ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD) in the specialty 8D06101 – "Information Systems"

Shermantayeva Zhazira Utegenovna

Development of an information system for electric power industry using iot technology

The relevance of the study is justified by the following factors:

- Demand for energy and sustainable development: by 2040, global electricity demand is projected to increase by 70%. In Kazakhstan, consumption volumes are growing, and the task has been set to raise the share of renewable energy sources to 15% by 2030.
- Need for digital transformation: technologies based on Smart Grid, IoT and artificial intelligence aim to improve energy efficiency, reliability and competitiveness of the market.
- Instability of renewable energy sources: generation of wind and solar energy depends on climatic conditions, which requires reserve capacity and intelligent management to maintain power balance.
- Energy security: autonomy and resilience of local energy systems (microgrids) in emergency situations strengthen energy independence.
- Intelligent monitoring: systems based on FPGA and IoT perform real-time control, reducing losses and increasing reliability.
- Challenges of renewable energy integration: insufficient automation and generation instability can be addressed through Smart Grid, ESS and Demand Response technologies.

The present study proposes the formation of local energy systems through the implementation of intelligent monitoring and control systems based on IoT and Smart Grid technologies. These solutions make it possible to reduce energy losses by 12%, decrease the number of emergency outages and strengthen the energy security of Kazakhstan. The study aligns with the goals of the national project and contributes to the transformation of Kazakhstan's energy sector in line with global energy trends.

The main goal of the dissertation research is to create an information system based on IoT technology that ensures real-time monitoring and efficient operation of electric power systems.

To achieve this goal, the following tasks have been set:

1. Conduct an analysis of modern technologies and directions of digital transformation in the energy sector.
2. Develop a model for the operation of electric networks based on renewable energy sources.
3. Create an IoT monitoring device for the electric power system.

4. Develop an intelligent (Smart) monitoring system for the electric power system.

Object of research — electric power systems of the Turkestan region, in particular LLP “Oñtüstik Jaryq Transit”, 35/10 kV substation “Novaya” and distribution networks.

Subject of research — Smart Grid and intelligent energy systems, theory of information systems, architecture of information systems, artificial intelligence systems.

Theoretical and practical significance of the work

Theoretical significance:

1. A new methodology has been developed for assessing the reliability and quality of local electric energy systems (LEES) based on the synthesis of Markov processes and similarity theory (MSSB algorithm), and the applicability of an integral quality indicator has been scientifically substantiated.
2. A multi-level architecture of a hybrid information system combining IoT and FPGA technologies has been proposed, which complements the theory of information systems in energy.
3. New models for processing and managing data in real time have been developed, expanding the theoretical foundations of Smart Grid and microgrids.

Practical significance:

1. As a result of pilot implementation at substations of LLP “Oñtüstik Jaryq Transit” in Turkestan city, technological electricity losses decreased by 10%, the number of emergency outages reduced, and the average network loading factor increased from 0.67 to 0.76.
2. The developed software products (Energy Monitoring 360 and other modules) are protected by copyright and are used in actual operation.
3. The monitoring device based on FPGA and ESP32 is recommended for serial production.
4. The obtained results directly contribute to the implementation of the state program “Digital Kazakhstan” of the Ministry of National Economy of the Republic of Kazakhstan, as well as UN Sustainable Development Goal 7 (Affordable and Clean Energy).

The dissertation work contributes to the development of the theory of information systems in energy, and from a practical point of view, it strengthens the energy security of Kazakhstan and provides a specific economic effect.

Reliability and validity of the results In the course of the dissertation work, the following certificates were obtained as scientific works and entered into the state register: Copyright certificate No. 34772. Date of issue: 18.04.2023. Title: “Software complex for determining and visualizing the dynamics of a two-machine electric power system”. Copyright certificate No. 49103. Date of issue: 16.08.2024. Title: “Energy Monitoring 360”. Authors: Shermantayeva Zhazira Utegenovna, Mamyrbayev Orken Zhumazhanovich. Copyright certificate No. 110971. Year of issue: 2024. Title: “Hybrid model EWT-LSTM-RELM-IEWT and monitoring and forecasting system for emergency situations at electric power substations based on the Internet of Things” (Appendix Ә).

Approval of the dissertation work The research results were presented and discussed at the following scientific and practical conferences, as well as at scientific seminars of domestic research institutes and educational institutions (Appendix Б):

1. VII International Scientific and Practical Conference “Informatics and Applied Mathematics” (Almaty, October 20–21, 2022);
2. XIX International Asian School-Seminar “Problems of Optimization of Complex Systems” (August 14–22, 2023);
3. VIII International Scientific and Practical Conference “Informatics and Applied Mathematics” (Almaty, October 26–27, 2023);
4. Scientific seminars of the Institute “Information and Computing Technologies” (2020–2023, Almaty);
5. Scientific seminars of the Faculty of “Information Technologies” of Al-Farabi Kazakh National University (2020–2023, Almaty).

Publications Based on the dissertation materials, Zh.U. Shermantayeva published 13 articles. Of them: 4 articles were published in journals recommended by the Committee for Control in the Field of Science and Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan; 4 articles were published in proceedings of foreign and Kazakhstani international scientific and practical conferences; 5 articles were published in editions indexed in Scopus and Thomson Reuters databases.

