



**EDITORIAL**

## **Introduction to the Special Issue on Advanced Artificial Intelligence and Machine Learning Methods Applied to Energy Systems**

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Diverse energy and power systems have been playing a significantly critical role in the revolution of sustainable energy supply for the future, which have a great impact on energy resources and efficiencies. Due to the emerging artificial intelligence and machine learning, traditional modeling techniques in these energy systems have met challenges in still leveraging physics model and first principle-based approaches. Moreover, with the rapid development of hardware and computing techniques, new modeling approaches for energy systems have become more and more important for system design, integration, analysis, control, and management. A total of 18 were selected based on a robust peer-reviewed process. The 18 articles are authored by researchers from world-wide universities, and are worthwhile to explore and present and disseminate the most recent advances related to modeling theory, approaches, and applications of energy systems.

The first paper “Intelligent Fractional-Order Controller for SMES Systems in Renewable Energy-Based Microgrid” by Alatwi et al. [1], introduces a hybrid dual-loop control method to stabilize the DC-link in a DC microgrid. Simulation results demonstrate the superior performance of the proposed controller in a 33.3% reduction in the objective function. This reduction holds significant implications for developing hybrid distributed energy systems, fostering the widespread integration of renewable energy sources (RESs) globally.

The second paper “Multi-Step Clustering of Smart Meters Time Series: Application to Demand Flexibility Characterization of SME Customers” by Bañales et al. [2], proposes an innovative multi-step clustering procedure to segment customers based on load-shape patterns at the daily and intra-daily time horizons, by a real-world electricity consumption dataset of 325 Small and Medium-sized Enterprise (SME) customers. The application of the methodology includes selecting key parameters via grid search to ensure the robustness of the results.

The third paper “Stability Prediction in Smart Grid Using PSO Optimized XGBoost Algorithm with Dynamic Inertia Weight Updation” by Binbusayyis and Sha [3], dedicates to predict stability from the smart grid stability prediction dataset using machine learning algorithms. The regression process is performed using Modified PSO optimized XGBoost Technique with dynamic inertia weight update. The hyperparameters of XGBoost are fine-tuned for achieving promising outcomes on prediction. Regression results are measured through evaluation metrics which determine the efficacy of the system.

The fourth paper “Enhancing Safety in Electric Vehicles: Multi-Tiered Fault Detection for Micro Short Circuits and Aging in Battery Modules” by Luo et al. [4], develops a multi-tiered fault detection algorithm for series-connected lithium-ion batteries. Simulations and experiments conducted under various levels of micro short circuits validate the effectiveness of the algorithm, demonstrating its ability to distinguish

between short-circuited, aged, and normal batteries under different conditions. This technology can be applied to enable early warnings to ensure safety and prevent thermal runaway.

The fifth paper “Prediction and Comparative Analysis of Rooftop PV Solar Energy Efficiency Considering Indoor and Outdoor Parameters under Real Climate Conditions Factors with Machine Learning Model” by Şahin et al. [5], investigates the influence of indoor and outdoor factors on photovoltaic (PV) power generation at Utrecht University to accurately predict PV system performance by identifying critical impact factors. The machine learning models used for solar energy forecasting show high performance and produce results close to actual values.

The sixth paper “Enhanced Fault Detection and Diagnosis in Photovoltaic Arrays Using a Hybrid NCA-CNN Model” by Turhal et al. [6], proposes a hybrid model integrating Neighborhood Components Analysis (NCA) with a Convolutional Neural Network (CNN) to improve fault detection and diagnosis. The hybrid model combines NCA with CNN, a fundamental deep learning architecture, to enhance fault detection and diagnosis capabilities. The experimental evaluation demonstrates that the NCA-CNN model outperforms existing methods.

The seventh paper “Predicting Short-Term Wind Power Generation at Musalpetti Wind Farm: Model Development and Analysis” by Rathnayake et al. [7], develops a machine learning-based predictive model for the Musa petti Wind Farm in Sri Lanka to address the need for localized forecasting solutions. Using data on wind speed, air temperature, nacelle position, and actual power, lagged features were generated to capture temporal dependencies. These findings underscore the reliability of short-term predictions.

The eighth paper “A Hybrid LSTM-Single Candidate Optimizer Model for Short-Term Wind Power Prediction” by Balci et al. [8], presents an innovative hybrid method for short-term wind power prediction by combining a Long Short-Term Memory (LSTM) network with a Single Candidate Optimizer (SCO) algorithm. Experimental findings demonstrate that the SCO-optimized model enhances prediction accuracy by up to over standard LSTM implementations.

The ninth paper “Extending DDPG with Physics-Informed Constraints for Energy-Efficient Robotic Control” by Elsafi et al. [9], propose Physics-Informed DDPG (PI-DDPG), which integrates physics-based energy penalties to develop energy-efficient yet high-performing control policies. Experimental results confirm that PI-DDPG substantially reduces energy consumption compared to standard DDPG, while maintaining competitive task performance.

