ABSTRACT
of the dissertation research by
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on the topic:
“RESEARCH AND DEVELOPMENT OF METHODS AND TOOLS FOR FORMATION A CUSTOMER-ORIENTED INTEGRATED AUTOMATED SYSTEM FOR CALCULATING AND MANUFACTURING TRANSFORMERS”,
submitted for the degree of Doctor of Philosophy (PhD) in the specialty
8D07103 – Automation and Control

General Characteristics of the Research. The dissertation research is submitted for defense in the form of a series of scientific articles in accordance with Clause 5-1 of the Rules for Awarding Academic Degrees (Order of the Minister of Science and Higher Education of the Republic of Kazakhstan No. 127 dated March 31, 2011, as amended on July 18, 2024).
The choice of this format is justified by the applicant’s authorship of three publications in international peer-reviewed scientific journals indexed in the Web of Science Core Collection and ranked in the first and second quartiles (Q1, Q2). The set of submitted articles constitutes a unified, completed scientific study, integrated by a common goal, methodology, and object of research.

Purpose of the Research. The purpose of the dissertation research is to improve quality and reduce production lead time of transformer equipment by creating an integrated automated system that combines design (CAD), engineering analysis (CAE), and manufacturing management (CAM) loops into a single digital environment with feedback.

Research Objectives:

1. To develop a method for numerical analysis and minimization of vibroacoustic activity of reactor equipment for integration into the system’s calculation module (solution presented in Article No. 3, *Cogent Engineering*).
2. To conduct experimental research and develop optimization algorithms for the solid insulation drying process for the technological module of the system (solution presented in Article No. 2, *Results in Engineering*).
3. To develop an architecture and principles for building customer-oriented design systems that take customer requirements into account at early design stages (solution presented in Article No. 1, *Journal of Computational and Cognitive Engineering*).
4. To create software and algorithmic tools (CAD systems) for implementing the proposed methods (solution presented in Article No. 1, *Journal of Computational and Cognitive Engineering*).

Object of Research. The object of the research is automated control of design and manufacturing processes of high-voltage oil-filled equipment (transformers and reactors).

Subject of Research: The subject of the research includes methods and algorithms for automating calculations, design, and control of technological manufacturing parameters (with vibroacoustic processes and insulation drying taken as case studies).

Research Methodology. The research methodology is based on an inductive systems approach and follows the principle "from the particular to the general":

1. Stage 1 (2023–2024): Problems of identification and automation of critical technological subsystems were solved.
   - A mathematical model for vibroacoustic analysis was developed (article in *Cogent Engineering*, Q2).
   - Control algorithms for the insulation drying process were synthesized for the CAM subsystem (article in *Results in Engineering*, Q1).
2. Stage 2 (2025): Based on the obtained models and algorithms, theoretical synthesis was performed. A general architecture of a customer-oriented system integrating these partial solutions was developed. The results were presented in a review and analytical article (*Journal of Computational and Cognitive Engineering*, Q1).

Scientific Novelty:

1. For the first time, the concept of a customer-oriented automated transformer manufacturing system has been substantiated, characterized by end-to-end integration of customer requirements into technological processes (drying, assembly).
2. A method for evaluating vibroacoustic characteristics of shunt reactors has been developed, accounting for the influence of structural dampers on resonance frequencies of the active part.
3. Regularities of solid insulation drying kinetics have been identified, enabling the development of an algorithm for selecting optimal thermo-vacuum treatment methods to enhance dielectric strength.

Main Provisions Submitted for Defense:

1. Architecture of an integrated design system ensuring transformation of customer requirements into verified technical solutions.
2. Methodology for computational analysis of reactor vibroactivity that ensures compliance with sanitary noise standards at the design stage.
3. Technological algorithm for controlling the insulation drying process, ensuring maximization of transformer service life through moisture removal without cellulose degradation.

Relevance of the Research.

Transformer manufacturing, as a key sector of power engineering, remains one of the most labor-intensive and conservative industries. Traditional design approaches based on fragmented CAD systems, document management, and planning tools no longer meet modern requirements for data processing speed, adaptability, and calculation accuracy.

Under Industry 4.0 conditions, transformer manufacturing faces a systemic problem: existing automation tools are fragmented. Designers work in isolated CAD systems, analysts use independent calculation packages, and technologists manage

manufacturing processes such as drying and assembly often based on empirical experience without direct digital linkage to the original design.

This discontinuity leads to loss of customer requirements at stage interfaces and neglect of physical production constraints (e.g., vibration risks) during design, increasing development time and reducing operational reliability.

Thus, an urgent scientific and practical task is the creation of a customer-oriented integrated automated system for transformer calculation and manufacturing, uniting engineering calculations, design and technological documentation, production processes, and customer interaction within a single digital enterprise environment.

Practical Significance.

The developed customer-oriented integrated automated system for transformer calculation and manufacturing has been implemented at Asia Trafo LLP and TRENCO R&D LLP, demonstrating significant technological, organizational, and economic effects.

The average project cycle duration was reduced from 45 to 30 calendar days, and technical documentation approval time from 10 to 3 days. Data transfer errors between design and production departments decreased more than fivefold.