Articles in the Scopus database (5 articles, including 1 in the 85th percentile)

1. Wójcik W., Lezhniuk P., Shermantayeva Z. Integrated Assessment of the Quality of Functioning of Local Electric Energy Systems // Energies. 2025. Vol. 18. Issue 1. Article 137. DOI: https://doi.org/10.3390/en18010137 (22 pp.).
2. Mamyrbayev O., Shermantayeva Zh. Cybersecurity Framework for IoT Integrated Electric Power Information Systems // International Journal of Industrial Engineering and Management. 2024. DOI: https://doi.org/10.24867/ijiem-376 (12 pp.).
3. Kalimoldayev M., Wójcik W., Shermantayeva Zh. Development Of A Monitoring System For Electric Power Substations Based On IoT And Implementation Of Designs On FPGA // International Journal of Electronics and Telecommunications. 2023. DOI: https://doi.org/10.24425/ijet.2023.147708 (10 pp.).
4. Wójcik W., Tymchenko L., Shermantayeva Z. Optical System Visualization of Combined Reflectance Model Based on Cubic and Quadratic Functions // Proceedings of SPIE - The International Society for Optical Engineering. 2023. DOI: https://doi.org/10.1117/12.3023138 (8 pp.).
5. Kalimoldayev M.N., Abdildayeva A.A., Shermantayeva Zh.U. Implementation of a Database on Solar Resources for the Design of PV Solar Technologies // Book Chapter. 2024. DOI: https://doi.org/10.1007/978-3-031-49711-7_26 (15 pp.).

Articles in journals included in the List of the CCSES of the Republic of Kazakhstan

1. Kalimoldayev M., Shermantayeva Zh. Model Development and Calculations for 35/10 kV Electrical Substations in Turkestan Region Using RastrWin3 Program // Scientific Journal of Astana IT University. 2024. DOI: https://doi.org/10.37943/16DGMZ9449 (14 pp.).
2. Wójcik W., Шермантаева Ж.У. Problems of development of the electric power industry based on IoT technology // Bulletin of KazNPU named after Abai. 2022. Vol. 78. No. 2. DOI: https://doi.org/10.51889/2022-2.1728-7901.16 (9 pp.).
3. Shermantayeva Z., Mamyrbayev O. Development and Creation of Hybrid EWT-LSTM-RELM-IEWT Modeling in High-Voltage Electric Networks // News of the National Academy of Sciences of the Republic of Kazakhstan. Physico-Mathematical Series. 2024. Vol. 3. No. 351. Pp. 223–240. DOI: https://doi.org/10.32014/2024.2518-1726.302 (18 pp.).
4. Wójcik W., Shermantayeva Zh. Parallel-Hierarchical Optical Network as a Model of Natural Neural Network // Optical Fibers and Their Applications. 2023. DOI: https://doi.org/10.1117/12.3023432 (6 pp.).

International conferences

1. Шермантаева Ж. Overview of the Internet of Things (IoT) in electric power industry and energy systems // 3rd Online International Conference on Renewable Energy and Sustainable Technologies. 2022. Proceedings: 97–108 pp. (12 pp.).
2. Шермантаева Ж.У., Ахметжанов М.А. Internet of Things for modern energy systems // VII International Scientific and Practical Conference “Informatics and Applied Mathematics”, Almaty, October 20–21, 2022. Proceedings: 112–120 pp. (9 pp.).
3. Шермантаева Ж.У. Application of data analysis and processing methods based on IoT for an electric substation in the Republic of Kazakhstan // “Problems of Optimization of Complex Systems”, Novosibirsk, August 14–22, 2023. Proceedings: 85–92 pp. (8 pp.).
4. Шермантаева Ж.У., Алшинбаева Д.О. Transformer distribution monitoring and fault elimination based on IoT technology // VIII International Scientific and Practical Conference “Informatics and Applied Mathematics”, Almaty, 2023. Proceedings: 7 pp.

Patents and certificates for intellectual property objects (3 objects)

1. Software complex for determining and visualizing the dynamics of a two-machine electric power system. Copyright certificate No. 34772 dated 18.04.2023.
2. Energy Monitoring 360. Copyright certificate No. 49103 dated 16.08.2024. Authors: Shermantayeva Zhazira Utegenovna, Mamyrbayev Orken Zhumazhanovich.
3. Monitoring and forecasting system for emergency situations at electric power substations based on the Internet of Things and hybrid model EWT-LSTM-RELM-IEWT. Utility model, Reg. No. 2024/1652.2 dated 25.12.2024. Authors: Mamyrbayev O.Zh., Shermantayeva Zh.U.

Structure of the work The dissertation consists of an introduction, four chapters, conclusion, list of references and appendices.

Definitions: IoT, FPGA, Smart Grid, energy cells, etc. Designations: RES (ВИЭ), transmission lines (ЛЭП), ESS, SCADA.

Introduction: The goal and objectives of the research are substantiated, scientific novelty is presented. During the work, 13 scientific articles were published, including in authoritative international and republican editions. Copyright certificates were obtained and entered into the state register for 2 objects (No. 34772 dated April 18, 2023 and No. 49103 dated August 16, 2024), as well as a certificate for a utility model No. 110971.

Chapter 1: Modern trends in digital transformation in electric power industry and information technologies.

Chapter 2: Information structure and models of electric power systems. Chapter 3: Methods of data processing and forecasting in electric power systems. Chapter 4: Design, development and implementation of an information system based on IoT for electric power industry.

Conclusion: Conclusions, recommendations, areas of application. List of references: 131 sources. Appendices: Diagrams, codes, results, charts.

Scientific internship: Lublin University of Technology, Lublin, Poland, from April 29 to June 27, 2023.