frontiers | Frontiers in Energy Research

TYPE Editorial
PUBLISHED 23 January 2024
DOI 10.3389/fenrg.2024.1365496

OPEN ACCESS

EDITED AND REVIEWED BY
Michael Folsom Toney,
University of Colorado Boulder, United States

*CORRESPONDENCE
Fouzi Harrou,
fouzi.harrou@kaust.edu.sa

RECEIVED 04 January 2024
ACCEPTED 15 January 2024
PUBLISHED 23 January 2024

CITATION
Harrou F, Sun Y, Taghezouit B, Dairi A and Khadraoui S (2024), Editorial: Advanced data-driven methods for monitoring solar and wind energy systems, volume II.
Front. Energy Res. 12:1365496.
doi: 10.3389/fenrg.2024.1365496

Editorial: Advanced data-driven methods for monitoring solar and wind energy systems, volume II

Fouzi Harrou[1]*, Ying Sun[1], Bilal Taghezouit[2], Abdelkader Dairi[3] and Sofiane Khadraoui[4]

[1]Computer, Electrical and Mathematical Sciences and Engineering (CEMSE) Division, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia, [2]Centre de Développement des Energies Renouvelables (CDER), Algiers, Algeria, [3]Computer Science Department, University of Science and Technology of Oran-Mohamed Boudiaf (USTO-MB), Bir El Djir, Algeria, [4]Department of Electrical Engineering, University of Sharjah, Sharjah, United Arab Emirates

KEYWORDS

wind turbine, photovoltaic systems, wind and solar power prediction, fault detection, cybersecurity, data-driven methods

Editorial on the Research Topic
Advanced data-driven methods for monitoring solar and wind energy systems, volume II

Wind turbine fault and damage diagnosis and prognosis

Renewable energy systems, including solar and wind power, are pivotal contributors to tackling global challenges, such as climate change, reducing fossil fuel dependence, and promoting sustainable development. Solar power harnesses the boundless energy radiated by the sun, offering an abundant and environmentally friendly alternative to traditional fossil fuels. Simultaneously, wind energy capitalizes on the kinetic energy of the atmosphere, converting it into electricity through technologically advanced wind turbines. These systems mitigate environmental degradation, curb greenhouse gas emissions, and contribute to resilient energy infrastructures by harnessing clean and abundant natural sources. In the face of increasing global energy needs, the shift towards renewables becomes increasingly critical for ensuring energy security, fostering innovation, and sustaining a cleaner, more equitable future.

The rapid evolution of the renewable energy market has resulted in a substantial surge in demand for photovoltaic systems and wind turbines. Despite their promising potential, the efficacy of these systems can be compromised when faults or cyber-attacks occur. In particular, disruptions in photovoltaic and wind power production can decrease overall energy output. Therefore, the precise detection and identification of faults and the prevention of cyber-attacks are crucial aspects of the operation of photovoltaic plants and wind turbines. Effectively addressing these challenges is essential to ensure that the generated power consistently meets the desired levels, contributing to the reliability and sustainability of renewable energy sources. In this context, advancing fault detection and cybersecurity technologies become paramount for the continued success and widespread adoption of photovoltaic and wind energy systems.

Over the years, operators have faced persistent challenges. Advanced instrumentation, control, and automation generate voluminous data, often unexploited, resulting in the data-rich, information-poor dilemma. Timely analysis and modeling are imperative to extract valuable information that enhances process understanding, enables online prediction, facilitates process monitoring, and supports predictive control. Employing advanced data-driven methods is vital in monitoring, modeling, and fault detection, improving the prediction accuracy and overall performance of these renewable energy systems and supporting the integration of renewable energy in the power grid.

This Research Topic is motivated by the requirements posed in the specifications of the advanced renewable energy systems (wind and solar), and new relevant concepts where machine learning can potentially be a true enabler. Artificial Intelligence (AI) methods, such as machine learning and deep learning, are critical in monitoring and optimizing solar PV and wind energy systems' performance, reliability, and efficiency. These methods can analyze large amounts of data from the systems and identify patterns and trends that are not immediately apparent to humans. The focus is on innovative contributions related to fault detection, diagnosis, power prediction, condition monitoring, and the application of data-based methods for optimizing these renewable energy systems.

This collection extends the previous volume, "*Advanced Data-driven Methods for Monitoring Solar and Wind Energy Systems*." Following a rigorous review process, eight high-quality articles contributed by 39 authors were finally accepted for their contributions to the Research Topic.