The tenth paper “A Flexible Decision Method for Holonic Smart Grids” by Taleb et al. [10], proposes a novel control and simulation framework based on a holonic multi-agent architecture. The major results demonstrate the system’s dual resilience mechanisms. Collectively, these findings validate the holonic model as a robust decision-support tool capable of managing both systemic and localized faults, thereby significantly enhancing the operational resilience and stability of isolated smart grids.

The eleventh paper “IoT Based Transmission Line Fault Classification Using Regularized RBF-ELM and Virtual PMU in a Smart Grid” by Swain et al. [11], presents a regularized radial basis function (RBF) Extreme learning machine (ELM)-based fault detection and classification system for transmission lines, utilizing a LabVIEW based virtual phasor measurement unit (PMU) and IoT sensors. The proposed methodology is validated in real-time on a practical transmission line. This has the potential to significantly influence future fault detection strategies.

The twelfth paper “Efficient Time-Series Feature Extraction and Ensemble Learning for Appliance Categorization Using Smart Meter Data” by Madran et al. [12], proposes a novel, computationally efficient framework for feature extraction and selection tailored to smart meter time-series data. The proposed

solution demonstrates a high classification accuracy (97.93%) for the case of nine-class problem and dimension reduction (17.33-fold) with minimal front-end computational requirements.

The thirteenth paper “A Review of Modern Strategies for Enhancing Power Quality and Hosting Capacity in Renewable-Integrated Grids: From Conventional Devices to AI-Based Solutions” by El-Ela et al. [13], provides a comprehensive overview on the exit strategies to enhance distribution system operation, with a focus on harmonic mitigation, voltage regulation, power factor correction, and optimization techniques. Modern optimization algorithms are also discussed as effective procedures to find the settings for power system components for optimal operation.

The fourteenth paper “Optimizing Performance Prediction of Perovskite Photovoltaic Materials by Statistical Methods-Intelligent Calculation Model” by Fan et al. [14], proposes a novel methodology by hybridizing the random forest-knowledge distillation-bidirectional gated recurrent unit with attention technology (namely RF-KD-BIGRUA), which is applied in perovskite photovoltaic materials. The results demonstrate that integrating statistical techniques into intelligent optimization models can quantify photovoltaic system uncertainties.

The fifteenth paper “Spatio-Temporal Graph Neural Networks with Elastic-Band Transform for Solar Radiation Prediction” by Choi [15], proposes a novel forecasting framework that simultaneously captures the strong periodicity and irregular meteorological fluctuations inherent in solar radiation time series. Adopt the Elastic-Band Transform (EBT) to decompose solar radiation into periodic and amplitude-modulated components, which are then modeled independently with separate graph neural networks. The experimental results demonstrate improved predictive accuracy compared to conventional methods.

The sixteenth paper “TransCarbonNet: Multi-Day Grid Carbon Intensity Forecasting Using Hybrid Self-Attention and Bi-LSTM Temporal Fusion for Sustainable Energy Management” by Ksibi et al. [16], proposes a novel hybrid deep learning framework with self-attention characteristics added to the bidirectional Long Short-Term Memory (Bi-LSTM) network, namely the TransCarbonNet, to forecast the carbon intensity of the grid several days. The effectiveness of the proposed solution has been validated in numerous cases of operations.

The seventeenth paper “High-Performance Segmentation of Power Lines in Aerial Images Using a Wavelet-Guided Hybrid Transformer Network” by Baraklı and Küçüker [17], presents the Wavelet-Guided Transformer U-Net (WGT-UNet) model, a new hybrid network that combines Convolutional Neural Networks (CNNs), Discrete Wavelet Transform (DWT), and Transformer architectures. Experiments conducted on the TTPLA dataset reveal that the version using the ConvNeXt backbone outperforms other alternative approaches with an F1-Score of 79.33% and an Intersection over Union (IoU) value of 68.38%.

The eighteenth paper “Fuzzy k-means Clustering-Based Machine Learning Models for LFO Damping in Electric Power System Networks” by Shafiullah [18], proposes a clustering-based machine learning (ML) framework to enhance the stability of EPS networks by suppressing LFOs through real-time tuning of key power system stabilizer (PSS) parameters. According to the results, the proposed methodology outperforms the others in enhancing the stability of the selected EPS networks by damping out the observed unwanted LFOs under various loading conditions.

As a final remark, it is hoped that the presented topics will give this special issue a much more lasting value and make it appealing to a broad audience of researchers, practitioners, and students who are interested in advanced AI and ML methods in energy systems, and each reader can find in this special issue something useful or inspiring.

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