ANNOTATION

of dissertation work (series of articles) for the Philosophy Doctor (PhD) degree in specialty "8D06201–Radioengineering, electronics and telecommunications" by

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on the topic

OPTIMIZATION AND EFFICIENCY IMPROVEMENT OF PHOTOVOLTAIC SYSTEMS WITH POWER OUTPUT PREDICTION BASED ON ARTIFICIAL INTELLIGENCE

The dissertation work (series of articles) is dedicated to the study of optimizing and improving the efficiency of photovoltaic system power output forecasting using artificial intelligence and intelligent algorithms. High-accuracy forecasting of photovoltaic system power output, their integration with solar trackers, and the use of intelligent algorithms allow for the full realization of their potential.

Relevance of the dissertation theme

The relevance of this research is driven by the need to apply control algorithms for photovoltaic systems based on power output forecasting, which allows for increased efficiency, reduced losses, and reliable integration into a sustainable energy system. Despite significant advances in solar panels and their associated converters, the operational efficiency of photovoltaic systems is limited by several factors: the variability of solar radiation, weather conditions, partial shading, and load instability. Traditional methods for forecasting and managing solar installations lack sufficient adaptability to rapidly changing illumination conditions and, as a result, demonstrate low efficiency during cloudy weather.

The use of artificial intelligence in the management, forecasting, and optimization of photovoltaic installations opens up new opportunities to enhance their efficiency and reliability. Machine learning algorithms allow not only the analysis and accurate forecasting of electricity generation based on large datasets that account for solar radiation dynamics, weather conditions, and system technical status, but also the optimization of solar tracker control strategies. This ensures maximum utilization of available solar energy, cost reduction, and overall improvement in the performance of photovoltaic systems.

The inability of a photovoltaic system to operate at its maximum power point prevents full utilization of its potential and reduces its overall energy efficiency. For this reason, an equally important direction for improving the efficiency of photovoltaic systems is the implementation of intelligent control based on advanced Maximum Power Point Tracking (MPPT) algorithms.

Although traditional MPPT methods, such as Perturb and Observe (P&O) or Incremental Conductance (IncCond), are widely used, they suffer from slow maximum power point tracking and can produce errors under rapidly changing weather conditions or partial shading of solar panels. Intelligent agent-based MPPT

algorithms are capable of finding the maximum power point faster than traditional methods and achieve higher conversion efficiency, as they adapt to changing environmental conditions and utilize the interaction of multiple agents to identify the optimal solution.

Therefore, improving MPPT controller algorithms based on intelligent control is one of the key factors in enhancing the significance of solar energy and reducing energy losses.

Objective of the research

To optimize and improve the efficiency of a photovoltaic system's power output through the use of intelligent algorithms and artificial intelligence–based forecasting.

Research Tasks

To achieve the objective of this study, the following tasks need to be addressed:

- To predict the output power of photovoltaic systems equipped with horizontally oriented panels, single-axis and dual-axis solar trackers on cloudy days using artificial intelligence, experimentally verify its accuracy, and also investigate the output power of a solar tracker with adaptive control and compare it with the results of these systems.
- Study, experimentally test, and compare an MPPT controller using intelligent optimization algorithms with other MPPT algorithms to enhance the power output of the photovoltaic system.
- Investigate the maximum power point tracking algorithm of a photovoltaic system under varying load conditions to improve the system's reliability.

Research methods

- Forecasting the power output of photovoltaic systems using machine learning algorithms such as LSTM, GRU, XGBoost, and 1D-CNN.
- Investigation of the tracking time and efficiency of the maximum power point using the Social Spider Optimization algorithm for the MPPT controller through simulation of various shading conditions.
- Investigation of the maximum power point tracking time using the Heavy Ball Optimization algorithm for the MPPT controller through simulation of varying load conditions.

Object of the research

Intelligent adaptive solar tracking system and MPPT controller.

Subject of the research

Photovoltaic system power output, machine learning algorithms, forecasting accuracy index, adaptive solar tracker, metaheuristic algorithms, current–voltage characteristics of photovoltaic systems, partial shading, and photovoltaic system load.

Scientific Novelty of the research

The scientific novelty of this work lies in the fact that, for the first time:

1. The threshold value of the clear-sky index was determined, at which the power output of a horizontally configured photovoltaic system exceeds that of solar trackers for the climatic zone of Almaty.

2. The Social Spider Optimization (SSO) algorithm for the MPPT controller under partial shading was improved, and its parameters were optimized to simplify tuning.

3. The Heavy Ball algorithm was optimized and applied to MPPT controllers to eliminate errors caused by load fluctuations.

The main provisions for the defense.

1. Intelligent dual-axis tracker, using the clear-sky index and AI-based power output forecasting under conditions of strong diffuse sunlight, generates 18.3%, 14.9%, and 10.01% more energy compared to horizontal, single-axis, and dual-axis trackers, respectively.

2. The Maximum Power Point Tracking (MPPT) controller based on the Improved Social Spider Optimization (ISSO) algorithm converts photovoltaic system energy with an efficiency of 99.8%.

3. Under changing load conditions, the MPPT controller based on the Heavy Ball algorithm identifies the maximum power point within 0.1 seconds.

Practical and theoretical importance of the dissertation.