In the article "*Wind power interval prediction based on variational mode decomposition and the fast gate recurrent unit*," Zhang et al. tackle the challenge of integrating large-scale wind power into the grid due to the uncertainty of wind power. They introduce a wind interval prediction model that incorporates Variational Mode Decomposition (VMD) and the Fast Gate Recurrent Unit (F-GRU), with parameter optimization accomplished via an Improved Whale Optimization Algorithm (IWOA). This approach involves decomposing the wind power series into Intrinsic Mode Function (IMF) components using VMD, constructing an interval prediction model based on lower and upper bound estimation, and optimizing F-GRU parameters with IWOA to derive the final prediction interval. Results based on wind power datasets extracted from a wind farm revealed that the hybrid model VMD-IWOA-F-GRU performs well in wind power prediction.

In the article "*Probabilistic prediction of wind power based on improved Bayesian neural network*" Deng et al. propose a Bayesian LSTM neural network (BNN-LSTM) constructed on Bayesian networks, incorporating *a priori* distributions on the LSTM network layer weight parameters. The methodology uses a temporal convolutional neural network (TCNN) to process historical time-series data for wind power prediction, aiming to extract correlation features and capture trend changes in the time-series data. Additionally, the authors apply the mutual information entropy method to analyze meteorological datasets, reducing dimensionality and simplifying the prediction model structure by eliminating variables with low correlation. Simultaneously, the Embedding structure is employed to acquire temporal classification features related to wind power. The final prediction model integrates TCNN-processed time series data, dimensionality-reduced meteorological data, and temporal classification features into the BNN-LSTM. Comparative analysis with Bayesian neural network, continuous interval method, and Temporal Fusion Transformer (TFT) demonstrates that the improved BNN-LSTM yields more accurate responses to wind power fluctuations, resulting in superior prediction outcomes.

The article by Wang and Niu, titled "*Wind power output prediction: a comparative study of extreme learning machine*," addresses the need for accurate wind power prediction to mitigate the impact on power systems and alleviate scheduling challenges in wind power-integrated systems. The study introduces an improved tunicate swarm algorithm–extreme learning machine (ITSA-ELM) model, where the improved tunicate swarm algorithm (ITSA) optimizes the random parameters of the extreme learning machine (ELM) for enhanced prediction performance. ITSA overcomes the drawbacks of the tunicate swarm algorithm (TSA) by introducing a reverse learning mechanism, a non-linear self-learning factor, and a Cauchy mutation strategy. The comparative analysis with TSA-ELM demonstrates ITSA-ELM's superiority, showing a decrease of 1.20% and 21.67% in Mean Absolute Percentage Error (MAPE) in May and December, respectively.

In the article "*Polynomial surface-fitting evaluation of new energy maximum power generation capacity based on random forest association analysis and support vector regression*," Hu et al. focused on frequency issues stemming from wind power integration in ultra-high-voltage DC systems. Importantly, they assess the maximum generation capacity of large-scale new energy sources to enhance frequency regulation capacity and improve frequency stability control in power systems. The approach involves constructing a random forest model to analyze key features and select relevant indexes for the generation capacity. An innovative aspect of the proposed model involves the maximization analysis processing of key feature variables. Polynomial surface-fitting iterative calculation constructs the upper envelope in the 3D scatterplot of the key feature variable—wind plant output—to meet maximization evaluation requirements. Furthermore, the study employs the Whale Optimization Algorithm–Support Vector Regression (WOA–SVR) algorithm to predict maximum power generation capacity, demonstrating its superiority over the unoptimized SVR algorithm through a comparative analysis. The accuracy of the new energy maximum generation capacity assessment model, grounded in feature selection and maximization processing, significantly influences assessment and analysis results. While the data-driven model can integrate with the maximum power tracking point of the physical model to analyze the available Frequency Modulation (FM) capacity of new energy, the study acknowledges limitations in dealing with sparse data point distributions. The authors suggest further studies involving a physical model for a more comprehensive analysis.

