, and distribution equipment.

Diagnostic competency – identifying faults, overloads, voltage drops, and short-circuit conditions in the system.

Digital competency – working with engineering software, simulation tools, and digital models.

Analytical competency – drawing conclusions and making optimal decisions based on technical data.

Innovative competency – improving energy efficiency, reducing electrical losses, and developing modern technological solutions.

Another important aspect of digital twin technology is that it enables the improvement of laboratory sessions. In traditional laboratory sessions, some experiments may be dangerous or costly in material terms. For example, testing a short-circuit condition on a real device is limited from a safety perspective. In a digital twin environment, however, such conditions can be safely modeled multiple times.

Digital twin technology also improves the effectiveness of independent study. A student can work with the virtual model outside the classroom, change various parameters, compare results, and form his or her own conclusions. This develops the student's independent thinking, engineering reasoning, and research skills.

Discussion

Introducing digital twin technology into the subject "Power Supply of Industrial Enterprises" requires new methodological preparation from the teacher. The teacher functions not only as a lecturer, but also as a designer of the digital environment, a manager of student activity, a technical consultant, and a methodologist who analyzes results.

In this context, the teaching process is integrated with the following methods:

– problem-based learning;
– project-based instruction;
– case study;
– virtual laboratory;
– simulation sessions;
– reflective assessment;
– collaborative project work.

Digital twin technology gives students the opportunity to find answers to the question "what will happen?" through experimentation. For example, questions such as "if the load increases by 25%, how will the transformer operate?", "if the cable cross-section is incorrectly selected, how will energy losses change?", "if a short circuit occurs, how should the protective device respond?" enliven the learning process.

This strengthens the practical orientation of engineering education and prepares students for real professional activity.

Conclusion

In conclusion, teaching the subject "Power Supply of Industrial Enterprises" based on digital twin technology brings the professional training of future engineers to a qualitatively new level. Through this technology, students not only study power supply systems theoretically, but also acquire skills in analyzing, designing, diagnosing, and optimizing them based on digital models.

Based on the research, the following conclusions were drawn:

First, digital twin technology enables the reflection of real production processes in a virtual environment when teaching power supply systems.

Second, this technology is an effective tool for developing students' technical, design, diagnostic, digital, and analytical competencies.

Third, teaching based on a digital twin improves the quality of laboratory sessions, independent study, and project work.

Fourth, through virtual modeling, the opportunity is created to safely study dangerous or complex production situations.

Fifth, digital twin technology strengthens collaboration between teacher and student, serving to organize the educational process in an active, interactive, and results-oriented manner.

Based on the research results, it is recommended to develop virtual laboratories, cases, project assignments, and digital assessment criteria based on digital twin technology when teaching the subject "Power Supply of Industrial Enterprises" at technical higher education institutions.

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