The implemented vacuum drying technology under isostatic pressing increased insulation polymerization degree, improved dielectric properties, and extended transformer service life by 10-12%. Drying cycle time was reduced by more than half, and energy consumption decreased by 30%. Vibroacoustic measures reduced shunt reactor noise by 18% and vibration by 25%.

Economic efficiency is confirmed by a 22-25% reduction in direct design and order support costs, a 20-25% decrease in production cycle duration, and a 40% increase in engineering productivity, enhancing enterprise competitiveness and export potential.

Reliability of Results.

All results are confirmed by CAD-based computer modeling (TRDO/TDS), agreement with experimental data, and expert evaluations. Research findings were validated through publications in international peer-reviewed journals (Q1–Q2 Web of Science), national journals recommended by the Committee for Quality Assurance in Science and Higher Education, and obtained intellectual property protection documents.

Compliance with National Scientific Programs.

The research was conducted in accordance with approved research plans and within the framework of the following projects:

- GSSS/GMSN No. 5 dated November 10, 2021: “Development and implementation of a customer-oriented integrated automated system for transformer calculation and manufacturing”.
- AP14871951: “Extending transformer service life through research of solid insulation drying and pressing processes”.
- AP09057919: “Investigation of vibration and noise reduction in reactors of 110–750 kV voltage class”.

Structure of the Dissertation Submitted in the Form of a Series of Articles.

The dissertation is presented in the form of a series of scientific articles and intellectual property protection documents, published by the applicant individually and in co-authorship, in which the main scientific provisions of the dissertation are consistently presented and substantiated.

The dissertation includes the following publications:

1. **Tazhibayev A.A.**, Utepbergenov I.T., Skliarova I.V. *Development of Customer-Focused Automated Systems for Transformer Design and Manufacturing: A Comprehensive Review // Journal of Computational and Cognitive Engineering*. –2025.

*(*Author's contribution – the applicant initiated and prepared the main part of the review study, formulated the concept of customer-oriented automated systems, analyzed existing approaches, and generalized the results.)

2. **Tazhibayev A.**, Amitov Y., Arynov N., Shingissov N., Kural A. *Experimental investigation and evaluation of drying methods for solid insulation in transformers: A comparative analysis // Results in Engineering*. – 2024.

*(*Author's contribution – the applicant developed the experimental research methodology and participated in the processing and interpretation of experimental data.)

3. **Tazhibayev A.**, Utepbergenov I.T., Amitov Y., Ateyev D. *Assessing noise and vibration mitigation in low-vibroacoustic shunt reactors // Cogent Engineering*. – 2024.

(Author's contribution – the applicant made the primary contribution to the analysis of vibroacoustic characteristics and proposed engineering solutions for their reduction.)

4. **Tazhibayev A.A.**, Utepbergenov I.T., Amitov E.T., Ateyev D.T. *An approach to reducing noise and vibration of shunt reactors based on improvements in design and applied materials // Bulletin of the Almaty University of Power Engineering and Telecommunications*. – 2023.

(Author's contribution – the applicant developed design proposals and justified the selection of materials.)

5. **Tazhibayev A.**, Utepbergenov I., Amitov E., Skliarova Y., Kulakbayev G. *Analysis of automation strategy for an integrated customer-oriented system via smart digital nodes in distribution transformers // Bulletin of KazATC*. – 2024.

(Author's contribution – the applicant formulated the architecture of the automated system and participated in the development of control algorithms.)

6. Amitov E., **Tazhibayev A.,** Ateyev D., Arynov N., Shingissov N. *Investigation of drying and pressing methods for solid insulation of power transformers aimed at extending equipment service life // Bulletin of KazATC*. – 2024.

(Author's contribution – the applicant participated in problem formulation and analysis of research results.)

Intellectual Property Protection Documents Obtained Within the Dissertation Research

As part of the dissertation research, the following intellectual property protection documents were obtained:

- Certificate of registration in the State Register of Copyrighted Objects No. 28228 (2022): *Customer-oriented integrated automated calculation system "REng"*.

(Author's contribution – the applicant participated in the development of the software architecture and functional modules.).

- Patents for utility models and inventions (2022–2024), including high-efficiency battery energy storage systems, shunt reactors, current transformers, and continuous monitoring systems for transformer equipment.

(Author's contribution – the applicant participated in the development of technical solutions, schematic and structural parameters, as well as in the preparation of patent documentation.)

The first dissertation provision submitted for defense is substantiated in Publications 1 and 5, which are devoted to the development and analysis of customer-oriented automated systems for calculation and design of transformer equipment.

The second provision is substantiated in Publications 2 and 6, which investigate drying and pressing methods for solid insulation of power transformers and their impact on extending equipment service life.

The third provision is confirmed by the results presented in Publications 3 and 4, which address noise and vibration reduction in shunt reactors through design and materials engineering solutions.

The obtained patents and certificates are directly related to the practical implementation of the dissertation's scientific results and confirm their applied significance.

All publications comply with the requirements of Clause 5-1 of the *Rules for Awarding Academic Degrees*.