The results of this research have significant theoretical and practical value for the design of photovoltaic systems with dual-axis trackers and maximum power point tracking (MPPT) controllers operating under variable cloudiness conditions. The findings can be used to optimize and enhance the reliability of large photovoltaic installations in regions with fluctuating cloud cover and sudden load changes.

Reliability and validity of the results

The reliability of the results is supported by publications in international scientific journals indexed in global databases with an impact factor above 4. Experimental studies based on the developed model demonstrated a high degree of agreement between the obtained data and calculated values.

The personal contribution of the author

The author independently carried out all parts of the research, including processing the obtained data in Python and using machine learning algorithms to forecast the power output of photovoltaic systems, mathematical modeling of the clear-sky index in Matlab, simulation of various shading conditions in Matlab Simulink, as well as the development and optimization of the MPPT algorithm. Experimental results were obtained using the Chroma Solar Simulation device and compared with other algorithms. The analysis of results and the formulation of research tasks were conducted with the guidance of the scientific supervisors.

Approbation of the Dissertation Work

The results of the dissertation work (series of articles) were published in the following sources and presented and discussed at scientific conferences:

Articles Published in Journals Indexed in International Scientific Databases (Thomson Reuters and Scopus):

1. **Koshkarbay N.,** Mekhilef S., Saymbetov A., Kuttybay N., Nurgaliyev M., Dosymbetova G., Orynbassar S., Yershov E., Kapparova A., Zholamanov B., Bolatbek, A. Adaptive control systems for dual axis tracker using clear sky index and output power forecasting based on ML in overcast weather conditions //Energy

and AI. – 2024. – V. 18. – P. 100432. **WOS: IF 9.6, Q1; Scopus: CiteScore 16.5, Percentile: 96%** https://doi.org/10.1016/j.egyai.2024.100432

2. **Koshkarbay N.,** Mohammed K. K., Mekhilef S., Kuttybay N., Almen D., Saymbetov A., Nurgaliyev M. Improved MPPT technology for PV systems using Social Spider optimization (SSO): Efficient handling of partial shading and load variations //Electric Power Systems Research. – 2025. – V. 247. – P. 111822. **WOS: IF 4.2, Q2; Scopus: CiteScore 8.2, Percentile: 84%** https://doi.org/10.1016/j.epsr.2025.111822

3. Kuttybay N., Mekhilef S., **Koshkarbay N.,** Saymbetov A., Nurgaliyev M., Dosymbetova G., Orynbassar S., Yershov E., Kapparova A., Zholamanov B., Bolatbek, A. Assessment of solar tracking systems: A comprehensive review //Sustainable Energy Technologies and Assessments. – 2024. – V. 68. – P. 103879. **WOS: IF 7, Q2; Scopus: CiteScore 17.3, Percentile: 95%** https://doi.org/10.1016/j.seta.2024.103879

Utility Model Patent

1. Kuttybay N, **Koshkarbay N.**, Saymbetov A., Nurgaliev M., Zholamanov B., Orynbasar S., Bolatbek A., Almen D., Система измерения метеорологических параметров для оптимизации фотоэлектрических установок, Пайдалы модельге патент №10890, Қазақстан Республикасы. Өтініш беруші және патентке иелік етуші әл-Фараби атындағы ҚазҰУ. 07.03.2025 жыл, №10890

Scientific Articles in Journals Recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science

1. Құттыбай Н.Б., Кусаин М.А., **Қошқарбай Н.Ж.**, Айтбекова Ш.Б., Есен Б.Е., Повышение эффективности фотоэлектрических систем с использованием солнечных трекеров, Вестник Торайгыров университета. Энергетическая серия (автоматизация,автоматизированные и информационныесистемы). – 2023. – № 4. С. 214-226. https://doi.org/10.48081/ZUNP4311

2. Құттыбай Н.Б., Аманжол Ә.А., **Қошқарбай Н.Ж.**, Жоламанов Б.Н., Сейтжанова А.К., Разработка системы слежения за солнцем на основе технологии Интернета вещей (IoT), Вестник КазНПУ. Серия «Физико-математические науки» (автоматизация, автоматизированные и информационные системы). – 2024. – № 2 (86). С. 211-221. https://doi.org/10.51889/2959-5894.2024.86.2.020

3. Құттыбай Н.Б., Айтбекова Ш.Б., **Қошқарбай Н.Ж.**, Болатбек А.Б., Жоламанов Б.Н. Прогнозирование выходной мощности фотоэлектрической системы на основе нейронных сетей, Вестник КазУТБ. Информационно-коммуникационные технологии. – 2024. №1 (22). С. 84-96. https://doi.org/10.58805/kazutb.v.1.22-255

4. Құттыбай Н.Б., Есен Б.Е., **Қошқарбай Н.Ж.**, Жоламанов Б.Н., Болатбек А.Б., Разработка эффективного контроллера отслеживания точки максимальной мощности для фотоэлектрической системы, Труды университета. Раздел «Автоматика. Энергетика. ИКТ». – 2024. – №1 (94). С. 499 – 507. DOI 10.52209/1609-1825_2024_1_499

5. Құттыбай Н.Б., Иманбаев Б.С. Ершов Э.П., **Қошқарбай Н.Ж.**, Разработка автоматизированной метеостанции для мониторинга климатических параметров, Вестник КазАТК. Автоматизация, телемеханика, связь, компьютерные науки. – 2025. – №3 (138). DOI 10.52167/1609-1817-2025-138-3