In the article "*An evaluation method of health condition for wind turbine based on asymmetric proximity*," Zhang et al. present a wind turbine condition assessment method based on asymmetric proximity. The method establishes a comprehensive state evaluation index system, integrating performance and output state indices of the wind turbine with weighting factors derived from a combination of subjective and objective weights. Subsequently, the membership function is formulated using set pair analysis, and the target layer's membership is deduced through the weighted average operator. The wind turbine state determination is guided by proximity degrees between status levels and target membership, aligning with the proximity principle. The effectiveness of this approach is evaluated using 2 years of data from 32 wind turbines within the same wind farm. Results indicate an accuracy rate of 97%, surpassing the maximum membership principle and reliability criterion by 6% and 8%, respectively. This approach contributes to a more reasonable and accurate assessment of wind turbine status.

In the article "*Distributed photovoltaic power output prediction based on satellite cloud map video frames*," Shaohua et al. introduce an innovative approach for predicting distributed photovoltaic (PV) power output based on satellite cloud map video frames. The method utilizes a dynamic convolutional generative adversarial network (DC-GAN) for irradiance prediction and a coupled Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) (CNN-LSTM) model for output prediction. Spatial correlations and various meteorological factors are considered. Specifically, this approach utilizes satellite cloud map video frames in the irradiance prediction stage. Video frames are established based on cloud map shading characteristics, and a DC-GAN model predicts future shading effects using dynamic changes from past periods as input. The CNN-LSTM model, combined with spatial correlations of centralized photovoltaic stations, then predicts irradiance data for distributed stations. In the distributed photovoltaic output prediction stage, the CNN network extracts irradiance features from future short-term cloud maps, followed by the establishment of a multi-layer photovoltaic output prediction model based on LSTM. This model utilizes irradiance information and additional meteorological data as input sequences, providing output predictions for distributed photovoltaic power stations in the near future. Comparative experiments confirm the superiority of the CNN-LSTM method over traditional approaches, demonstrating a significant 3.3% increase in prediction accuracy.

In the article "*Radical innovation detection in the solar energy domain based on patent analysis*," Feng and Han present a novel framework for detecting radical innovations in the solar energy domain through patent analysis. The proposed method combines technological convergence and scientific relation analysis, utilizing link prediction to identify potential radical innovations. Key findings include the uneven distribution of technological classes and scientific categories, with the top 15 classes representing 75.46% of all classifications. Additionally, 130 patents with new convergence relationships are identified as radical innovations, primarily in solar photovoltaic, heat storage, heat exchangers, and solar collectors. The study identifies five potential radical innovation topics, such as automatic plants for producing electric energy and solar energy ecology houses, with implications for scientists, policymakers, and investors in the solar energy domain. The results align with authoritative reports, validating the effectiveness of the proposed framework.

In the mini-review article "*Cybersecurity of photovoltaic systems: challenges, threats, and mitigation strategies: a short survey*," Harrou et al. surveys the cybersecurity challenges faced by PV systems, emphasizing their increased vulnerability to cyber threats and anomalies due to their reliance on standard IT infrastructure. The expansion of PV systems in the energy sector has led to a rise in reported cyber-attacks. The paper highlights the urgency of implementing robust cybersecurity measures to safeguard the integrity and reliability of PV installations within the power grid. Pertinent strategies include a multi-layered approach with Intrusion Detection and Prevention Systems (IDS/IPS) to monitor real-time network activity and respond quickly to threats. Additionally, adopting encryption, firewalls, secure communication protocols, regular software updates, and user training programs are vital to enhancing system cybersecurity and resilience.

This Research Topic emphasizes applying data-driven techniques, including machine learning and deep learning, to enhance the monitoring and prediction of wind and solar energy systems. These approaches are gaining prominence due to advancements in sensor technology, high-speed internet, and cloud computing and are expected to play a crucial role in advancing the condition monitoring and performance management of wind turbines and photovoltaic systems. The guest editors thank the authors for their valuable contributions and the reviewers for their careful evaluations. Special thanks are also conveyed to the journal's editor-in-chief and the editorial board for their support throughout this Research Topic.

Author contributions

FH: Conceptualization, Formal Analysis, Investigation, Writing–original draft, Writing–review and editing. YS: Conceptualization, Investigation, Resources, Supervision, Writing–original draft. BT: Conceptualization, Formal Analysis, Investigation, Writing–original draft. AD: Conceptualization, Formal Analysis, Investigation, Writing–original draft. SK: Conceptualization, Formal Analysis, Investigation, Writing–review and editing.

Acknowledgments

The guest editors would like to extend their gratitude to all the authors for their insightful contributions, as well as to all the reviewers for their tremendous work on the reviews. We would especially want to thank the journal's editor-in-chief and the editorial board for their outstanding support of this Research Topic.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note